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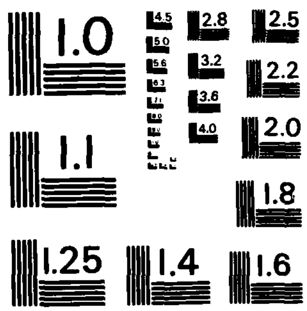

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DEPARTMENT OF DEFENCE

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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Structures Technical Memorandum 362

REPORT ON VISIT TO THE U.S. AND EUROPE IN MAY 1983, COVERING THE 1983 ICAF MEETINGS AND RELATED VISITS

G.S. JOST

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Structures Technical Memorandum 362

REPORT ON VISIT TO THE U.S. AND EUROPE IN MAY 1983, COVERING THE 1983 ICAF MEETINGS AND RELATED VISITS

by

G.S. JOST

SUMMARY

In May 1983 the author made a number of fatigue-related technical visits in the US, and attended the 1983 meetings of the International Committee on Aeronautical Fatigue (ICAF) held in Toulouse, France. This report summarises the matters discussed during these visits.

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CONTENTS

ABBREVIATIONS AND NOMENCLATURE

AIAA	American Institute of Aeronautics and Astronautics
AMD	Avions Marcel Dassault, Paris
ASTM	American Society for Testing and Materials
CRACKS	Crack growth prediction program
CRKGRO	Crack growth prediction program
CW	Cold-working (of hole)
CWIF	Cold-working plus interference fit fastener
CX	Cold-expansion process including final ream to size (FTI designation)
CX2S	Cold-expand to size - as above but without final ream (FTI designation)
DADTA	Durability and damage tolerance analysis
ESDU	ESDU International Ltd., London
FTI	Fatigue Technology Inc., Seattle, USA (marketers of Boeing split sleeve cold expansion process)
IF	Interference fit (fastener system)
K	Stress intensity factor
K_c, K_Q	Stress intensity factor at failure
MCAIR	McDonnell Aircraft Company
MIL-A-83444	(USAF) Military Specification on Airplane Damage Tolerance Requirements. July 2, 1974.
R	Stress ratio (minimum stress/maximum stress in constant amplitude fatigue testing)
STP	Special Technical Publication (of ASTM)
USAF	United States Air Force
USN	United States Navy
WPAFB	Wright-Patterson Air Force Base, Dayton, Ohio.

1. INTRODUCTION

The author visited the US and Europe in May and early June 1983 to:

(a) visit aircraft and research centres in the US and Britain for discussions on aeronautical fatigue, with particular emphasis on lugs, joints and fatigue improvement fastener systems; and

(b) attend, as Australian National Delegate, the 18th Meetings of the International Committee on Aeronautical Fatigue (ICAF) held in Toulouse, France from May 25 to May 31, 1983, and to present a Review of progress in Australian investigations on aeronautical fatigue during the past biennium[1].

A summary of the itinerary and main contacts is given in Appendix 1. During the visits a number of reports, notes and other information were acquired: these are listed/presented in subsequent appendices.

2. VISITS TO ESTABLISHMENTS IN THE US

Visits were made to six aeronautical establishments in the US prior to the ICAF Meetings. Additional visits to AMD at St. Cloud, Paris and ESDU, London planned for Monday, May 23 and Wednesday, June 1 could not be made because of a French public holiday and unavailability of staff respectively.

The establishments to be visited had been chosen for their research and development activity in one or more of the fields of fracture mechanics, fatigue crack growth under service conditions, residual strength and the stress and fatigue analysis of modern fastener systems using interference fit and/or cold expansion. They were the Lockheed-California Company and Northrop Corporation in Los Angeles, the McDonnell Aircraft Company in St. Louis, Lockheed-Georgia in Marietta, the Wright-Patterson Air Force Base at Dayton, Ohio and the NASA Langley Research Centre at Hampton, Virginia. A visit was also made to Imperial College in London.

2.1 Lockheed - California Company, Burbank
(T.R. Brussat, D. Richardson)

Discussions were held first with Mr Brussat, whose recent publications have focussed on fatigue crack growth prediction and fatigue in joints. He provided a paper on lug design[2] which details the current Lockheed approach. On damage tolerant design he pointed out that all design is iterative to some extent, damage tolerant design more so than the alternatives.

For crack growth prediction, Lockheed uses the modified Willenborg model. Willenborg alone tends to be unconservative whereas the modified version can be made reliably conservative, given experience. On stress intensity factor formulations, Newman's later solutions are used. There is no effort made to grow cracks of changing geometry: the latter is assumed/given at the beginning and mostly its growth along the surface only is computed. The movement of a single point on the crack perimeter is thus tracked, corresponding to a one dimensional analysis. To avoid conceptual difficulties associated with the free surface, and with incipient break through to the back surface of a corner crack from a hole, crack growth is sometimes tracked along a ray at about ten degrees to the material surface.

Discussions on fatigue improvement fastener systems were held mainly with Mr Richardson. He extolled at length the virtues of the FTI* system of cold expansion. Apparently virtually all manufacturers are using this method for extracting additional fatigue life from joints, even McDonnell Douglas, who already have their own alternative system. A full understanding of the means by which a several-fold increase in fatigue life may be obtained does not exist, nor is Lockheed active in this area. This is because Lockheed has no new aircraft design which might require them, and the L1011 has yet to experience any related problems. The extensive and effective use of FTI fasteners by British Aerospace in its refurbishment of the Trident was noted.

The evident dimensional repeatability of the process was remarked upon, and by way of indicating the range over which it is being used, "others" are cold-expanding holes as small as 3/32" diam. in titanium alloy, and as large as 2" diam. in steel. FTI has recently secured the services of Mr M. Landy from WPAFB, and is thought to be assembling a film using stresscoat indicating the benefits of improved fastening systems over the conventional clearance fit alternatives.

Finally, there was discussion of a new process from FTI called CX2S - cold expand to size. This is basically the original scheme, but without final reaming. It is claimed that this technique provides further improvement in fatigue life, along with reduced scatter#. Even the ridge left in the bore from the split sleeve is evidently beneficial in aiding bolt insertion. Reference was also made to cold-expansion of countersinks: FTI has a system under development for doing this (see section 3.4)

2.2 Northrop Corporation, Hawthorne
(Dr A.F. Liu, Mr D.P. Wilhem)

Dr Liu has published many papers in recent years on crack growth prediction and stress intensity factors for cracks from holes. He has made use of the five-parameter Collipriest equation for crack

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* Fatigue Technology Inc., Seattle, Washington, the patent holders of the original Boeing Split Sleeve process.

Post cold-expansion reaming is held to be largely responsible for variability in hole quality and shape and hence scatter in fatigue life.

growth, but Northrop now considers this too expensive to use on a routine basis. Simpler representations are favoured, and the Walker, Forman, Wheeler and Willenborg formulations are all used, particularly the generalised form of the latter. The segmental fitting of local straight lines to experimental sigmoidal crack growth rate data is another technique used to shorten execution times.

In discussing failure criteria, it was noted that valid K_{Ic} values may be quite inappropriate, for example, in judging when a constant amplitude loaded sheet specimen will fail. The appropriate sheet K_c or K_Q for the material thickness and sequence must be used. For part through cracking Liu favours the tracking of K_{max} along at least two rays (e.g. bore and surface) as the crack grows, failure being deemed to occur when one of these reaches K_Q. Lin understands that Newman has fine tuned his analytical 1976 paper on cracks from holes to agree more closely with his (Newman's) finite element results. The outcome is to be published in a paper in STP791 (still to be issued). He believes that this will become the definitive usable formulation of stress intensities for cracks from holes (see ref. 16).

For growth of corner cracks from holes, Liu currently uses a two dimensional approach[3], where growth is predicted along both surface and bore (or 10° to each) up to and beyond the back surface, i.e. along the bore extended. This avoids problems associated with back surface breakthrough and subsequent crack shape and gives, in the actual material, a crack front which slowly straightens up as crack depth increases. This is a good approximation to what happens in practice, and the work is documented in a paper to the AIAA April 1983 meeting[4]. The experimental data generated for and used in this paper were obtained under constant amplitude loading using marker bands to assist in fractography. For R=0 loading, for example, some thousands of marker cycles were run at R=0.8 or 0.9, the maximum load being held constant. This technique provides the required marking without causing unrepresentative yielding at the crack tip.

Northrop has no activity underway concerning fatigue improvement fastener systems. Liu's qualitative understanding of the means whereby stress fields are changed runs as follows:

IF gives a higher mean stress, but lower stress range than for the unworked hole, and the beneficial effect of the latter predominates. Clearly, mean stress cannot be increased indefinitely and there must, in general, be an optimum interference for maximum fatigue life.

CW gives a compressive mean stress, but with no change in stress range. A limit to the extent of plastic working is often set by considerations relating to stress corrosion, and an optimum degree of CW is not therefore generally predictable.

In CWIF, CW dominates the mean stress resultant, while the IF gives a reduction in stress range. This technique usually provides the greatest improvement in fatigue life, and the presence of counteracting effects should result in optimum combinations in given cases. These optima do not seem to be predictable, however.

In some work on the effect of compressive residual stress on fatigue crack initiation and growth, Liu has used preyielded plates containing holes. Prior to testing, the plate is stretched to cause yielding adjacent to the hole where cracking will begin under fatigue loading. This technique for creating the plastically deformed region requires no physical contact (and hence potential damage) there. This work was also reported to the AIAA Conference[4].

Mr Wilhem is a senior technical specialist on the wing and empennage structural analysis and refurbishment of the F5. In discussing this project it was noted that the original CX FTI process is being used in hole reworking, with final reaming after cold expansion. Close tolerance bolts are then fitted. He brought to notice the fracture mechanics course to be run towards the end of this year reproduced in Appendix 2.

2.3 <u>McDonnell Aircraft Co., St. Louis</u>
(L.F. Impellizzeri, H.D. Dill, R.E. Pinkert, R. Badaliance, D.L. Rich)

During this two day visit, several topics were discussed with the above. In addition, visits were made to the fatigue specimen test laboratory area, the full scale F-18 and related tests and a manufacturing tour which included the F-15 and F-18 assembly areas.

For some years now MCAIR has adopted a two stage approach to the prediction of fatigue life. Total fatigue life is considered as comprising a component of time to cause crack initiation (defined typically as a crack 0.010 in deep) plus the time to grow that crack to its critical size. Thus, the requirements of both the USN and USAF may readily be accommodated. The USN considers fatigue life to be made up of the above components whereas the USAF considers fatigue life to be only the crack growth phase from (typically) a 0.050 in deep crack to failure, the precrack stage being ignored for certification purposes. (Each authority does, of course, have its own additional scatter factor and testing requirements).

Life to crack initiation as defined above is calculated by Neuber notch root analysis. The principles of this procedure have been well documented in the literature although MCAIR have their own particular technique for using it[5]. Cyclic stress-strain data, and strain-life data are the basic inputs. Uncertainties associated with this approach include questions regarding the validity of Neuber's rule for situations quite remote from that for which it was derived, the equivalence of closed hysteresis loops and fatigue damage, and the cumulative damage rule used. In the detailed analysis there is at least one parameter which may be varied to permit/force agreement between experiment and theory. MCAIR have considerable experience with this model, and have no doubt about using it to effect.

Their crack growth model has been developed in-house and uses contact (closure) stresses as its basis. It has been widely reported in the literature in recent years: see, for example, ref. 6. It was developed because of deficiencies in yield zone models in being able to predict known effects relating to multiple overloads and to crack growth acceleration. The contact stress model is based upon crack closure and the assumption that crack growth is controlled by the plastic zone ahead of the crack and the residual plastic deformation left behind, as the crack grows through previously deformed material. The capability of the model, as it presently exists and as indicated in handouts, is impressive: it successfully predicts

a) retardation following high loads;

b) stress ratio influence;

c) increased retardation following high loads;

d) effects of compressive loads;

e) delayed retardation;

f) crack growth acceleration.

The contact stress model for predicting crack growth requires cycle by cycle computation. MCAIR is now looking at the possibility of developing another contact stress model (mark III) in which the concept of a (quasi) constant effective minimum K approach is being used. Such a model has the potential for effecting very substantial savings in computer time and cost over cycle by cycle computations. Although the concept is not new, it has yet to be shown to compete with cycle by cycle predictions for spectrum or flight by flight loadings.

Discussions were also held on flight loads monitoring. The cassette recorder used in the F-18 samples 15 channels at a fixed rate of 10 samples per second. Typically, seven strain sensors and eight flight parameters are recorded. In MCAIR's opinion there are no long term problems with strain gauges, provided they have been well bonded in the first place. Rebonding for whatever reason during service they see as having the potential for creating subsequent problems for the user. They have had problems with gauge wiring becoming detached. Data processing to predict crack initiation and/or crack growth is evidently readily available if required: such processing is already being effected for the F-15 on behalf of both Israel and Saudi Arabia.

MCAIR also have a disciple of the redoubtable Sih working on applications of the strain energy density concept to fatigue crack growth prediction[7]. In this approach, it is postualated that fatigue crack growth rate is a function of the range of the strain energy density factor (rather than of the usual stress intensity factor). All of the preprocessing is done on constant amplitude data alone, no reference being made to spectrum loading effects or tests as described above. The method is then used to predict crack growth under spectrum loading, with good results. Unlike the conventional approach, the strain energy density approach can predict mixed mode (I and II) cracking[8] as well as mode I cracking, again with apparent success. Development of the model is continuing.

2.4 Lockheed-Georgia Co., Marietta
(L.G. Darby, A.P. Shewmaker, K. Kathiresan)

Discussions at Lockheed often centred around activities associated with refurbishment/redesign of the C-130 and C-5A transport aircraft. A tour of inspection of the manufacturing area included the redesigned C-5A wing and the C-130.

In the early 1970's Lockheed-Georgia carried out an extensive comparative testing program on several patent hole fatigue improvement systems to discover which could be used to greatest effect in extending the fatigue life of the C-5A wing. It was found that the fatigue performance of specimens representing the original clearance fit lower wing surface holes could be improved by interference-fit bolts, and further again by cold-working. This latter is now being used on C-5A replacement wings. The particular cold-working process found to be best was the J.O. King seamless sleeve system. In their endeavours to extend the fatigue life of the original wing, Lockheed were unsuccessful, and extensive redesign was necessary. There is no analytical activity current on fatigue improvement fastener systems - judgement is based wholly on the results of experimental programs.

Reference was made to a standard problem in fatigue testing where runouts occur. The question is how to allow for the information contained in unfailed specimens in calculating, e.g. mean and standard deviation. ARL's work[9] in this area was unknown to them, but Stagg's[10] method they found unsatisfactory. A simple tabular/graphical method - the Watson method - was developed which apparently worked well.

No work is being done on crack initiation, because Lockheed's main customer is the USAF and USAF certification is, of course, based on damage tolerance and assumed pre-existing flaws in all fatigue critical locations. A typical NDI threshold crack depth is considered to be 0.10 inch in the sense that this is the largest crack which might reasonably be missed on inspection. Recurring inspections are made at one half the time to grow the crack from 0.10 inch to its maximum depth, which will just sustain limit load. Any inspection technique for which the threshold as defined above is greater than 0.10 inch will therefore result in a shorter inspection interval, and vice versa.

On crack growth prediction, little progress was possible. The author was told that load interaction effects were taken into account in a model which was programmed and used routinely. Unfortunately, the originator of that package (T.M. Hsu) is no longer with Lockheed. The package evidently comprises the CRACKS program (see Section 2.5), together with Willenborg and closure modelling, and is not published. Forman crack growth data, segmented if necessary, is used.

For the C-130 DADTA program, completed some time ago, some 735 candidate critical areas were examined, of which 393 were analysed in detail. The total cost was approximately US$5M. It was noted that MIL-A-83444 permits a reduction in assumed initial flow size from 0.050 inch to 0.005 inch provided test results confirm predicted crack growth.

This must provide great incentive for the development of crack growth models which work. Incidentally, assembly of the first of the new C-130 wing planks using Hi-tigues (a patent fastener providing both cold-expansion and subsequent interference fit) is now underway.

Non-destructive inspection was discussed briefly. Lockheed has an in situ hole inspection capability using an "ultrasonic spinner", in several sizes. It uses the protruding bolt head as the centreing device, and is rotated by hand. It is claimed to be highly reliable, and to penetrate down to 0.15 inch in searching for bore cracks. In a telephone call, Mr W. Adams of Lockheed emphasised repeatedly the effectiveness of this device, and the fact that Lockheed is extremely pleased with its performance. It is said also to have second layer inspection capability by a "pitch/catch" technique which uses two transducers. The device is marketed by the following, from whom all assistance was said to be available:

Mastercraft Enterprises Inc.,
P.O. Box 6065A,
Marietta,
Georgia, 30065.

Final discussions were held with Dr Kathiresan, who has taken over some of Hsu's work . On fatigue improvement fastener systems, an analysis has been made of an elastic interference fit case containing a crack. An optimum degree of interference to maximise fatigue life was thought to be related to the onset of separation of bolt and hole in a joint: no active analytical work is underway for cold-expanded holes. Kathiresan said that A.K. Rao (Bangalore) and his students have gone on from their infinite plate work on loaded, interference fit holes, to consider the effect of finite width. He did not know whether the analyses now included plasticity effects.

2.5 Wright-Patterson AFB, Dayton, Ohio
(R.M. Bader, R. Engle, J.M. Potter, J.L. Rudd)

Discussions began with Mr Engle outlining the development of the WPAFB crack growth prediction programs, which have become something of a base to which reference is often made in the literature. The original CRACKS program was very simple and dates from around 1970. Then the Wheeler and Willenborg retardation models were added to yield CRACKS II. CRACKS III was an intermediate program which became CRACKS IV with the inclusion of the Grumman crack closure model. Up to 1980, WPAFB used the CRACKS programs extensively: they were easy to use and modify, and were ideal for R and D type use. They had one drawback, however; they were relatively slow and hence expensive to run*.

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* CRACKS IV evidently spends three quarters of its running time calculating updated stress intensity factors.

According to WPAFB, by 1979 the USAF "got serious about crack propagation" in their tracking programs, and decided that a more specific, production oriented program yielding one answer per problem was required (CRACKS IV provides the user with a choice of prediction methods). This led to an Air Force Production Program for which Rockwell won the contract to develop CRKGRO. This comes in three versions: a production oriented program, a simple, fast running program and one suitable for a small computer. The generalised Willenborg model is used, so that both retardation and acceleration effects are predicted. Newman's stress intensity factor solutions are used. The shorter running times of CRKGRO over CRACKS IV derives from the use of subroutines containing all geometric detail and associated stress intensity factors. The latter do not, therefore, have to be evaluated at every update of crack length, but simply "looked up". Round robins comparing different crack growth models have evidently shown that CRKGRO consistently provides the best predictions. WPAFB also has an in-house audit capability, Structures Technology Evaluation Program, for checking contractor predictions of crack growth. STEP is more of a black box tool: expertise in fracture mechanics is not necessary for its use.

In discussions on stress intensity factors from flawed fastener holes, Mr Rudd referred to a massive program carried out and reported nearly a decade ago by Hall, Shah and Engstrom[11]. Unfortunately minimum crack sizes considered were typically of the order of 0.15 inch, or rather larger than moderate oversize reaming might remove. Open and filled loaded holes were included, along with interference fit and cold worked holes, and tested under both constant amplitude and spectrum loading. Subsequent work using crack depths down to 0.005 inch had evidently provided results consistent with those of the first investigation and the beneficial effect of cold working on crack growth was stated to have diminished as crack depth increased, as would be expected*. There has been no further work along the above lines at WPAFB.

Regarding the reduction in initial crack size for certification purposes from 0.050 inch to 0.005 inch when cold working is used (Section 2.4), the smaller crack must then be grown from an assumed open hole, i.e. the beneficial effect of cold-working is to be ignored. This was cited as one reason why there was no point in pursuing the stressing of cold-worked holes. The USAF is evidently quite concerned, in the fatigue improvement fastener field, about holes intended to be cold-worked but somehow escaping this treatment in production. There are some "foolproof" ways of circumventing this problem, however#.

In a round robin on corner cracks from holes, the participants were provided with crack growth data from centre and edge cracked panels of 7075 aluminium alloy and asked to predict, under constant

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* This latter work was done by Rudd and others at Lockheed.

\# For example, a clearance fit installation where the bolt can be inserted only into a cold worked hole.

amplitude loading, the fatigue crack life from initiation at a corner of the hole to just reach the back surface (transition life), total crack life, critical crack size and the crack dimension at three points on its perimeter, i.e. its shape at failure. The results, which were said to be good in general, are to appear in an ASTM STP. Most used Newman's stress intensity factor solutions, although J.B. Chang (Rockwell) evidently did best. It is proposed to repeat the round robin but at higher stress levels, so that local yielding occurs, and using spectrum loading.

Brief reference was made to finite-element work on tapered lugs[2] carried out while Rudd was at Lockheed. The analysis examined the effect on stress and stress intensity factor of lug geometry, loading direction and pin loading distribution. It highlighted yet again the profound effect of the latter upon stress intensity factor and hence fatigue crack growth. An effective understanding of the likely crack initiation locations for given loading directions was obtained. The work is to appear in more detail in a series of technical reports.

On problems associated with initial and/or very small flaws, a large scale program is underway using multiple hole coupon fatigue specimens[12]. Maximum crack sizes considered are of the order of 0.10 inch. Crack growth data is being obtained on naturally initiating cracks, and these are then being extrapolated back to time zero (using whatever method is considered reasonable for the purpose in hand). Thus, equivalent initial flaw sizes at time zero (or any other intermediate stage) can be inferred, and the distribution of sizes found. This technique is not new, but perhaps the comprehensiveness of the program is. So far, it has been found that the three parameter Weibull distribution generally provides the best data fit where Paris extrapolation has been used.

Final discussions at WPAFB were held with Mr Potter of the Flight Dynamics Laboratory. A tour was also made of the full scale fatigue testing laboratory and the small specimen test laboratory. The latter includes an X-ray facility where in residual stresses in specimens containing, for example, a cold-worked hole may be measured freestanding or with applied remote load. The X-ray spot size is approximately 0.020 inch, which is small enough to permit quite detailed localised evaluation of residual stress profiles and crack tip stress distributions. Recent work using this facility has been reported[13].

The view was expressed that the analysis of plastically deformed holes must contain substantial uncertainties associated, in particular, with two- and three-dimensional effects (plane stress, plane strain and combinations) and effects associated with the split sleeve (in the case of the FTI process). For IF fastener systems, these typically have high fatigue life variability. In comparing candidates he stressed that this variability must be allowed for, and one method is to use, e.g. the 95% minimum life, rather than the mean[14]. Thus a fastener with a lower mean may have a lower scatter such that its 95% minimum life exceeds that of a competitor with a rather higher mean life. He stressed the importance of repeatable quality installation in interference fitting.

The K-lobe IF fastener he quoted as being excellent. Because of the greater "forgiving" of CW systems over IF systems (to do with dimensional tolerance bounds) the former is, given a free choice, to be preferred. This view is generally held.

A completed project in which the effect of "errors" in hole preparation on subsequent fatigue life has yet to be written up. However, the US contribution to the AGARD sponsored Fatigue Rated Fastener Systems program where standardised loading sequences are being used in conjunction with many candidate fastener systems is to be presented to a meeting in the US later this year. The main objectives[15] of the FRFS program are to -

(a) determine fatigue lives for a range of fatigue rated fastener systems in combination with hole preparation techniques;

(b) establish relative costs in relation to fatigue performance;

(c) identify the prime parameters involved in fastener systems selection; and

(d) develop a reference datum for the comparison of test results produced in different countries using different specimen geometries.

Both FALSTAFF and TWIST flight-by-flight sequences are being used, and joint specimens exhibiting no, low and high load transfer with and without secondary bending are included in the program. Testing is to be completed by late 1983 with a consolidated report of the results from all seven* participating countries to be published by mid 1984.

2.6 <u>NASA Langley Research Center, Hampton, VA</u>
(Drs. J.C. Newman, W.S. Johnson, J.H. Crews, W.B. Fichter)

In opening discussions at NASA, Dr Newman outlined recent developments there. From 1975 work on metals was virtually abandoned in a switch to composites. In more recent times a modest metallic input has returned - currently given as four out of 18 in the Materials Division. There is now a big computational analytical effort underway for which the Cyber system network has opened up great possibilities. In particular three-dimensional cracking problems can be tackled, and Newman has published extensively in this area in recent times (see Appendix 3).

One of the very useful ways in which Newman has utilised 3-D solutions is to refine his own empirical analytical expressions. Thus the approximate expression for the stress intensity of surface crack at one point on the boundary has, via the 3-D solutions for many points on the boundary, been generalised so that the new formulation provides the finite element information in analytical form. He has also now done this

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* US, UK, Sweden, France, Netherlands, Italy, Germany

for both corner cracks from holes and for cracks initiating from the hole itself[16]. This work allows for the prediction of progressive crack shape and for the location of the maximum stress intensity around the crack perimeter as it grows to be tracked. This latter becomes important for correct residual strength assessment.

Problems associated with the transition or breakthrough of the crack to the back face (for a corner flaw) or the side faces (for a central hole crack) remain unresolved. Newman considers the crack to become a through crack immediately the face(s) are reached: Johnson, however, works on the basis of this happening when the crack length on the back face is 90% of that on the front face.

On crack growth prediction, NASA Langley has several recent offerings (Appendix 3). Johnson briefly reviewed his multi-parameter yield zone model[17] for predicting crack growth under spectrum loading. This accounts for retardation, acceleration and underload effects. The load interactions are attributed to plastic deformation at and in the wake of the crack tip. Newman has developed a crack closure model[18] in which closure is considered to resu from plastic deformation in the wake of the crack, using a Dugdale-like plasticity model. An interesting aspect of both models is that plane stress, plane strain or any combination of these conditions can be included, and the "right" constraint factor for a given application is determined from the corresponding constant amplitude data by regression analysis. Incidentally, Johnson is in no doubt that threshold stress intensity factor phenomena are a consequence of crack closure, but crack closure here is not yield induced. The presence of oxide layers on the crack surfaces, and/or surface mismatch caused by mixed mode I and II cracking in short cracks at threshold levels are held to be responsible.

Brief discussions were held with Dr Crews on the analysis of fatigue improvement fastener systems. He has published several NASA reports on this subject, the last being in 1975. From that time he has been working wholly in the composites field, particularly on the stress analysis of bolted joints. He sees the problems of pull-through resulting from high clampup as quite major in composites joints. For the case of joints in metals, he felt that the greater the interference, the better would be the fatigue life. This process pushed into the plastic region was seen as better again. Something along these lines is, of course, the process of cold working holes. He cautioned against the disastrous possible consequences of the combination of clearance fit fastenerers in cold worked holes under compressive loading.

Dr Fichter has recently carried out an "exact" plane stress intensity factor for the double cantilever beam specimen. In the past only approximations have been available, although these have now been shown to be remarkably accurate. In a recently published paper[19] he has also analysed the problem of stresses in an infinite sheet containing a circular hole into which an "imperfect" interference-fit fastener has been installed. The imperfection takes the form of two equal and opposite arcs of contact between which there is no contact, and the analogy to the split sleeve of the FTI cold-working process can be noted. An elevation in hoop stress occurs at the end of the contact region which can reach twice the ambient level for full contact interference when the gap is very small. This result would probably be modified with the onset of plasticity.

Final discussions at NASA were again with Dr Newman where he outlined his most recent work on the prediction of crack initiation, growth and final instability under monotonic loading[20]. He uses an elasto-plastic (incremental and small strain) finite element analysis together with a critical crack-tip-opening displacement crack growth criterion to judge whether the crack was to grow, and if so by how much. Predictions have been compared with test data, and the agreement is impressive. His first conclusion states:

"The present elastic-plastic analysis predicted three stages of crack-growth behaviour, characteristic of metals, under monotonic loading to failure:

(a) a period of no crack growth,
(b) a period of stable crack growth, and
(c) crack-growth instability under load-control conditions".

3. REPORT ON THE 1983 ICAF MEETINGS

3.1 Introduction

The 1983 ICAF Meetings were held in the Salle de Conference of the Ecole Nationale Superieure des Inqenieurs de Constructions Aeronautiques (ENSICA) in Toulouse, France from Wednesday 25th May to Tuesday 31st May, 1983. Australia was represented at the Meetings by Mr J.Y. Mann of ARL, Mr C. Torkington and Mr C.T. Stefoulis of the Department of Aviation, Mr G.E. Lawrence of the Australian Aircraft Consortiu, Flt. Lt. P.J. Burgess of the RAAF, Paris and the author as Australian Delegate to the ICAF. Total registration at the Meetings was 180.

On this occasion the Meetings began with a three day Symposium during which 19 papers were presented. In the following week the presentations of the National Reviews of each member country were given, a short, informal technical discussion completing the 1983 ICAF Meetings.

3.2 Twelfth ICAF Symposium - May 25-27, 1983

Although 21 papers had been scheduled for presentation at the Symposium, two of these did not materialise. As is now customary, the Symposium began with the invited Plantema Memorial Lecture which was given on this occasion by Mr J.Y. Mann of ARL on "Aircraft fatigue - with particular emphasis on Australian operations and research"[21]. The paper was well received and may with justification be regarded as the definitive account of Australian aircraft fatigue to this time.

Symposium papers were equally divided between two main themes: Industrial Applications of Damage Tolerance Concepts and Structures of High Fatigue Performance. The first theme is self explanatory; under the second, papers discussing fatigue-improvement fastener systems predominated, along with those on composites. Titles and authorship of all Symposium papers are given in Appendix 4, along with their summaries*. The papers themselves are to be published in a single volume later this year by the French as the Proceedings of the 12th ICAF Symposium, 1983. Copies of all but Paper 1.4 are held at ARL.

3.3 <u>18th ICAF Conference</u> - May 30 and 31, 1983

The National Reviews of investigations carried out in the field of aeronautical fatigue in the ICAF member countries during the past biennium were presented by the respective National Delegates. Conference details are given in Appendix 5; an indication of the main topics dealt with in the various reviews is also given. As is usual, the Australian National Review for the period April 1981 to March 1983[1], had been compiled in advance from willing contributors here in the military and civil aeronautical scene. The 13 National Reviews are also to be published later this year in a single volume as the Minutes of the 18th ICAF Conference, 1983. Single copies of all National Reviews are held at ARL.

3.4 <u>ICAF Advertising</u>

It usually happens that at least one new or appropriate piece of equipment receives something of a special airing or presentation during the week of the ICAF Meetings. On this occasion two such items received attention.

The Swiss Federal Institute of Technology has developed a recording and processing system for signals from strain or acceleration transducers. Details of the Spectrapot system are summarised in Appendix 6. The hardware was stated to be available in small quantities "off the shelf". An approximate price was quoted as US$25,000 for three data collector units (one channel per unit) and the data processor; individual collector units are about US$5,000 each. Collectors have been installed in aircraft of Swissair since 1981 and are reported to be performing as expected.

The second item to receive publicity was the FTI system of hole cold-expansion. Mr R.L. Champoux, the manager of the parent company in Seattle, Washington, USA and Mr M.J. Wynne the manager of the English subsidiary company in Birmingham distributed appropriate literature and specimens containing stress-free and cold-expanded holes. The process was demonstrated on birefringent coated specimens. The new tooling for the cold-expansion of countersunk holes was also shown and

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* The titles of two papers as finally presented were slightly altered from those listed in Appendix 4. These corrections have been made in Appendix 5.

explained. As a result of subsequent discussion, information has now been received on both the past and a future discussion meeting on the cold-expansion process. Some details of the meeting held in 1982 are given in Appendix 7; publication of the text of the nine papers presented is proceeding and a copy is to be forwarded to ARL when available. A further meeting is to be held in September 1984 in Britain.

3.5 Business Meeting

The following items of general interest arose out of the Business Meeting of the National Delegates:

(a) Since the previous report of the present author to the 1979 ICAF Meetings[22], four changes have occurred in ICAF representation. The current listing of ICAF delegates is given in Appendix 8.

(b) During the past four years, Israel has been invited to join ICAF, and has accepted. More recently Japan has also accpeted ICAF membership. Each of these countries has been participating in ICAF activities to the full for several years. Delegates from thirteen countries now comprise ICAF: The Netherlands, U.K., Sweden, Belguim, Switzerland, Germany, France, Italy, Australia, U.S.A., Canada, Israel and Japan.

(c) An offer by Prof. Salvetti of Pisa to hold the 1985 ICAF Meetings in Italy was formally accepted at the Business Meeting, and it is expected that these will take place in Pisa early in June, 1985.

REFERENCES

1.	Jost, G.S.	A review of Australian investigations on aeronautical fatigue during the period April 1981 to March 1983. Dept. Defence Support, Aeronaut. Res. Labs., Structures Technical Memorandum 359, March 1983.
2.	Kathiresan, K., Hsu, T.M., Rudd, J.L.	Stress and fracture analysis of tapered attachment lugs. Paper presented to an ASTM meeting, early 1982.
3.	Liu, A.F. Kan, H.P.	Growth of corner cracks at a hole. Trans ASME, J. Eng. Mat & Tech., v. 104, 1982, pp 107-114.
4.		24th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Lake Tahoe, Nevada, April 1983.
5.		Structural analysis methods. Vugraph presentation of crack initiation and crack growth analysis methods. MCAIR Handout.
6.	Dill, H.D. Saff, C.R.	Spectrum crack growth prediction method based on crack surface displacement and contact analyses. ASTM STP 637, 1977, pp. 141-152.
7.	Badaliance, R.	Fatigue crack growth theory based on strain energy density factor. Proc. Sym. on Absorbed Spec. Energy/Strain Energy Density (Sih, Czoboly, Gillemot eds). Publishing House of the Hungarian Academy of Sciences, 1981, pp 329-345.
8.	Badaliance, R.	Mixed mode fatigue crack propagation. McDonnell Aircraft Company. Report MCAIR 80-035, 1980.
9.	Ford, D.G.	Maximum likelihood estimtors for truncated samples from normal populations. Dept. Supply, Aeronaut. Res. Labs. Report SM264, October 1958.
10.	Stagg, A.M.	Parameter estimation for the log-normal parent population of fatigue failures from a sample containing both failed and non-failed components. RAE Technical Report 70145, 1970.
11.	Hall, L.R. Shah, R.C. Engstrom, W.L.	Fracture and fatigue crack growth behaviour of surface flaws and flaws originating at fastener holes. AFFDL-TR-74-47, May 1974.
12.	Potter, J.M. Yee, B.G.W.	Use of small crack data to bring about and quantify improvements to aircraft structural integrity. Paper presented to AGARD Specialist's Meeting on Behaviour of Short Cracks in Aircraft Structures. Toronto, Canada, September 1982.

<u>REFERENCES (CONTD.)</u>

13.	Allison, J.E.	Measurement of crack-tip stress distributions by X-ray diffraction. ASTM STP677, 1980, pp 550-562.
14.	Potter, J.M., Stewart, R.P., Adams, F.D.	Evaluation of fatigue rated fastener systems: constant amplitude fatigue test results. AFFDL-TM-77-75-FBE, November 1977.
15.	van der Linden, H.H.	Fatigue rated fastener systems in aluminium alloy structural joints. Paper presented to the 12th ICAF Symposium, Toulouse, France, May 1983.
16.	Newman, J.C., Raju, I.S.	Stress-intensity factor equations for cracks in three-dimensional finite bodies. NASA Technical Memorandum 83200, August 1981.
17.	Johnson, W.S.	Multi-parameter yield zone model for predicting spectrum crack growth. ASTM STP 748, 1981, pp 85-102.
18.	Newman, J.C.	Prediction of fatigue crack growth under variable-amplitude and spectrum loading using a closure model. ASTM STP 761, 1982, pp 255-277.
19.	Fichter, W.B.	Hoop stress elevation caused by imperfections in interference-fit fasteners. Int. J. Fracture, v. 17, n. 6 December 1981, pp. 593-600.
20.	Newman, J.C.	Finite-element analysis of initiation, stable crack growth, and instability using a crack-tip-opening displacement criterion. NASA Technical Memorandum 84564, October 1982.
21.	Mann, J.Y.	Aircraft fatigue - with particular emphasis on Australian operations and research. Dept. Defence, Aeronaut. Res. Labs., Structures Technical Memorandum 361, April 1983.
22.	Jost, G.S.	Report on visit to Europe in May 1979, covering the 16th Meetings of the ICAF and associated visits. Dept. Defence, Aeronaut. Res. Labs., Structures Technical Memorandum 293, July 1979.

APPENDIX 1

OVERSEAS VISIT - ITINERARY AND MAIN CONTACTS

Monday 9th May	Lockheed-California Company, Burbank, California. (Mr T.R. Brussat)
Tuesday 10 May	Northrop Corporation, Hawthorne, California. (Dr A.F. Liu)
Thursday 12th May & Friday 13th May	McDonnell Aircraft Company, St. Louis, Missouri. (Mr L.F. Impellizzeri)
Monday 16th May	Lockheed-Georgia Company, Marietta, Georgia. (Mr L.G. Darby)
Tuesday 17th May & Wednesday 18th May	Wright Patterson Air Force Base, Dayton, Ohio. (Mr R.M. Bader)
Thursday 19th May & Friday 20th May	NASA Langley Research Center, Hampton, Virginia. (Dr J.C. Newman)
Wednesday 25th May to Tuesday 31st May	12th ICAF Symposium and 18th ICAF Conference, Toulouse, France.

APPENDIX 2
AN INTRODUCTION TO PRACTICAL FRACTURE MECHANICS

COURSE OUTLINE

MONDAY, [illegible]

8:30 - 12:00 noon

• Introduction to Basic Concepts (Wilhem & Ratwani)
Stress Intensity Factor; Strain Energy Release Rate;
Crack Opening Displacement and Crack Growth Resistance

1:00 - 4:30 p.m.

• Application of Basic Concepts (Wilhem & Ratwani)
Stress Intensity Factors for Standard Test Specimens
Development of Boundary and Geometric Influences on K
Introduction to the J-Integral

TUESDAY, [illegible]

8:30 - 12:00 noon

• Stress Intensity Factors for Typical Problems (Wilhem & Ratwani)
Through-the-Thickness Cracks
Part-Through Crack at a Hole
Cracked Lug
Biaxially Loaded Cracks

1:00 - 5:00 p.m.

• K_{Ic} Laboratory Test Session (FitzGerald)
Validity Calculations; Specimen Measurement and Preparation
Use of the Clip Gage; Crack Length Measurement; Determining
K_Q; ASTM E399 Specifications

WEDNESDAY, [illegible]

8:30 - 11:00 a.m.

• Government Regulation and Specifications (Wood & Swift)
DOD MIL-STD-A-83444, FAR 25, Pressure Vessel Codes
The Responsibility of the Fracture Analyst

1:00 - 4:30 p.m.

• Crack Growth Analysis with Variable Amplitude Loading (Carter)
Crack Growth Retardation Models
Test Correlation; Sample Problem
• Constant Amplitude (da/dN) Laboratory Test (FitzGerald)
Specimen Measurements; Precracking Procedures
da/dN Test; Data Reduction

THURSDAY, [illegible]

8:30 - 10:30 a.m.

• Residual Strength Analysis (Ratwani)
Factors Influencing Strength
Residual Strength Analysis of Complex Structures (K & √J)

10:30 - 11:30 a.m.

• Fracture of Composites (Ratwani)

12:30 - 1:30 p.m.

• Development of Load Spectra (Carter)

1:30 - 2:30 p.m.

• Determining Stress Intensity Factors for Complex Structures Experimentally (Wilhem)

2:30 - 3:15 p.m.

• Fatigue Life Improvement Techniques (Wilhem & Carter)
Cold Working, Shot Peening, etc.

3:15 - 4:30 p.m.

• Open Discussion/Problem Presentations (Ratwani, Wilhem, Carter, Wood, Swift)

LECTURERS

• [illegible] RATWANI is Manager of the Structures Life Assurance Group of Northrop Aircraft Division. Dr. Ratwani obtained his Ph.D in applied mechanics from Lehigh University and has twelve (12) years experience in stress analysis, fatigue and fracture of metallic structures, as well as advanced composites. He has authored over sixty (60) technical papers and reports and developed analytical techniques for residual strength prediction, adhesively bonded structure analysis, and nonlinear fracture mechanics methods.

• DAVID WILHEM is a Senior Technical Specialist in the F-5 Wing, Empennage and Systems Analysis Group of Northrop Aircraft Division, and has twenty-five (25) years of direct experience in applied fracture, fatigue and fatigue crack growth research. Eight (8) of these years were spent at U.S. Steel Applied Research Laboratories developing some of the first standardized tests for fracture of materials. Mr. Wilhem is Vice Chairman of ASTM Committee E24 on Fracture Testing, and has written numerous reports, handbooks, etc., on fracture mechanics and fatigue crack growth, and lectured extensively here and abroad in applied fracture mechanics.

• JACK FITZGERALD is a Senior Engineering Technologist at Southwest Research Institute, San Antonio Texas, Department of Materials Science. He has twenty-four (24) years of mechanical property test experience, with over fourteen (14) years directly related to fracture mechanics testing. Prior to Southwest Research, he spent nine (9) years at Northrop Aircraft Division, where he was responsible for all metallic and non-metallic fracture mechanics, crack growth and fatigue testing. His prior experience was senior lead engineer at Lehigh University's Fracture Mechanics Laboratory. Mr. FitzGerald is an active member of ASTM Committee E24 and has published several papers on fatigue crack growth modeling.

• HOWARD WOOD is an Aerospace Engineer at the U.S. Air Force Aeronautical Systems Division at Wright Patterson AFB, Ohio. He has over twenty (20) years experience in aerospace structures; the last fourteen (14) mainly in the area of fatigue and fracture mechanics. Mr. Wood has been directly responsible for the development of life prediction methods and damage tolerance policy for the Air Force, and has had considerable firsthand experience with the application of fracture mechanics to system problems. He has published numerous papers in life prediction and fracture mechanics applications.

• TOM SWIFT is a National Resource Specialist in Fracture Mechanics/Metallurgy for the Federal Aviation Agency. He has over twenty-four (24) years of experience in Airframe Design and Structural Analysis, including Section Chief of the Fatigue and Fracture Mechanics Group at Douglas Aircraft Company. As a National Specialist in Fracture Mechanics, he serves as an advisor to all of the FAA regions on type certification boards, air worthiness directive boards, special certification review teams, and FAA/NTSB Accident Investigation teams. Mr. Swift has published numerous papers on applied fracture mechanics design principles.

• JOE CARTER is an Engineering Specialist at Northrop Corporation, Electronics Division, Turbine Engine Monitoring Systems Unit. He has over ten (10) years of experience in the Fatigue and Fracture Mechanics analysis of aircraft structure. He has developed a number of computer programs used in crack growth analysis and recently served as the Principle Investigator on the F-5E/F Individual Aircraft Tracking Program. Currently, he is the Structures Specialist on the A-10 STEMS program and is responsible for developing structural tracking methods using the TEMS microprocessor.

ABOUT THE PROGRAM

The foundation supplied by this series will enable each participant to become confident in using current fracture mechanics techniques and testing procedures. If you or your management need a good "ground floor" exposure to this rapidly expanding field of damage tolerance analysis, or an updating of skills to effectively handle military and civil damage tolerant codes, this course is for you.

If your work requires knowledge of damage tolerance requirements, use of K_{Ic} data, making life estimates and value judgments, establishing inspection intervals (predicting fatigue crack growth), and residual strength (fracture) for complex structure and loading, this lecture series is for you.

You will be provided a basic foundation in fracture mechanics analysis as applied to structural problems. These methods are required to meet federal codes, which will also be detailed. Superposition of stress intensity solutions will be emphasized. The procedures used in determining stress intensities from fatigue crack growth data will be shown for several complex crack geometries - including adhesively bonded structures. The use and comparison of spectrum fatigue crack growth computer programs will be given. A unique feature will be a "hands-on" workshop demonstrating a K_{Ic} test and current fatigue crack growth testing and data reduction methods.

REGISTRATION INFORMATION

Pre-Registration is required. Reservations may be made by completing the attached form and returning it to:

Professor [illegible]
Department of Mechanical Engineering
California State University, Long Beach
1250 Bellflower Boulevard
Long Beach, California 90840

together with a check for $500. The registration fee includes: cost of coffee, tea, lunch, and lecture notes. Check should be made payable to C.S.U.L.B. Foundation.

Further Details:

All inquiries about the course, housing, and transportation should be directed to the Department of Mechanical Engineering, California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, California 90840.
Telephone: (213) 498-4407

Dates to be announced.
Approx. Nov-Dec '83.

APPENDIX 3

PAPERS AND REPRINTS OBTAINED FROM US ESTABLISHMENTS

Northrop Corporation

Liu, A.F. and Kan, H.P. Growth of corner cracks at a hole. Trans. ASME, J. Eng. Mat. & Tech., v. 104, April 1982, pp. 107-114.

McDonnell Aircraft Company

Dill, H.D. and Saff, C.R. Analysis of crack growth following compressive high loads based on crack surface displacements and contact analysis. MCAIR Report 76-006, 1976.

Dill, H.D. and Saff, C.R. Spectrum crack growth prediction method based on crack surface displacement and contact analyses. MCAIR Report 75-007, 1975.

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Rich, D.L. and Impellizzeri, L.F. Fatigue analysis of cold-worked and interference fit fastener holes. MCAIR Report 76-007, 1976. Also in ASTM STP 637.

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Pinkert, R.E. Improved fatigue life tracking procedures for Navy aircraft structures. MCAIR Report 83-004, 1983.

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Potter, J.M. and Millard, R.A. The effect of temperature and load cycling on the relaxation of residual stresses. Advances in X-ray Analysis, v. 20, 1977, pp. 309-319.

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Potter, J.M. and Yee, B.G.W. Use of small crack data to bring about and quantify improvements to aircraft structural integrity. Paper prepared for AGARD specialists meeting on Behaviour of Short Cracks in Aircraft Structures. Toronto, Canada, September 1982.

Potter, J.M., Stewart, R.P. and Adams, F.D. Evaluation of fatigue rated fastener systems: constant amplitude fatigue test results. AFFDL-TM-77-75-FBE, November 1977.

NASA Langley Research Center

Newman, J.C. and Raju, I.S. Analyses of surface cracks in finite plates under tension or bending loads. NASA Technical Paper 1578, December 1979.

Newman, J.C. and Raju, I.S. An empirical stress-intensity factor equation for the surface crack. Eng. Fracture Mechanics, v. 15, n. 1-2, 1981, pp. 185-192.

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Newman, J.C. A crack-closure model for predicting fatigue crack growth under aircraft spectrum loading. ASTM STP 748, 1981, pp. 53-84.

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APPENDIX 4
12TH ICAF SYMPOSIUM: SCHEDULE AND PAPERS

12th ICAF SYMPOSIUM

WEDNESDAY, 25 MAY 1983

9.00 REGISTRATION

9.45 OPENING by R. LABOURDETTE

9.55 WELCOMING ADDRESS by M.C. FRANTZEN, Direction Générale de l'Aviation Civile

10.15 9th PLANTEMA MEMORIAL LECTURE :
AIRCRAFT FATIGUE with particular reference to its impact on Australian operations and research, by J.Y. Mann, ARL, Australia

11.00 Break

I - INDUSTRIAL APPLICATIONS OF DAMAGE TOLERANCE CONCEPTS

CHAIRMAN J.B. DE JONGE

11.30 1.1 VERIFICATION OF METHODS FOR DAMAGE TOLERANCE EVALUATION OF AIRCRAFT STRUCTURES TO FAA REQUIREMENTS by T. Swift, FAA, USA

12.10 1.2 THE EVOLUTION OF A SINGLE FATIGUE AND DAMAGE TOLERANCE REQUIREMENT FOR AEROPLANES AND HELICOPTERS by D.J. Maxwell and A.W. Cardrick, RAE, UK

13.00 Lunch

CHAIRMAN A. JOHN

14.30 1.3 DAMAGE TOLERANCE OF AERO-ENGINE DISKS by H. Huff and L. Fromig, MTU, Germany

15.10 1.4 STATISTICAL APPROACH TO DAMAGE TOLERANCE ASSESSMENT by J.M. Thomas, Aerospatiale, France

15.50 Break

CHAIRMAN A. SALVETTI

16.20 1.5 FINITE ELEMENTS ANALYSIS OF PIN LOADED LUGS by H. v. d. Velden, Fokker, the Netherlands

17.00 1.6 THE EFFECT OF FRICTIONAL FORCES ON FATIGUE CRACK GROWTH IN LUGS by J.P. Mann, RAE, UK

THURSDAY, 26 MAY 1983

CHAIRMAN O. BUXBAUM

9.00 1.7 A DETERMINISTIC APPROACH TO DAMAGE TOLERANCE CERTIFICATION by U.R. Turner and C. Mandera, Canadair Ltd, Canada

9.40 1.8 ELEMENTS OF DAMAGE TOLERANCE VERIFICATION by U.G. Goranson and J.T. Rogers, Boeing Commercial Airplane Co, USA

10.20 Break

CHAIRMAN P.R EDWARDS

10.50 1.9 DESIGN FOR MAXIMUM DURABILITY AND DAMAGE TOLERANCE IN THE MANUFACTURE OF A HEAVY TRANSPORT WING, by A.P. Shewmaker, I.L. Russ, J.L. Hopkins, Lockheed Georgia Co, USA

11.30 1.10 PRATICAL APPLICAT ONS OF DAMAGE TOLERANCE CONCEPTS TO U.S. NAVY AIRCRAF , by C.R. Larson, the Vought Corp, USA

12.10 1.11 MAINTENANCE SYSTEM BASED ON DAMAGE TOLER NCE CONCEPT, by Dr. K.H. Gelda. Lufthansa, Germany

13.00 Lunch

II - STRUCTURES OF HIGH FATIGUE PERFORMANCE

14.30 Visit of CEAT Facility

CHAIRMAN G.B JOST

16.15 2.1 APPLICATION OF DAMAGE TOLERANCE CONCEPTS TO "SHORT CRACKS" IN SAFETY CRITICAL COMPONENTS, by Prof. D.W. Hoeppner, University of Toronto, Canada

16.55 2.2 THE CYCLIC BEHAVIOUR OF A POWDER NI-BASE SUPERALLOY, by M.A. Hicks, R.A. Howley, B.P. Towill, Rolls Royce Ltd, UK

17.35 Adjourn

20.30 Symposium dinner

FRIDAY, 27 MAY 1983

CHAIRMAN H.H BADER

9.00 2.3 EXPERIMENTAL AND ANALYTICAL STUDY OF STRENGTH DEGRADATION DURING FATIGUE OF GRAPHITE/EPOXY LAMINATES, by R. Prinz, H.C. Goetting, H. Schmidt DFVLR, Germany

9.40 2.4 FATIGUE PERFORMANCE OF 0° ± 45° CFRP WITH WOVEN AND NO WOVEN ± 45° LAYERS, by S.M. Bishop, RAE and J. Morton, A. Rycroft, Imperial College, UK

10.20 2.5 FATIGUE BEHAVIOUR (UNDER ZERO OR NO ZERO MINIMUM STRESS) OF CARBON/EPOXY COMPOSITE MATERIALS, by M. Soulezelle, Aérospatiale, France

11.00 Break

CHAIRMAN A. MAENHAUT

11.30 2.6 RESULTS OF A STUDY OF RESIDUAL STRESSES AND FATIGUE CRACK GROWTH IN LUGS WITH EXPANDED HOLES, by A.A. Jongebreur, Fokker Company, and A.U. de Koning NLR, the Netherlands

12.10 2.7 INTERFERENCE FIT AND CRACK GROWTH PREDICTION, by D. Chaumette, R. Cazes, and C. Czinczenheim, AMD/BA, France

13.00 Lunch

CHAIRMAN J. SCHIJVE

14.30 2.8 FATIGUE DESIGN OF BOLTED JOINTS, by L. Jarfall, Saab-Scania, Sweden

15.10 2.9 FATIGUE RATED FASTENER SYSTEMS IN ALUMINIUM ALLOY STRUCTURAL JOINTS, by H.H.v.d. Linden, NLR, the Netherlands

15.50 Closure

All meetings will be held in the "Salle de conférences"

12TH ICAF SYMPOSIUM: ABSTRACTS OF PAPERS

PAPER 1.1

VERIFICATION OF METHODS FOR DAMAGE TOLERANCE EVALUATION OF AIRCRAFT STRUCTURES TO FAA REQUIREMENTS, BY T. SWIFT (FEDERAL AVIATION ADMINISTRATION, U.S.A.)

The Federal Aviation Administration (FAA) requirements for the damage tolerance evaluation of aircraft structures, contained in Federal Airworthiness Requirements (FAR) 25.571, are written in general terms. Thus the manufacturers have a certain degree of latitude in how compliance with the regulation is effected. Because the requirements are relatively new and general many manufacturers, particulary the smaller ones, have experienced difficulty in judging the scope of the evaluation and what will be acceptable to the FAA. As the National resource Specialist for Fracture Mechanics/Metallurgy for the FAA this author has for the past two years been responsible for interpreting the requirements and advising manufacturers on the necessary validation of analytical procedures used for the damage tolerance evaluation. There are currently a number of aircraft both foreign domestic for which damage tolerance evaluations are being conducted to satisfy FAR 25.571 and a number are planned for the future. The proposed paper will outline in general the requirements for a damage tolerance evaluation of commercial transport aircraft to FAR 25.571. Since the evaluation is essentially analytical, due to the large number of elements under consideration, particular attention will be given to outlining requirements for the validation of crack propagation and residual strength analytical methods.

The following points will be included in the discussion :

- It will be pointed out that stress range truncation levels to be used in stress spectra for crack propagation analysis are necessarily much lower than would be required for linear cummulative damage analysis. Necessary tests will be described to determine a stress range truncation level which minimizes crack growth life.

- Since each manufacturer develops his own crack growth computer program, incorporating certain da/dn simulation and retardation models etc., it is essential for each manufacturer to validate the basic prediction capability of his program by crack growth testing under spectrum loading.

- The damage tolerance evaluation is to be performed on complex stiffened structure. This requires the calculation of the effects of stiffening elements and fastening systems on the stress intensity factor to be used in crack growth and residual strength analysis. It is required that each manufacturer validate his ability to make these calculations in stiffened structure by a certain amount of crack growth and residual strength testing.

- Consideration must be given to multiple site damage where the possibility exists that a number of small cracks, each of less than detectable length, may suddenly join together to form a long critical crack.

- The propagation of longitudinal cracks in the pressure cabin is particulary difficult to calculate due to bulging caused by curvature effects. Thus in areas requiring crack growth analysis the analytical methods must be validated by test.

- The pressure cabin should be substantiated for a certain amount of discrete source damage such as may be inflicted by disintegrating engine fragments. This evaluation should be substantiated by test.

- When conducting residual strength testing for simulated fatigue damaged structure on large components the fatigue damage is often simulated by saw cuts. Usually on such static test components the ability to cycle the loading to form fatigue cracks at the saw cut ends is not feasible. Depending on the material and saw cut configuration a higher residual strength may result if the fatigue crack is not properly simulated. Thus a certain amount of validation testing may be required to substantiate the validity of the large component test.

The content of the proposed paper is not intended to specify in precise detail how the FAA requirements should be met. Such a position would remove the freedom of means of compliance for the manufacturers and perhaps stifle inovation. The paper content should however, create an atmosphere for discussion at the forthcoming ICAF meeting and perhaps stimulate a certain amount of feedback from manufacturers who are currently making a damage tolerance evaluation.

PAPER 1.2

PROGRESS IN THE REVISION OF THE U.K. MILITARY AIRWORTHINESS REQUIREMENTS FOR FATIGUE AND DAMAGE TOLERANCE, by R D J Maxwell and A W Cardrick, (RAE Farnborough, U.K)

In the UK we are currently revising our requirements for military aircraft. The opportunity is being taken to unify safe life requirements for aeroplanes and helicopters and introduce additional procedures to provide increased tolerance to rogue defects, accidental damage and unforeseen high stress levels.

We are fortunate in having close contacts with the airworthiness authorities of many of the member nations of ICAF. In consequence we have benefited from their experience and our emerging requirements can be seen to have something of an international flavour.

We explain why we have retained a safe life requirement as part of our procedure and how we are developing rules for the use of life an stress factors. It is envisaged that we will achieve improved standards of damage tolerance by using the principles advanced by the USAF in MIL-A-83444, but taking advantage of material screening tests and supplementary safe life calculations to reduce the amount of fracture mechanics analysis that needs to be done.

PAPER 1.3

DAMAGE TOLERANCE OF AERO-ENGINE DISKS, by H.Huff, G.König (M.T.U., München, F.R.G.)

Abstract

In order to assess the damage tolerance of aero-engine disks a program was performed including.

- Specimen tests with disk-materials containing surface defects (i.e. machining grooves, etch pits etc.) which may occur at critical sites of a component. The aim was to investigate the effect of various defects on the fatigue life.

- Cyclic spin tests with disks to determine the crack initiation life as well as the residual crack propagation life to failure in relation to the crack size. The crack propagation data were obtained by evaluating the cyclic spin tests by non destructive crack inspection tests and by fractography. Part of the disks were provided with artificial cracks produced by spark-cutting to get crack propagation at any desired location.
  The crack propagation results are compared to fracture mechanics calculations which allow the estimation of the residual crack propagation life for different geometries, materials, temperatures and loading conditions.

  The results of the program are used to discuss and compare different safety-assurance approaches, such as the "safe crack initiation life", the "safe crack propagation life" as well as the "retirement for cause" approaches.

PAPER 1.4

STATISTICAL APPROACH TO DAMAGE TOLERANCE ASSESSMENT, by B.Lachand C.Laurent J.M.Leonard and J.M.Thomas

The fatigue life of an aircraft depends on several parameters : empty and loaded weitht, flight frequency, mission, flight duration, atmospheric characteristics, type of control, stress levels, sturctural design in order to customize aircraft fatigue life predictions for each airline, Aerospatiale has adopted a vast statistical fatigue methodology. This methodology has two distinct aspects :

* a fatigue life prediction using a entirely statistical approach which takes the cumulative probabilities of all events (runway, turns, justs, manoeuvres, touch-down...) over a large number of flights into consideration.
  An extension of the rainflow method to a statistical spectrum is then used to separate the main effects, such as ground-air-ground and large stress deviations, from the residual effects. A cumulative damage law then provides a life for a large number of structural components (many hundreds) of a given aircraft, whose whole life will have thus been statistically analysed.

* a complete study of a "parametric" aircraft, that is, an aircraft whose main characteristics.
(empty weight, evolution of total weight in flight, type of mission, control law, tyme of rumway ...) can evolve. For a large number of structural components a tress sensitivity study is made with respect to these different parameters using a finite element model or flight recordings. A data base is used to collect these results and then interpolate the customised aircraft that will be representative of the operations of a given airline. This aircraft is then subjected to the calculation described above.
This approach has already been applied to the fatigue life prediction of the Concorde supersonic transport and is now being used for Airbus A 310 analysis and ATR 42 commuter predictions.

Today the Aêrospatiale Aircraft Division this possesses a modern aircraft fatigue prediction and analysis tool which will enable each airline to have a customised fatigue study, withing the coming year, this approach will be extended to crack propagation and fracture mechanics

* Engineers in the structural stressing Departement.

** Head of the structural stressing Methods group.

PAPER 1.5

FINITE ELEMENT ANALYSIS OF CRACKED, PIN LOADED LUGS, by R.V.Van Der Velden and E.P.Louwaard (Fokker, Netherlands)

A literature survey of the stress intensity factors (K) for cracked lugs revealed that the values of K as proposed by different authors show considerable variation.

To determine which K-values should be used, it was decided to perform a 2-D finite element analysis of cracked lugs.

Different parameters that influence the stress intensity factors were varied : load transfer between pin and lug, presence of frictional forces between pin and lug and the shape of the lug.

Special attention was given to the load transfer between pin ang lug. The resulting pressure distribution was represented by different analytical functions, both with and without frictional forces.

To determine which pressure distribution is the most realistic one for a certain lug configuration, special connecting elements were used, which are capable of transfering compressive loads only. Through an iterative procedure the load transfer between an aluminium lug and a steel pin was calculated for several crack lengths. Both perfect fit pins and pins with clearance were used. The results of the calculations showed that all parameters mentioned above have a marked influence on the calculated values of the stress intensity factors.

PAPER 1.6

THE EFFECT OF FRICTIONAL FORCES ON FATIGUE CRACK GROWTH IN LUGS, by J.E.Moon (RAE Farnborough, U.K.)

At the last ICAF Symposium, experimental stress intensity factor range (ΔK) distributions derived from crack propagation rate measurements were presented for a pin-loaded lug.

It was shown that crack growth rate at short crack lengths was much faster, by up to almost an order of magnitude, than predicted by available fracture mechanics solutions. It was proposed that this was due to the action of frictional forces between the pin and hole surface. These forces are normally ignored, it being assumed that load is transferred by radial pressure alone.

Further crack propagation rate measurements have been made on lugs with normal clearance fit pins which confirm the earlier results.

Experiments are described in which the frictional forces were reduced by lubricant and removed altogether from around the crack origin using pins with flats. It is found that crack propagation rate at short crack lengths is significantly reduced by both of these measures, indicating values of ΔK nearer to those predicted ignoring frictional forces.

It is found that the inclusion of the action of frictional forces in a fracture mechanics analysis of a lug leads to an increase in the predicted ΔK at short crack lengths. Closer agreement with experimental results is obtained if it is assumed that these forces build up more in the region of the crack origin and are therefore effective for the important region of short crack lengths.

PAPER 1.7

This paper was not presented.

PAPER 1.8

ELEMENTS OF DAMAGE TOLERANCE VERIFICATION, by U.G.Goranson and J.T.Rogers (Boeing Commercial Airplane Company, U.S.A.)

Significant advancements have been made in recent years in the capability to analyze structure with damage. Rational and streamlined fracture mechanics methods now permit evaluations of residual strength and damage growth characteristics of complex details or assemblies. Substantial test verifications have been necessary to address residual strength and damage growth characteristics of structures with multiple damage sites. The advent of high technology test equipment has permitted laboratory evaluation of typical load spectra comprising of several load levels and flight types. Similar flight-by-flight spectra are now applied to the 767 and 757 full-scale fatigue test articles which will provide valuable information to confirm Boeing durability design criteria and support selection of initial inspection thresbolds for fatigue damage detection. Such fatigue testing is however not an alternative to the structural inspections required to maintain a damage tolerant design.

Traditional fracture mechanics methods provide information on damage growth periods from detectable to critical damage but fail to recognize fleet size effects, multiple fleet cracking events and interaction of multiple type and methods of inspections. The ultimate control in ensuring damage tolerance of new and aging jet transports is to assure timely damage detection. Boeing has focused major efforts on establishing quantitative damage detection evaluation methods that permit rational comparative analyses. This Damage Tolerance Rating (DTR) system provides additional flexibility for operators of new and aging aircraft to incorporate any supplemental inspections for detection of fatigue damage in selected candidate aircraft that have reached sufficient maturity to benefit exploratory fleet leader inspection programs.

Damage detection standards are based on reported service cracking which has been fitted to statistical distributions for both visual and non-destructive test methods. Interaction of non-detections and levels and types of inspections have been considered in establishing probability of detection curves. Additional detection opportunities from subsequent cracking of similar details in a fleet of aircraft is also accounted for. Required damage detection reliability levels can be achieved by modifying and/or complementing existing maintenance programs in terms of level and frequency of inspections on all candidate aircraft or selected fleet leaders. The Boeing DTR system provides an efficency measurement of inspection activities and permits flexible maintenance planning without compromising safety.

PAPER 1.9

DESIGN FOR MAXIMUM DURABILITY AND DAMAGE TOLERANCE IN THE MANUFACTURE OF A HEAVY TRANSPORT WING, by A.P.Shewmaker, J.L.Russ (Lockheed-Georgia Company, U.S.A.) and J.L.Hopkins (Wright-Patterson Air Force Base, U.S.A.)

The C-5A Wing Modification Program is an example of a wing designed for minimum structural maintenance throughout the planned life of the force aircraft. This paper describes the design development and testing associated with that program. It also describes the inter-disciplinary coordination between engineering, tooling, manufacturing, and quality control which assures a consistent, high-quality end product with maximum durability and damage tolerance capability.

The C-5A Wing Modification Program is divided into the four major phases, Design, Testing, Kit Fabrication, Force Modification. A unique aspect of this program is the performance warranty relative to the durability and damage tolerance test article.

Phase I, Design, consists of the engineering required to establish the final configuration. The primary activities in this phase are the development of the design/operational loads and material specifications, design development testing, detail analysis, design, and the development and implementation of a Fatigue and Fracture Control Plan. The Phase I schedule included lead time for the technology disciplines to establish a stable data base for development of the final design.

Phase II, Testing, includes the manufacture of two wing modification configuration specimens, flight testing of one of the wings on a modified force aircraft, and flight-by-flight durability and damage tolerance testing of the other wing.

Kit Fabrication is Phase III and Force Modification is Phase IV.

PAPER 1.10

PRATICAL APPLICATIONS OF DAMAGE TOLERANCE CONCEPTS TO U.S. NAVY AIRCRAFT, by C.E.Larson (Vought Corporation, U.S.A.)

One of the most useful applications of damage tolerance concepts is the analytical design of proof loads for tension loaded structure. Proof loading, if properly planned, may constitute a positive and highly reliable non-destructive inspection technique which not only defines the upper boundary of the present damage state but also guarantees a specified remaining operational life. This paper describes this application of fracture theory to six different non-redundant structural components. The research was funded by the U.S. Naval Air Systems Command, Washington, D.C., U.S.A.

The subject components discussed are five safety of flight critical catapult launch and recovery components and one hydraulic pressure vessel belonging to U.S. Navy carrier suitable aircraft. The preventive maintenance schedule called for each component to be routinely proof loaded to near limit load at a specified operational interval in an attempt to enhance safety. It was discovered that the proof loadings provided extremely limited remaining life information due to their low magnitudes. It was further determined that the interval of the proof loading event was unnecessarily short. Dramatic improvements in safety confidence and economics were realized by the derivation of new proof loads and resulting intervals.

Each program discussed consisted of (1) a load spectrum determination phase, (2) a series of component tests to determine the fatigue critical location under the operational spectrum, (3) a series of tests to characterize crack propagation rates and fracture toughness ; (4) a series of tests to determine residual strength as a function of flaw size, (5) fractographic analyses of failed surfaces to characterize flaw geometry, (6) a data analysis and operational life criteria formulation, and (7) a series of verification tests. The components represented a variety of material/heat treatment combinations (steel, Inconel, aluminium), type of critical location (lugs, welds, radii), environments (salt water, laboratory air, high temperature), and spectra (constant amplitude, random). Both plain strain and plain stress fracture modes were evident. In all cases the new proof loads themselves were included in the respective load spectrum and their effects evaluated.

Each program is summarized to present interesting fracture results and economic advantages of the method application. For example, one of the programs resulted in a proof load that increased the testing interval by 550 percent with an attendant increase in the safety confidence. Economic savings for the article was estimated to be such that a forty to one return on investment was realized.

PAPER 1.11

This paper was not presented.

PAPER 2.1

APPLICATION OF DAMAGE TOLERANCE CONCEPTS TO "SHORT CRACKS" IN SAFETY CRITICAL COMPONENTS, by D.W. Hoeppner, (University of Toronto Canada)

"Short cracks" can either exist in numerous aircraft components initially or they can be created by numerous use related mechanisms of mechanical behaviour. Some use related mechanisms that produce "short cracks" are cyclic loading (fatigue), corrosion fatigue, stress corrosion cracking, fretting fatigue, creep fatigue. As damage tolerance concepts are extended to engines, critical fittings, and numerous helicopter components, it will become necessary to develop an increased understanding of the physical behaviour of "short cracks" produced by the mechanisms mentioned as well as those that are inherent to the component initially. This paper describes the current level of understanding of short crack behaviour ; summarizes physical models ; presents mathematical models that may be used to model behaviour and establish predictions, and, presents examples of short crack behaviour in real aircraft components. Emphasis will be on engine components and advanced materials for airframes.

PAPER 2.2

THE CYCLIC BEHAVIOUR OF A POWDER Ni-BASE SUPERALLOY, by M.A.Hicks, R.A.Newley, B.P.Towill, (Rolls-Royce LTD, Bristol, U.K)

The planned incorporation of a high strength nickel-base powder superalloy as a disc material in the aero engine will allow components to run at higher stresses and temperatures, thereby contributing to the overall efficiency of the engine. However, because of the eexistance of small defects within the material, a thorough knowledge is required of their performance under severe operating conditions. Consequently an extensive programme of material testing has been carried ou at Rolls Royce in order to determine the influence of the inherent defect population in the alloy on its cyclic properties. This paper discusses some interesting observations concerning the role of defects in fatigue and the interaction of microstructure, crack size, temperature and stress conditions on the mode of crack growth. The selection and interpretation of test piece data for the prediction of safe lives for actual components in fatigue is also discussed.

PAPER 2.3

EXPERIMENTAL AND ANALYTICAL STUDY OF STRENGTH DEGRADATION DURING FATIGUE OF GRAPHITE/EPOXY LAMINATES, by R.Prinz, H.C.Goetting, K.Schmidt (DFVLR,FRG)

The development of Fatigue damage in unnotched multidirectional graphite/epoxy T 300/914 C laminates was investigated for both tension and compression cycling. During and after fatigue loading specimens were examined for damage growth using light microscopy, scanning electron microscopy, ultrasonic C-scans and x-radiography. Ply cracking and edge delamination were found to be the dominant types of fatigue damage.

For a better understanding of the strength degradation the formation of the observed delaminations was correlated with finite-element calculations and the results of a damage growth model. During fatigue loading the defects propagate due to interlaminar stresses to a point where the specimens fail by short buckling or because of shearing.

Considering the statistical nature of the test results, good correlations were estblished between experimentally observed residual strength and analytical predictions.

PAPER 2.4

FATIGUE PERFORMANCE OF NOTCHED (0°, ±45°) CFRP WITH WOVEN AND NON WOVEN ±45° LAYERS, by S.M.Bishop (RAE, Farnborough, U.K.), and J Morton (Imperial College, London, U.K.)

Two CFRP laminates were prepared with the same 0°, ±45° lay-up.

One laminate contained unidirectional fibres in each layer while the other had woven fabric in place of each pair of ±45° plies. Sharp central notches were cut in coupons taken from the laminates and the notched strength determined. Further coupons were then loaded in zero-tension fatigue with maximum loads corresponding to approximately 80 and 95 % of the static notched strength. It was found that failure did not occur in any specimen in less than 2 x 10^6 cycles. Some fatigue tests were interrupted after a predetermined number of cycles, ultrasonically scanned to assess the scale of fatigue damage around the notch and then fractured to determine the post-fatigue residual strength. In the specimens made from non-woven material the fracture mode after fatigue was quite different from that in the statically loaded speciments while in the coupons with woven ±45° plies, no transition in fracture mode occurred. Also the shape of the damage zone was quite different for specimens with woven and non-woven ±45° plies but the load bearing capacities of both materials were very similar. In both laminates the residual strength after fatigue was almost 40 % greater than the initial notched strength. Micrographic sections of fatigued specimens were prepared and the variation in residual strength with varying fatigue cycles was determined.

PAPER 2.5

BEHAVIOUR OF CARBON EPOXY : COMPOSITE UNDER AXIAL FATIGUE AND CRACK PROPAGATION BY DELAMINATION IN GLASS EPOXY COMPOSITE, by B.Soulezelle and D.Aliaga, SNIAS Suresnes

This paper presents fatigue results obtained with a carbon-epoxy composite material (T300/Narmco 5208). Three different lay-ups are studied, 0° unidirectional, 0/ ±45/90 quasi isotropic and crossed with 44 % fibers in the loading direction, under different types of loading cycles, tensile, tensile/compression and compression the tests demonstrate a great sensitivity to tensile/compression loading cycles.

Likewise, this paper presents fatigue crack growth curves in glass epog material. Crack propagation is obtained by delamination of two wovenfabrics, in opening mode (mode I) and shear mode (mode II). The existance of a fatigue threshold is shown. Threshold values are approximathy 3 times lower than the Kc values. In addition the effect of wet aging and humid environment are studied.

PAPER 2.6

RESULTS OF A STUDY OF RESIDUAL STRESSES AND FATIGUE CRACK GROWTH IN LUGS WITH EXPANDED HOLES, by A.A.Jongebreur (Fokker, Netherlands and A.U.De Koning (NLR, Netherlands)

Equations describing the stress and deformation fields during and after cold working a central hole in thin and thick walled rings are presented. Results calculated for these axially-symmetric discs are compared with data obtained experimentally from tests on actual lugs. Deviations are explained on the basis of differences in the geometry and the use of a split sleeve in the expansion process.

The theoretical model is used to study the effect of some parameter variations such as, ratio of inner and outer radius, strain hardening coefficient and yield stress, on the residual stress field. Areas critical for stress corrosion cracking are indicated.

Further, the beneficial effect of hole expansion on the fatigue resistance of lugs is discussed. Results known from the open literature are compared with new experimental data. In addition some results obtained for lugs precracked before application of the cold expansion process are presented. In these tests the applied load can be characterized as spectrum loading.

From the results it can be conclued that cold expansion of holes can have a beneficial effect on the fatigue resistance of lugs.

This summary was prepared for presentation on the 12th ICAF meeting to be held in Toulouse, 1983.

PAPER 2.7

INTERFERENCE FIT AND CRACK GROWTH PREDICTION, by D.Chaumette, R.Cazes and C.Czinczenheim, Avions Marcel Dassault-Bréguet Aviation (ST CLOUD)

The beneficial influence of interference fit on fatigue and crack growth life are well known. Two typical applications of the process are the interference fit bolts and lugs with expansible pins. A finite element analysis of the effect of interference fit (on both bolts and lugs) has been performed at AMD-BA ; this analysis has necessitated the use of non linear three dimensionnal finite elements, and a code developped by AMD-BA. Exemples of finite element models and the associated results are presented, as well as comparisons with tests results, which prove a reasonable agreement between prediction and experiment.

Since this kind of analysis is very expansive, a simpler method has been investigated (simplified computation method associated with reference curves), thus allowing a rough assessment of the effect on interference fit on fatigue and crack growth life. This second kind of approach and its results are also presented here.

PAPER 2.8

SHEAR LOADED FASTENER INSTALLATIONS, by Lars Jarfall, (SAAB-SCANIA, SWEDEN)

The paper is an attempt to review the state of the art in procedures for designing and optimizing bolted or riveted joints. Methods and data desired for the design procedure will be defined and compared with what is available today. Following major steps in the design procedure may be identified :

Calculation of the force distribution in the joint, which requires methods and data to account for fastener flexibility, excentricities and bending support from surrounding structure.

Calculation of the fatigue quality or the fatigue life, which requires that the influence from by pass stress, load transfer and secondary bending on the fatigue performance must be known for various combinations of material qualities (of the joined members), hole qualities and fastener types.

Particular attention will be paid to experimental techniques and specimen types for determination of fastener flexibility and fatigue data. Some recent findings about the interplay between friction and bearing during fatigue cycling of bolted joints will be reviewed.

PAPER 2.9

FATIGUE RATED FASTENER SYSTEMS IN ALUMINIUM ALLOY STRUCTURAL JOINTS, by H.H.Van Der Linden (NLR, Netherlands)

Abstract :

An overview is given of objectives, methods and means of accomplishment and technical requirements of a cooperative testing programme on Fatigue Rated Fastener Systems.(FRFS).
The programme will mainly assess the fatigue lives of a range of fatigue rated fastener systems in combination with hole preparation techniques using different joint geometries. Establishment of cost figures in relation to the fatigue performance and the development of a reference datum for the comparison of test results produced in different countries are the secondary objectives.

Special emphasis is given to the core programme on high load transfer single shear joints : different single shear joint designs and their double shear equivalent designs are evaluated and compared.
This evaluation includes testing under Falstaff loading and the measurement of load transfer and secondary bending using standard procedure.

Fatigue test results of low load transfer-, medium load transfer 1½ dogbone-, high load transfer double shear specimens from the author's laboratory are also included. The procedures for the measurement of load transfer ans secondary bending are illustrated using NLR results on 1½ dogbone specimens.

APPENDIX 5
18TH ICAF CONFERENCE:
SCHEDULE AND NATIONAL REVIEWS

18th ICAF CONFERENCE : NATIONAL REVIEWS

INTERNATIONAL COMMITTEE ON AERONAUTICAL FATIGUE

ICAF

18th CONFERENCE — 12th SYMPOSIUM

TOULOUSE — 25-31 May 1983 — FRANCE

MONDAY, 30 MAY 1983

9.00	REGISTRATION	
9.30	OPENING AND WELCOME	R. LABOURDETTE
	CHAIRMAN A. BERKOVITS	
9.40	ICAF SECRETARY'S REVIEW	J. SCHIJVE
9.50	THE NETHERLANDS	J.B DE JONGE
10.35	BREAK	
11.00	UNITED KINGDOM	P.R EDWARDS
12.00	AUSTRALIA	G.S JOST
13.00	LUNCH	
	CHAIRMAN G.S CAMPBELL	
14.30	GERMANY	O. BUXBAUM
15.10	SWEDEN	[illegible]
16.10	BREAK	
	CHAIRMAN [illegible]	
16.30	SWISS	A. [illegible]
17.00	UNITED STATES OF AMERICA	[illegible]

TUESDAY, 31 MAY 1983

	CHAIRMAN T. KANIYAMA	
9.00	BELGIUM	A. MAENHAUT
9.30	ITALY	A. SALVETTI
10.00	BREAK	
	CHAIRMAN J. SCHIJVE	
10.30	FRANCE	R. LABOURDETTE
11.15	CANADA	G.S CAMPBELL
11.45	ISRAËL	A. BERKOVITS
12.15	JAPAN	T. KANIYAMA
13.00	LUNCH	
	CHAIRMAN R. LABOURDETTE	
14.30	COLLOQUIUM (GENERAL DISCUSSION)	
16.30	ADJOURN	

18TH CONFERENCE
NATIONAL REVIEWS

12TH SYMPOSIUM

INDUSTRIAL APPLICATIONS OF DAMAGE TOLERANCE CONCEPTS

STRUCTURES OF HIGH FATIGUE PERFORMANCES

NATIONAL REVIEWS PRESENTED TO THE 18TH ICAF CONFERENCE

The National Review for each ICAF country has been complied/edited/arranged by the corresponding National Delegate. As there is no specified presentation format, wide variations in layout and emphasis occur between Reviews.

By way of indicating the range and variety of work underway in each member country, the title and contents pages from each review are given at the end of this Appendix. It should be noted that countries engaged in limited fatigue activity tend to report in great detail, whereas others are forced to condense their material to manageable proportions. This may account for certain omissions: for example, the U.K. Review does not itemise any full scale fatigue testing, yet it is known that such tests are underway.

An additional indication of type and perhaps quality of fatigue activity may be gained from a listing of the organisations contributing to each National Review. This is given below

Netherlands	National Aerospace Laboratory (NLR) Delft University of Technology Fokker Aircraft Industries.
United Kingdom	British Aerospace Ltd. Central Electricity Research Laboratories University College, London Institute of Sound and Vibration Research University of Sheffield University of Cambridge University of Bath National Engineering Laboratory Royal Aircraft Establishment (RAE) Imperial College of Science and Technology.
Sweden	Aeronautical Research Institue of Sweden (FFA) The Saab-Scania Company The Royal Institute of Technology, KTH
Belgium	Aeronautics Administration SABCA BEKAERT
Switzerland	Swiss Federal Aircraft Factory (F+W) Swiss Federal Institute of Technology (ILS-ETH)
Germany	Audi NSU Auto Union Deutsche Airbus GmbH Dornier GmbH Hochschule der Bundeswehr Maschinenfabrik Ausburg-Nurnberg AG Technische Universitat, Munich Max-Planck-Institut fur Plasma-Physik

Germany (cont.)	Fraunhofer Institut fur Betriebsfestigkeit (LBF) Deutsche Forschungs-u.Versuchsanstalt fur Luft-und Raumfahrt (DVFLR) Technische Hochschule Darmstadt Industrieanlagen-Betriebsgesellschaft mbH Institut fur Statik und Dynamik, Stuttgart Messerschmitt-Bolkow-Blohm Vereinigte Flugtechnische Werke.
France	Centre d'Essais Aeronautique de Toulouse (CEAT) Office National d'Etudes et de Recherches Aerospatiales (ONERA) Aerospatiale Laboratoire Central (Suresnes) Aerospatiale Toulouse Avions Marcel Dassault-Breguet Aviation.
Italy	Institute of Aeronautics - University of Pisa Institute of Aircraft Construction - University of Bologna Italian Association for Fatigue in Aeronautics Fiat - Aviazione Aeronautica Macchi Aeritalia Costruzioni Aeronautiche Giovanni Agusta.
Australia	Australian Aircraft Consortium Aeronautical Research Laboratories Department of Aviation Government Aircraft Factories Department of Defence (Air Force Office) Royal Melbourne Institute of Technology.
United States	American Society for Testing and Materials (ASTM) NASA Langley Research Center NASA Lewis Research Center Air Force Flight Dynamics Laboratory Air Force Materials Laboratory Naval Air Development Center Northrop Corporation U.S. Army Research and Technology Laboratories Boeing Commercial Airplane Company Douglas Aircraft Company Lockheed-California Company Lockheed-Georgia Company McDonnell Aircraft Company Department of Transportation.
Canada	National Aeranautical Establishment de Havilland Aircraft of Canada Canadair Ltd. Aerospace Engineering Test Establishment Department of Transport University of Waterloo University of Saskatchewan University of Toronto

Israel	Technion-Israel Institue of Technology Israel Aircraft Industries Israel Air Force Tel Aviv University
Japan	National Aerospace Laboratory Technical Research and Development Institute Fuji Heavy Industries Mitsubishi Heavy Industries Kawasaki Heavy Industries Aircraft Accident Investigation Commission

Finally, it is noted that a number of collaborative programs are underway between ICAF countries. The nature of the collaboration and the countries involved are listed below.

Standard aircraft loading sequences

HELIX - (mid span) sequence for hinged helicopter blades (Netherlands, Germany, U.K.).

FELIX - (root region) sequence for fixed helicopter blades (Netherlands, Germany, U.K.).

Reconstitution of loading sequences

Aim : To devise methods for reconstituting fatigue sequences such that identical fatigue behaviour results from original and reconstituted sequences. (U.K., Australia, U.S., Canada).

AGARD Fatigue Rated Fastener System program

Aim : To evaluate and compare the performance of various candidate fatigue improvement fastener systems in joints under realistic conditions. (Netherlands, U.K., Germany, France, Italy, U.S., Sweden).

NLR MP 83016 U

REVIEW OF AERONAUTICAL FATIGUE INVESTIGATIONS IN THE NETHERLANDS DURING THE PERIOD MARCH 1981-FEBRUARY 1983

Edited by J.B. de Jonge

SUMMARY

A brief review is given of work performed in the Netherlands in the field of aeronautical fatigue. Where possible, applicable references have been presented.

This review will be presented at the 18th ICAF Conference, Toulouse, 30 and 31 May 1983

Division: Structures and Materials
Prepared: JBdJ/ 30/3
Approved: HPvL/

Completed : March 1983
Ordernumber: 840.303
Typ. : MM

CONTENTS

A REVIEW OF THE WORK IN THE UNITED KINGDOM ON THE FATIGUE OF AIRCRAFT STRUCTURES DURING THE PERIOD MAY 1981 TO APRIL 1983

edited by

P. R. Edwards

Royal Aircraft Establishment,
Farnborough, Hampshire

May 1983

SUMMARY

In this paper a review is given of work associated with fatigue of aircraft structures which has been carried out in the United Kingdom over the period May 1981 to April 1983. The review includes basic studies on the development of fatigue damage in metals and composites, studies of crack propagation and residual strength and work to increase knowledge of aircraft loading actions. A reference list is given of relevant papers issued during the period under review.

Paper to be presented at the 18th Conference of the International Committee on Aeronautical Fatigue, to be held at Toulouse, France, 30-31 May 1983.

LIST OF CONTENTS

LIST OF CONTENTS (continued)

LIST OF CONTENTS (concluded)

REVIEW OF SWEDISH WORK ON FATIGUE OF AIRCRAFT STRUCTURES
DURING THE PERIOD MAY 1981 TO APRIL 1983

Edited by

Sigge Eggwertz and Björn Palmberg

The Aeronautical Research Institute of Sweden

FFA

(FFA Technical Note No. HE-2427)

CONTENTS

REVIEW OF FATIGUE WORKS PERFORMED
IN BELGIUM DURING THE PERIOD
1981 - 1983

compiled by
A. MAENHAUT

TABLE OF CONTENTS :

MINISTERE DES COMMUNICATIONS
ADMINISTRATION DE L'AERONAUTIQUE
(Report MV. 83-11)
May 1983.

Review of the Swiss Investigations on Aeronautical Fatigue

Period May 1981 to April 1983

by

A. Jordi

F+W TA - 474

dated 16 May 1983

Swiss Federal Aircraft Factory (F+W)
CH-6032 Emmen

CONTENT | Page

Fraunhofer-Institut
für Betriebsfestigkeit
Darmstadt

ICAF Conference 1983 — LBF Report S-166

Review of Investigations on Aeronautical Fatigue in the Federal Republic of Germany

by
O. Buxbaum and D. Schütz

Period of Review
May 1981
to
April 1983

TABLE OF CONTENTS

REVIEW OF AERONAUTICAL FATIGUE INVESTIGATIONS
IN FRANCE
DURING THE PERIOD 1981 - 1983

COMPILED

by

R. LABOURDETTE

The present review will be presented at the 18 th ICAF Conference, Toulouse, 30 and 31 May, 1983. It consists of contributions of different sources

- Centre d'Essais Aéronautique de Toulouse (C.E.A.T.)
- Office National d'Etudes et de Recherches Aérospatiales (O.N.E.R.A.)
- Aérospatiale Laboratoire Central (Suresnes)
- Aérospatiale Toulouse
- Avions Marcel Dassault-Bréguet Aviation

A detailed list of subjects is given in the contents of this review.

TABLE OF CONTENTS

A.I.F.A. - ITALIAN ASSOCIATION FOR FATIGUE IN AERONAUTICS
Department of Aerospace Engineering - University of Pisa

REVIEW OF AERONAUTICAL FATIGUE INVESTIGATIONS IN ITALY DURING THE PERIOD MAY 1981 APRIL 1983

by

A.Salvetti and L.Lazzeri

April 1983

SUMMARY

This document was prepared for presentation to the 18th Conference of the International Committee on Aeronautical Fatigue scheduled to be held at Toulouse, on May 30 and 31, 1983.

A summary is presented of the main activities carried out in Italy in the field of aeronautical fatigue within Universities, Industries and other Institutions. The main topics discussed refer to specimens and full-scale fatigue tests, residual static strength, crack propagation.

CONTENTS

AR-002-944

DEPARTMENT OF DEFENCE SUPPORT
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

Structures Technical Memorandum 359

A REVIEW OF AUSTRALIAN INVESTIGATIONS ON AERONAUTICAL FATIGUE DURING THE PERIOD APRIL 1981 TO MARCH 1983

Edited by

G.S. JOST

SUMMARY

This document was prepared for presentation to the 18th Conference of the International Committee on Aeronautical Fatigue scheduled to be held at Toulouse, France on May 30 and 31, 1983. It is being distributed within Australia as an ARL Technical Memorandum.

A summary is presented of the aircraft fatigue research and associated activities which form part of the programs of the Aeronautical Research Laboratories, the Department of Aviation, the Royal Australian Air Force and the Australian aircraft industry. The major topics discussed include the fatigue of both civil and military aircraft structures, fatigue damage repair and refurbishment and fatigue life monitoring and assessment.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

A REVIEW OF RESEARCH ON

AERONAUTICAL FATIGUE IN THE UNITED STATES

1981 - 1983

Compiled by

Robert M. Bader

Air Force Wright Aeronautical Laboratories

Wright-Patterson Air Force Base, Ohio, USA

FOR PRESENTATION AT THE MEETING

OF THE

INTERNATIONAL COMMITTEE ON AERONAUTICAL FATIGUE

25-31 May 1983

Toulouse, France

TABLE OF CONTENTS

REVIEW OF CANADIAN AERONAUTICAL FATIGUE WORK 1981-83

By Glen S. Campbell

National Aeronautical Establishment
National Research Council

Summary

Canadian work in aeronautical fatigue during the period May 1981 to May 1983 is reviewed. A major effort has been concerned with the completion of the full-scale fatigue test on the Grumman Tracker, and the continuation of the test on the Canadair Challenger. Increased activity has occurred in the areas of corrosion fatigue, fretting, composite materials, and the fatigue and damage-tolerance analysis of Canadian Forces aircraft.

INDEX

MARCH 1983

REVIEW OF AERONAUTICAL FATIGUE INVESTIGATIONS IN ISRAEL

April 1981 - March 1983

by

A. Berkovits
Department of Aeronautical Engineering,
Technion - Israel Institute of Technology,
Haifa, Israel

TAE No 508

Prepared for Presentation at the 18th ICAF Conference
Toulouse, France, 30 and 31 May, 1983

CONTENTS

REVIEW OF AERONAUTICAL FATIGUE INVESTIGATIONS IN JAPAN

1981 - 1983

Compiled by

Tadao Kamiyama

Member of the Technical Council

National Aerospace Laboratory

and

Hiroyuki Terada

National Aerospace Laboratory

Tokyo, Japan

May 1983

The 18th Conference of the International Committee
on Aeronautical Fatigue

Toulouse, France

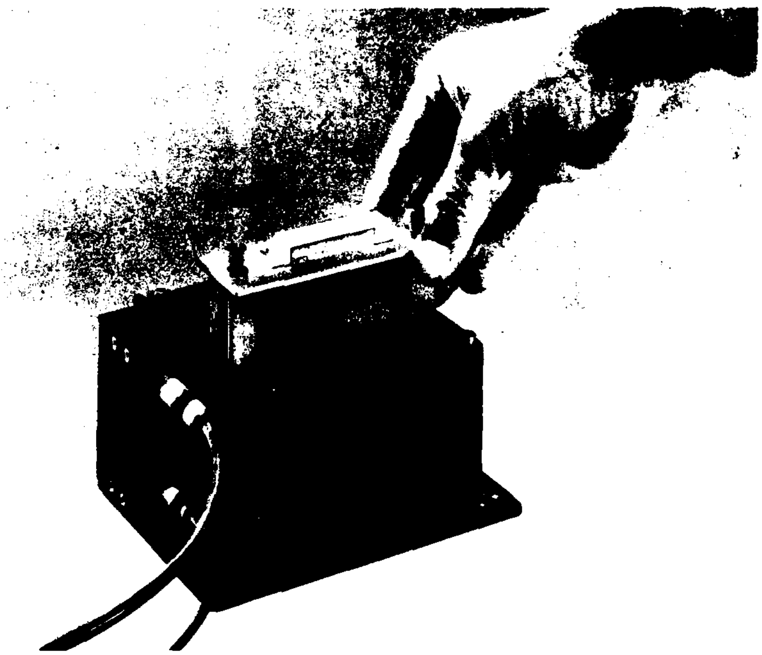
LIST OF CONTENTS

LIST OF CONTENTS

APPENDIX 6

SPECTRAPOT RECORDING AND PROCESSING SYSTEM

SPECTRAPOT DATA COLLECTOR



The SPECTRAPOT DATA COLLECTOR was originally developed at the INSTITUTE for AIRCRAFT and LIGHT WEIGHT STRUCTURES at the SWISS FEDERAL INSTITUTE of TECHNOLOGY in Zuerich to record, process and store strain data of dynamically loaded structures in their normal working conditions. Its signal, which may respond either to strain or to acceleration, depending on the transducer in use, is greatly reduced by the microprocessor and then stored in a non-volatile memory which uses no moving parts. This makes it possible to collect data with very little effort over a long period (up to several months). Since the DATA COLLECTOR requires an input voltage of only a few millivolts, it can be used also to measure other variables, such as temperature.

APPLICATIONS

With standard software (RAINFLOW, SEQUENTIAL PEAK VALLEY):
Producing strain histograms or strain data sequences.

With modified software:
Storing a recorded signal based on a given algorithm in a reduced form in the memory unit.

The small size and light weight of the DATA COLLECTOR make it convenient to use on airplanes, vehicles etc. under normal operating conditions.

SPECTRALAB Bruno R. Fricker, dipl. Phys. ETH
Brunnenmoosstrasse 7, CH-8802 Kilchberg
Telefon 01 - 715 56 40
Telex 53 249

SPECTRAPOT DATA COLLECTOR

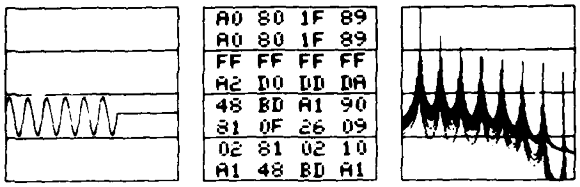
FUNCTION

As soon as the DATA COLLECTOR is energized it starts to measure according to the selected program, testing, for example the signal periodically for extreme values. The results of the program are written sequentially to the data memory, using in this instance the SEQUENTIAL PEAK VALLEY algorithm. At the conclusion of data recording, or at intervals, the memory unit is removed from the DATA COLLECTOR and connected to the DATA PROCESSOR. The contents of the memory unit are then written onto tape so that the recorded results are available at any time for further processing. Then the memory unit can be re-initialized and used again for measurements.

TECHNICAL DATA

Number of channels:	1
Transducer:	any strain gauge, either half or full bridge (or other device with suitable connection, which produces a voltage signal).
Gain:	adjustable by trim pot (max. 2000 V/V, which means for strain measurements a minimum of approx. 2000 microstrains for the full range).
Bridge excitation:	normally 5 V, variable from 4 to 12 V by changing an internal resistor.
Power requirements:	12 - 28 V DC (nominal) 10.5 - 32 V DC (extreme limits) 480 mA
Analog filter:	3-pole low pass, cut off frequency selectable from 2 to 5000 Hz, upper limit also depending on the algorithm in use.
Sampling rate:	1024 Hz (standard, other rates optional)
Microprocessor:	MC 6809
Programs:	SPV (SEQUENTIAL PEAK VALLEY) RTRF (REAL TIME RAIN FLOW) TAL (TIME AT LEVEL) All algorithms are EPROM-resident and thus exchangeable.
Memory unit:	non-volatile memory (CMOS-RAM); without any external power supply, data will be retained for 3 months by a stand-by battery.
Dimensions:	105 x 150 x 91 mm
Weight:	900 grams (2 lb)
Operating temp.:	-20 to + 71 °C (-4 to +160 °F), the equipment may be exposed while running to temperatures down to -55 °C (-67 °F).
Environment:	resistant to water, humidity and dust.
Shock:	more than 20 g in any direction
Vibration:	5 to 30 Hz : displacement 2.5 mm (0.1") 30 to 500 Hz : acceleration 5 g (peak) (MIL-E-5400T)
Electromagnetic compatibility:	meets EUROCAE ED-14A/RTCA DO-160A Cat. Z & A limits, for both conducted and radiated RFI.

May 1983



Acquisition Processing Display

SPECTRALAB
SPECTRALAB
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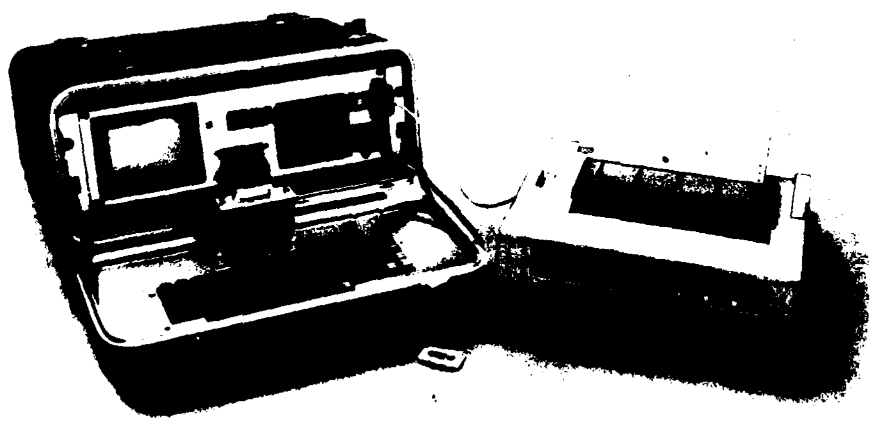
Made in Switzerland

SPECTRAPOT DATA PROCESSOR



The SPECTRAPOT DATA PROCESSOR is used to

prepare the data memory for measurement, e.g., to write a test identifier into the memory, to set parameters according to the recording program in use.

save the recorded data on the Mini Digital Cassette Recorder (MDCR).

display the recorded data on the screen or on a printer, depending on the processing program used.

transfer the data stored on MDCR tape to a host computer via the serial port.

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Brunnenmoosstrasse 7, CH-8802 Kilchberg
Telefon 01 - 715 56 40
Telex 53 249

SPECTRAPOT DATA PROCESSOR

SPECTRAPOT DATA PROCESSOR commands:

SAVE	Save data in memory on mini-cassette with name <filename> (Up to 8 characters).
INIT	Initialize memory for a new measurement. Parameters are asked interactively.
PROC	Process data in file <filename> and output to the screen or printer depending on the mode of the printer flag (altered by P+ and P-). The selection of a corresponding format depends both on the measuring algorithm and on the processing program in use (e.g. matrix form for RTRF, peak/valley plot for SPV).
SHOW	A summary of the file <filename> is output.
DUMP	The content of memory is output in hexadecimal and ASCII form.
REMOTE	Control is transferred to the serial port: input is accepted from the serial port only, output is also transferred to the serial port. The same commands are available.
LOCAL	Leave remote control.
P+	Output is duplicated on the printer.
P-	Disable output to printer.
DIR	Output of a directory of all files stored on one side of the MDCR tape.

SPECTRAPOT DATA PROCESSOR in closed box, for optimal protection against dust and water, may be used in the field and in the laboratory.

TECHNICAL DATA

Power requirements:	220 V AC (standard, others optional)
Mass storage:	Mini Digital Cassette Recorder (MDCR), capacity: 30 memory contents.
Memory connection:	socket connector on the keyboard to link the memory unit with the data processor.
Keyboard:	ASCII
Screen:	5.5"
Serial port:	V 24 / RS 232 C for connection to printer, terminal or host computer. Baud rate selectable from 50 to 19200 bits/s.
Weight:	18 kg (with case, without printer)
Dimensions:	19"/ 3U rack in 510 x 230 x 490 mm case
Software:	EPROM-resident or loadable from MDCR.

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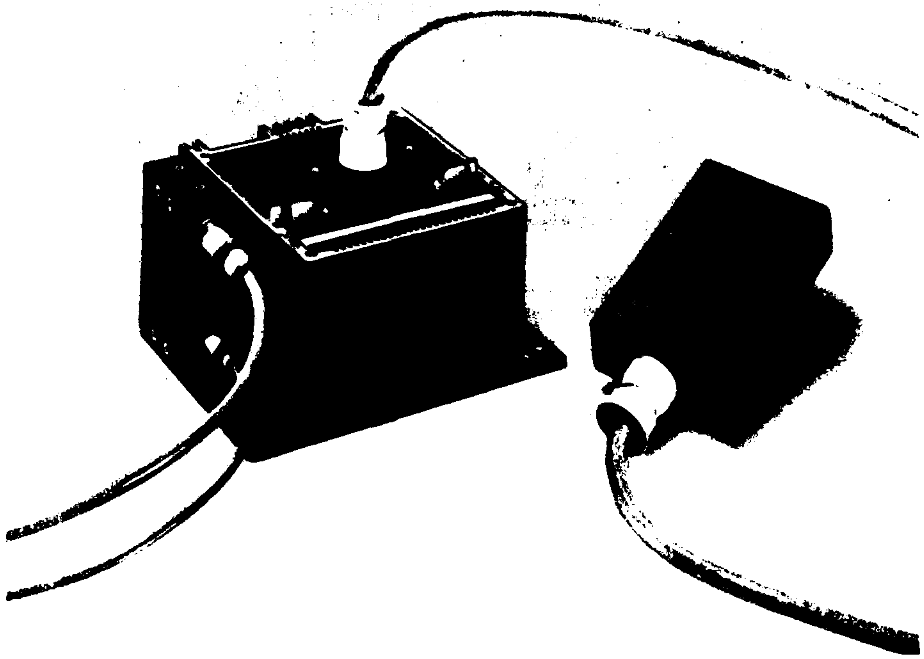
SPECTRAPOT CALIBRATOR



A measurement with the SPECTRAPOT DATA COLLECTOR requires proper calibration in advance, this means adjusting the instrument amplifier according to the expected signal range. The CALIBRATOR displays the following:

- the bridge balance by means of three Light Emitting Diodes (LED)
- the actual Analog/Digital Converter (ADC) value (256 steps)

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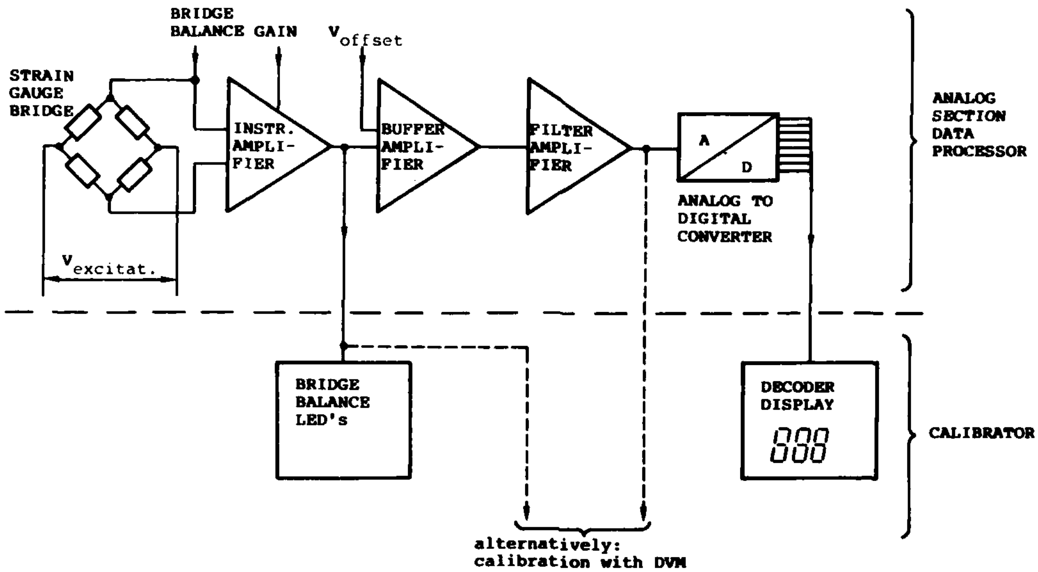
SPECTRAPOT CALIBRATOR



CALIBRATION PROCEDURE

The DATA COLLECTOR has three trimmer potentiometers to adjust the analog section appropriately:

Bridge balance: if the transducer is a Wheatstone Bridge, using for instance strain gauges, it must be balanced by means of a trim pot. The CALIBRATOR shows balance with a green LED.

Offset: the zero reference can be set to any ADC-step by means of a trim pot. The CALIBRATOR shows the actual ADC-step with three decimal digits.

Gain: the feature displaying any change of the input signal on the CALIBRATOR can be used to adjust the gain. When a strain gage bridge is in use this signal may be produced by applying a deformation to the testing object or by a shunt resistor.

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SPECTRAPOT RECORDING SOFTWARE

SPV / RTRF 3.0

Both programs, the SPV 3.0 (SEQUENTIAL PEAK VALLEY) and the RTRF 3.0 (REAL TIME RAIN FLOW), are stored on one EPROM (Erasable Programable Read Only Memory). The EPROM is located on the PROCESSOR board and can be extracted for change. Switching from SPV to RTRF requires no change , since the selection is done by the user during initialization with the SPECTRAPOT DATA PROCESSOR.

The peak / valley detection procedure is the same for both programs: each sample of the input signal (sampling rate 1024 Hz) is compared with the former one in order to detect extreme values (peaks or valleys). A range filter is used to reject smaller changes of the signal; its level can be set by the user during initialization (HYSTERESIS VALUE). A peak or a valley is then only accepted as such if the difference between the current and the preceding readings is at least equal to the HYSTERESIS VALUE.

SEQUENTIAL PEAK VALLEY:

The measured peaks and valleys are continuously recorded. Furthermore the user has the possibility of selecting a "time mark" during initialization. After each interval, which is also chosen by the user, a time mark is written into the sequence. Another mark is recorded when power is switched off. The available memory capacity limits the maximum number of peaks, valleys, time marks and power off marks to 1856, but the sequence of the load cycles is retained.

RAINFLOW:

The measured peaks and valleys are continuously reduced to combinations of amplitude and mean value according to the original description of Endo, T., Kyushu Institute of Technology, Japan. Each combination of amplitude and mean value is located in a 31 x 31 matrix, in which the number of load cycles is stored. Counting capacity is 16.7 x 10exp6 cycles per matrix element. In this way memory is limited to a reasonable size, but naturally the sequence of the load cycles is lost.

May 1983

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APPENDIX 7

I N T E R N A T I O N A L   D I S C U S S I O N   M E E T I N G

"THE COLD EXPANSION PROCESS -
ITS USAGE IN THE AVIATION INDUSTRY"

THURSDAY 9TH SEPTEMBER 1982

at

THE SELFRIDGES HOTEL
LONDON

AN OVERVIEW OF AIRFRAME STRUCTURAL APPLICATIONS OF FATIGUE RESISTANT FASTENERS

by

W G Heath
Chief Structural Engineer
and Research Manager
British Aerospace PLC Aircraft Group
Manchester Division

At the start of a new design the structural engineer is faced with three decisions:

Selection of material

Optimum structural form

Jointing media

These decisions cannot be made in isolation, since they are frequently interdependent.

The advent of monolithic structures has largely eliminated the need for conventional fasteners throughout much of the structure, but all major assemblies still require fasteners, especially in the fuselage longitudinal seams and the wing root joints. Thus monolithic construction has eliminated the lightly-loaded fasteners where fatigue was not a problem but the major sources of fatigue still remain.

To add to the structural engineer's problems aircraft are being utilised for longer periods, and the introduction of damage tolerant philosophies causes operators to demand simple repair schemes. These trends have led to an upsurge of research activity in fasteners, and the airframe designer is faced with a bewildering array of so-called 'fatigue-resistant' fasteners. Large R&D programmes are underway to find the most cost-effective solution.

The largest R&D programme is probably that organised by the AGARD Structures and Materials Panel, and this paper presents some recent results from the UK contribution to this programme. The effect of cold-working the holes before fitting a fastener (even without interference fit) is clearly demonstrated.

"Methods to improve the fatigue performance of a representative airframe joint"

DR. ING. LÜDER SCHWARMANN
V.F.W. - M.B.B.
Bremen, Germany

The various methods of jointing are described, using combinations of cylindrical shafted fasteners and compared with tapered shafted fasteners. Results are presented of fatigue tests undertaken with both these types of fasteners in both non cold worked and cold worked holes. Influence of the amount of interference of the fasteners is analysed.

The fatigue loading and its influence on the various combinations is evaluated, both constant amplitude and spectrum (FALSTAFF) loading being evaluated. Finally, the various combinations cost effectiveness are presented with the fatigue performance.

Contribution to International Discussion Meeting
'the Cold Expansion Process - Its usage in the Aviation Industry'

J. E. MOON
R. A. E., Farnborough

The problems associated with the evaluation of fastener systems which are claimed to increase the fatigue life of shear joints will be discussed. Consideration will be given to all types of fastener system, cold expansion, interference fit and high clamping. Particular emphasis will be placed upon the choice of load spectrum to be applied in fatigue tests, and the parameters to be considered in choosing joint specimens. The talk will draw upon knowledge gained in a large U.K. fastener evaluation programme, and research carried out in Structures Department, R.A.E., Farnborough.

Aeroengine Viewpoint

G. W. PRICE
Senior Materials Engineer
Rolls-Royce Limited, Derby

---

1. Rolls-Royce interest in the process

   a. To improve the integrity of potential life limiting features, both static and rotating parts (new parts)

   b. As an effective technique on engine components in service (overhaul and repair)

   c. To reduce production costs by relaxation of drawing tolerances.

2. Evaluation of process

   a. Waspaloy

   b. Titanium

   c. Steel

   Presentation of results and difficulties experienced.

3. Future work on the process at Rolls-Royce

   a. Effect of creep/fatigue interaction

   b. Evaluation of Technique on other materials

   c. X-Ray diffraction

AD-A133 415 REPORT ON VISIT TO THE US AND EUROPE IN MAY 1983 COVERING THE 1983 ICAF (..(U) AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA) G S JOST JUL 83

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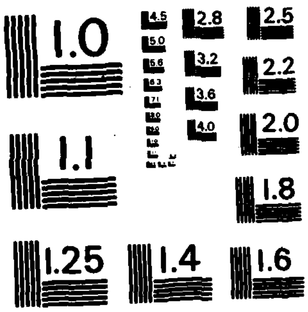

'The cold expansion process - its usage in the aviation industry'

'Civil aircraft - usage, B. Ae. viewpoint'

J. A. B. LAMBERT
(presented by P. D. WALTERS)

The cold-expansion process as a method for arresting the growth of small cracks in Trident spar caps is discussed. It is found that it is necessary to install interference-fit bolts in joints where there is sufficient load transfer to cause fretting damage. This does not result in any significant drop in the effectiveness of the cold-expansion process. The testing carried out at B.Ae. Hatfield is presented.

For new design, it is suggested that if cold-expanded holes are made in wing joints, in fuel tanks, then the joints will have to be wet-assembled, otherwise there is a risk that the interfay will be separated and the fuel will leak. Cold-expanding all the holes in a structure may be a way of complying with the requirements for tolerating accidental damage during build.

Aerospatiale Aircrafts Division view point

ALLAIN FERRAN
Aerospatiale, Toulouse
France

The purpose of the studies carried out by Aerospatiale since 1975 on sleeve cold expansion was to assess the improvement brought by this process for new structures i.e. when it is specified at the design stage and for repairing fatigue damaged structures.

This lecture presents a summary of the main results. The philosophy for using S.C.E. at Aerospatiale at the present time.Some examples for actual applications on Airbus family aircraft (Aerospatiale responsibility sections) and additional research in hand.

The results deal in the three themes

1. High load transfer of fasteners.
2. Assemblies with the comparison with other technologies, and
3. Fatigue damaged assemblies and lugs.

All these tests have been carried out with monotonic sinusoidal loading. Present studies are orientated on the following lines:

1. Effect of complex loading spectra
2. Optimum installation of Hilok-Bullnose fastners after cold working comparison.
3. Types of assembly repair of long cracks and
4. Optimum expansion rates for lugs.

'Experience gained at B. Ae. Warton from the use of cold-worked fastener holes as a means of achieving improved fatigue performance'.

A. P. WARD

Deputy Chief Stressman:
Technical Manager - Composites
British Aerospace P.L.C. - Warton

The presentation will describe work performed at B. Ae. Warton associated with the use of the cold work expansion process as an aid to achieving an improved fatigue performance at fastener holes.

After a brief discussion of early investigations of different processes the use of the Boeing Split-Sleeve method of expansion will be described. Development testing, including studies of the effects of short edge distance, will be reviewed. In-house cold-working procedures will be detailed.

The presentation will be concluded with a summary of the experience gained at Warton in using the cold-working process.

Airline Operators' Viewpoint

D. V. FINCH
Principal Engineer Airframe
British Airways

1. Potential economic advantage of cold working at the production stage
   a) Structure weight
   b) Economic fatigue life
   c) Probability of random problems related to production/rework standards

2. Effectiveness and reliability of rework programmes
   a) Requirements for crack detection, location and measurement
   b) Requirements for hole finish and sizing
   c) Suppression of residual cracks

3. Cost and reliability of detail inspection programmes
   a) Initial threshold
   b) Crack characteristics at detectable size necessary to:
      i) Increase inspection intervals
      ii) Reduce critical interpretation
   c) View of the Regulatory Authority

Current Research and Development efforts at Fatigue Technology Inc.

MICHAEL LANDY
Engineering Manager
F.T.I.

Fatigue Technology Inc. has on-going investigations to fully characterize the C.X. (Cold Expansion or cold work) process. The purpose of this briefing is to describe the status of current efforts in a number of different areas. These include:

1. Effect of oversize reaming on the fatigue life of cold expanded holes.

2. Effect of compressive loads on the fatigue life of cold expanded holes.

3. An enhanced stop drill repair procedure.

4. Effect of cold expansion on susceptibility to stress corrosion cracking.

5. Effect of cold expansion on crack growth, and

6. Computer library of cold expansion test results with search capability.

International Discussion Meeting "THE COLD EXPANSION PROCESS - ITS USEAGE IN THE AVIATION INDUSTRY"

Selfridges Hotel, London. 9th September 1982

PROGRAMME

1.	9.00 - 9.30	Registration and Coffee
2.	9.30	Welcoming address - Mr. B. F. Gibson
3.	9.40	Chairman of the I.D.M. - Mr. R. L. Champoux
4.	9.45 - 10.15	Mr. W. G. Heath, B.Ae., Manchester, U.K. Overview of the airframe structures applications
	10.15 - 10.20	Discussion
5.	10.20 - 10.50	Dr. Ing. Lüder Schwarmann, M.B.B.-V.F.W. Bremen, F.R.G. Methods to improve the fatigue performance of a representative airframe joint
	10.50 - 10.55	Discussion
6.	10.55 - 11.10	Coffee
7.	11.10 - 11.40	Mr. J. Moon, R.A.E., Farnborough, U.K. Testing analysis, certification viewpoint per airframes
	11.40 - 11.45	Discussion
8.	11.45 - 12.15	Mr. G. W. Price, Rolls-Royce, Derby, U.K. Testing, analysis, applications to aeroengines
	12.15 - 12.20	Discussion
9.	12.20 - 1.40	LUNCH
10.	1.40 - 2.10	Mr. P. Walters, B.Ae., Hatfield, U.K. Civil aircraft - its useage, B.Ae. viewpoint
	2.10 - 2.15	Discussion
11.	2.15 - 2.45	M. Allain Ferran, Aerospatiale, Toulouse France Aerospatial test work, useage and viewpoint
	2.45 - 2.50	Discussion

12.	2.50 -	3.20	Mr. A. P. Ward, B.Ae., Warton, U.K. Military aircraft useage - B.Ae viewpoint
	3.20 -	3.25	Discussion
13.	3.25 -	3.40	Tea
14.	3.40 -	4.10	Mr. D. V. Finch, British Airways, Heathrow, U.K. Airline operators' viewpoint
	4.10 -	4.15	Discussion
15.	4.15 -	4.45	Mr. M. A. Landy, F. T. Inc., Seattle, U.S.A. Latest developments in the process, testing and applications
16.	4.45 -	5.15	Open forum
17.	5.15		Concluding remarks - Mr. R. L. Champoux

APPENDIX 8

NATIONAL ICAF CENTRES - JUNE 1983

General Secretary

Prof Dr J. Schijve
Department of Aerospace Engineering, THD
Kluyverweg 1
2629 HS Delft
The Netherlands

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Sweden	Prof S. Eggwertz Aeronautical Research Institute of Sweden (FFA) Box 11021 S-161 11 Bromma 11
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Israel	Prof A. Berkovits Technion - Dept of Aeronautical Engineering Haifa 32000
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16. Abstract

In May 1983 the author made a number of fatigue-related technical visits in the US, and attended the 1983 meetings of the International Committee on Aeronautical Fatigue (ICAF) held in Toulouse, France. This report summarises the matters considered during these visits.

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