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MEETING OF THE STRUCTURES AND MATERIALS PANEL OF THE ADVISORY G--ETC(U)

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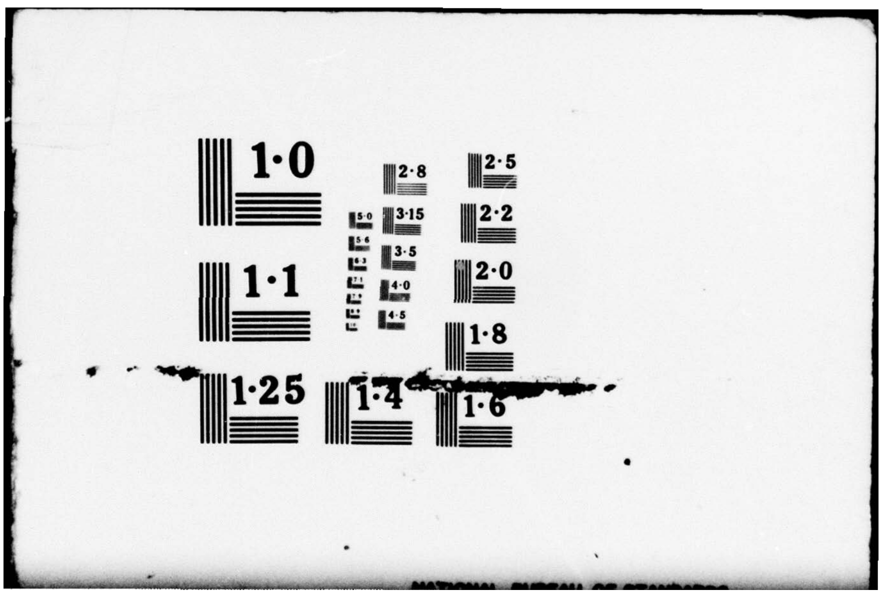
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THE 45th MEETING OF THE STRUCTURES & MATERIALS PANEL OF THE ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT (AGARD)

I.M. BERNSTEIN

7 MARCH 1978

UNITED STATES OF AMERICA

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The results of AGARD meeting on non-destructive inspection techniques as well as a planning session on corrosion fatigue testing are reported. Designers and users of aircraft components and structures discussed the need for reliable crack detection procedures. The importance of both automated techniques and human inspection were emphasized. The corrosion fatigue program will serve as the topic for a future AGARD meeting.

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THE 45th MEETING OF THE STRUCTURES AND MATERIALS PANEL OF THE ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT (AGARD)

This Meeting, held in Voss, Norway, from 25 to 30 September 1977, has been described in outline in a recent *ESN* article (*ESN* 31-12:493). The purpose of this report is to focus, more specifically, on two of the activities that took place: The specialists' meeting on "Non-Destructive Inspection Relationships to Aircraft Design and Materials" and the deliberations of the Working Group on Corrosion Fatigue, whose efforts will provide the topic for a future specialist's meeting.

SPECIALISTS' MEETING

A selection of papers chosen to give the flavor of the contributions will be described and, along with the more general discussion in the companion *ESN* article, will allow for some judgements to be made on the state-of-the-art of current non-destructive inspection (NDI) procedures. It should be emphasized that the authors and participants were primarily users of NDI methods, and assessments and judgements were largely based on applications to existing on-line problems. It is likely that researchers in the field would have treated many of the new techniques with more optimism and enthusiasm. The full program is addended.

Session I was a general overview of NDI techniques and problems from various purviews. A representative of Wright-Patterson Air Force Base presented the paper, "The Economic Implications of Non-Destructive Evaluation: Opportunities and Payoff," which centered about the increasing growth and importance of NDI. While in the quite recent past it was employed as a product uniformity and conformity procedure or as a remedial inspection tool, reanalysis of the economics of aircraft production and maintenance has shown the overall cost effectiveness of NDI when considering replacements, structural integrity verification, product life management, and safety. The trend, at least in the US, is toward increasing use of automatic scanning and decision information processing of ultrasonics, strain gauge, eddy current, etc., data.

A somewhat different approach was presented in a paper by Wing Commander H.M. Kent (RAF, UK Ministry of Defence). While also pointing out that increasingly stringent design requirements, financial constraints, and the continued demands for longer lives and better performance has increased the need and demonstrated the inadequacies of current NDI procedures, he stressed the importance of more reliable inspector observations rather than major reliance on automated monitoring equipment. Current approaches being undertaken in this regard include more stringent training, certification, and enhanced competency of NDI operators, as well as attempts to integrate design and inspection requirements, especially for complex structural designs in advanced materials.

A short contribution by S. Malmquist (Saab-Scania AB, Sweden) on "The Detection and Measurement of Cracks in Critically Loaded Holes" described the variability of NDI results from a group of inspectors. It was found, in agreement with the anecdotal experience of the other attendees, that the great majority of errors made were simply a matter of the inspector missing the flaw. The problem is not one of the equipment being unable to detect the flaw nor is it of the equipment detecting flaws that are not there. The primary difficulty is operator interpretation. Statistical data were presented to demonstrate this. Because there is such a major problem with flaws at bolt holes or rivet holes (one American speaker indicated that in the US Air Force experience about 60% of all flaws are at holes), considerable effort is being devoted to this subject. At the moment, it is possible to detect these cracks with a hand-held ultrasonic device with the fastener in place. However, this is relatively inaccurate. The crack needs to be about 6 mm long before it can be seen by this technique. The primary reason seems to be that the detecting device is not adequately centered on the hole, therefore the scan is not perfectly concentric. By automation, this detectable crack length can be reduced to 0.7 mm, and costs are cut by a factor of approximately 200. Variations on this method for other configurations and for wing skins and spars were also discussed at some length. The general impression from the papers and the extensive discussion was that while automation techniques to both to reduce cost and improve reliability are an important feature for future NDI developments, they are still considered by many as a complementary activity to accurate and careful inspection and decision making by operators.

The second session was concerned with NDI techniques and applications in metallic materials and structures. The technique papers considered a variety of procedures, some operational and others still in the development stage. One fairly well-developed technique is the measurement, using x-ray diffraction, of residual stresses at or just below the surface of a crystalline material. For profiling sub-surface stresses, a destructive technique necessitating the removal of successive layers of material either by chemical polishing or electropolishing is required. Dr. D. Kirk (Lancaster Polytechnic, UK) discussed several applications of the technique, including some of the sources of surface and sub-surface residual stresses, as well as machining, metallurgical changes, and shot-peening.

The method entails the measurement of the change of interplanar atomic spacing due to the presence of an imposed or residual stress; from this value, the corresponding strain can be straightforwardly calculated. To obtain the value of the strain parallel to the specimen surface, two other strain components are usually experimentally measured and the desired strain value obtained by calculation. By assuming elastic, isotropic behavior, the required surface stress to produce the measured elastic strain is then calculated.

Kirk discussed some of the problems besetting this technique, pointing out that many are soluble if identified. These include those that are physical, geometrical, and instrumental in origin; examples of the first are localized plasticity effects, non-isotropic effects, preferred orientation (texture), localized stress variations, and materials of low x-ray absorption, like beryllium. Examples of the second are sample geometry (since stresses cannot be measured inside small tubes or at the bottom of small holes) and curved specimen surfaces. Instrument problems include the need for portable x-ray diffractometers for field use, particularly with large components, and high-intensity radiation to limit the size of the irradiated area.

Other experimental techniques discussed in this section were small-angle neutron scattering and magnetic susceptibility. The holographic technique described in the nonmetallic section is hoped to have applicability to metals as well. Although each of these have interesting and in some cases unique characteristics, they suffer from being generally unsuited for on-site NDI of existing large components, such as aircraft. Many of these "exotic" techniques appear more applicable to laboratory research and at present are not yet standard NDI tools.

In the metals application section, a most interesting paper was presented by Mr. R. Schutz (IABG mbH, Germany), entitled, "NDI Methods on Full-Scale Fatique Tests and Their Service USage." By performing full-scale fatique tests on tactical and commercial aircraft, admittedly a very expensive proposition, they have been able to classify more accurately such important factors as inspectability, accessibility, criticality of specific parts, and fatigue crack propagation ratio. A variety of NDI tools were used, including visible inspection (with and without instrument aid), eddy current measurement, ultrasonic attenuation measurements, and x-ray surface-stress analysis.

There are obvious values to full-scale tests, since they permit critical comparison and possible synergistic combinations of different NDI procedures, indentification of critical areas, and possible location changes during service life. Further, undetected failures can be studied to determine the cause of the breakdown in inspection reliability. There are also disadvantages, besides the obvious ones of time and cost. Variabilities in manufacture and service conditions from one aircraft to another can have a dramatic effect on the nature and location of damage. Thus, the temptation to extrapolate too broadly the results of a very few full-scale tests should be carefully controlled. However, it is clear that tests of this type should provide invaluable guidance to the designer, materials selector, and inspector.

Session III was concerned with NDI techniques and applications in composite materials and structures. This is a much more poorly developed area than metallics. In fact, most of the attendees believed that while existing methods are adequate for metallic materials, the greatest need, or the largest gap, is for techniques to inspect adhesive joints in composite materials. These methods, in general, are not thought to be very advanced at this time and need extensive investigation and development to become practical. The greatest problem to people using adhesive joints in composite materials is to identify weak interfaces for which there is no existing inspection technique. There are techniques that identify so-called de-bonds, that is, areas where the material is not bonded together. But to find weak bonds that are nevertheless in physical contact seems to be something for which there is at present no reliable method. *The impetus for developing such* devices is engendered by the increasing use of such materials in commerical and military aircraft. The first speaker in this session was Dr. D.E.W. Stone (Royal Aircraft Establishment, Farnborough, Hants.) who professed that in his opinion present methods are insufficiently quantitative for composite material inspection. He gave considerable emphasis to the adhesive-bond strength problem, mentioned earlier, and also the problem of inspecting complex structures. He pointed out that while one can relatively easily inspect a flat rectangular plate in the laboratory when this is formed into a structure with a more complex shape, or if it is bonded to metallic structural parts, the difficulty of inspection increases considerably. The RAF experience to date has been that they are really not able to perform reliable inspection in these complex structures.

The next speaker was the Director of the Fokker-VFW Technical Center in the Netherlands, Dr. R.J. Schliekelman, who discussed among other topics efforts on developing optical and laser holography as an inspection technique. At the present, this approach is very difficult to implement because of its sensitivity to small vibrations from work processes. In fact, it is usually necessary to conduct holography inspections at night when no other shifts are working, or in a separate building. They therefore feel that, at least presently, holography inspections have a limited use on a production basis. In further discussion, several speakers indicated that another problem with this technique is that much more information is made available than is necessary to understand defects. It was referred to as an "information explosion" that can considerably confuse the inspection issue. In the more general discussion on composites, it was agreed that the failure modes of the composites are not well enough established to understand fully what the inspection needs are. The need to integrate fabrication and NDI problems (which is not now adequately being done) was also emphasized as a major stumbling block, particularly as there is relatively little understanding of the mechanical consequences in design terms of the various defects that are in fact observed. The usually very high cost of NDI for composites. This is not normally taken into account when calculating the economic usefulness of these materials. Dr. M. Kaitatzidis (Dornier GmbH, Friedrechshafen, Germany) expanded on this latter point, by presenting the experience of his firm with an airbrake part, previously made of an aluminum alloy and which is now being made of a carbon composite. The aluminum-alloy airbrake had an inspection cost over the life of the aircraft of about 7% of the manufacturing cost, while for their carbon-composite airbrake, they estimated it will be between 15 and 20% of the manufacturing cost, a considerable increase over the aluminum alloy. The need to improve material reliability is thus obvious. Another problem area is the absence of a NDI method to examine moisture absorption into carbon-fiber composites, whether they are in a plastic, epoxy, or carbon matrix. Both manufacturers and users are recognizing that considerable degradation in properties can occur by moisture absorption; at the moment it is not possible to observe this event by NDI. As the emphasis in this report suggests, there were many more far-reaching discussions on the meeting on the composite area than on metals, reflecting the relative maturity of NDI procedures for the two general classes of materials.

To summarize the main points of the Specialists' Meeting, it would appear for metallic structures that the problems are not primarily materials in nature. Furthermore, technique problems are not dominant, although all the speakers indicated a willingness to look at new methods if they could complement or extend present capabilities. The real problems are to understand how to make existing methods quantitative, which seems to be a very challenging problem; and how to improve the cost and accuracy of existing techniques, which under ideal conditions are capable of adequate inspection but under field conditions generate considerable errors, particularly when human operators are involved. For composites, on the other hand, there are definite technique needs as previously discussed.

Of overriding interest was the major concern of operator fatigue. This is not really a technical problem, but many discussants felt that it is absolutely central to the reliability problem in existing NDI establishments. Fatigue does not primarily mean physical fatigue in the sense of the labor of moving the inspection devices around, but mental fatigue: An operator must work 8 hours a day, week after week, and only occasionally find a flaw. He gets a very brief indication that he has that flaw; however, he has to be alert enough and interested enough to watch for that flaw. To motivate people to do this is the overriding requirement. It was pointed out peripherally that this is a long-standing problem with radar defense. Since the problem has not been solved in that area, it is not likely to be solved soon for NDI, so that technological methods such as automation will probably have to be increasingly relied upon as a more reliable indicator. Since automation also appears essential for cost reduction, efforts in this direction are presently of great interest.

As is the case with many technological areas, the meeting was more successful in identifying problems with NDI than in discovering solutions. This is, of course, a necessary sequence. It is anticipated that the pressure of economics will provide the driving force for significant advances in the near future.

WORKING SESSION ON CORROSION FATIGUE

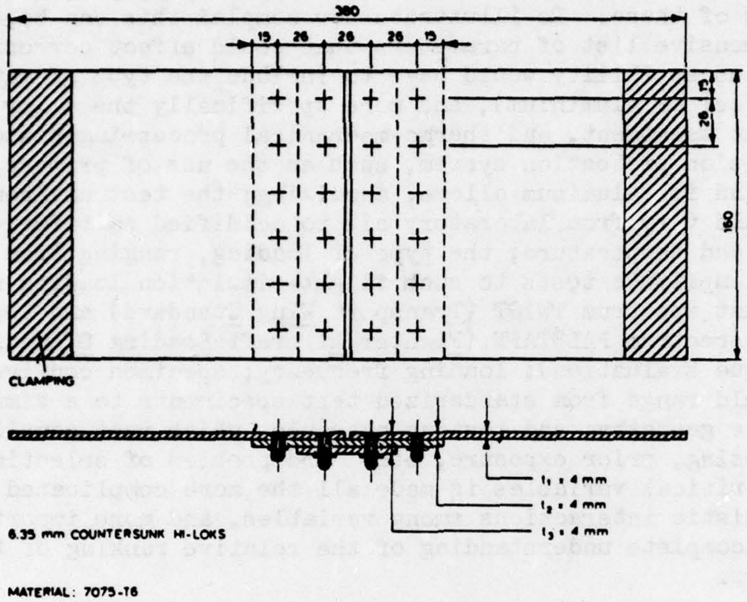
The focus of this committee's efforts is to establish a cooperative testing program among various AGARD-NATO laboratories in the area of corrosion fatigue of aircraft components in order to assess the effectiveness of existing protection schemes and to stimulate the development of new materials or protection approaches. Large-scale round-robin testing by laboratories in many countries would, it is hoped, improve the reliability of test specimens and procedures, as well as foster cooperative research.

The meeting was chaired by Dr. W. Bunk (Institut für Werkstoff-Forschung, DFVLR, Germany). Drs. R. Wanhill (National Aerospace Laboratory, Netherlands) and J. DeLuccia (Naval Air Development Center, Warminster, PA) are the European and North American coordinators, respectively, for the program.

Because of the large number of variables that can affect corrosion fatigue susceptibility, a major goal of this largely

planning-type session was to arrive at an agreement on the most important of the variables and to devise a testing program on the basis of these. To illustrate how complex this can be, a comprehensive list of parameters that could affect corrosion fatigue susceptibility would have to include the type of material (e.g., steel or aluminium), and more specifically the alloy type, heat treatment, and thermo-mechanical processing history; the corrosion protection system, such as the use of primers, paints, and for aluminum alloys, anodizing; the test environment, which could vary from laboratory air to acidified salt fog; the pressure and temperature; the type of loading, ranging from constant amplitude tests to such flight-simulation loading spectra as the gust spectrum TWIST (Transport WIng STandard) and the maneuver spectrum FALSTAFF (Fighter Aircraft Loading STandard For Fatigue Evaluation); loading frequency; specimen configuation, which could range from standarized test speciments to a simulation of service geometry; and testing schedule, which must consider pre-stressing, prior exposure, etc. The problem of selecting the few critical variables is made all the more complicated by synergistic interactions among variables, and more importantly by the incomplete understanding of the relative ranking of the parameters.

Following considerable discussion and by no means unanimity of opinion, the following consensus cooperative test program has, at least in principle, been established: The material is to be a 7075 high-strength aluminium alloy heat treated to be most resistant to intergranular stress corrosion cracking (the T7X treatment). This was a difficult choice, since it is anticipated that this alloy will not be used as extensively in the next generation of aircraft. Its choice was dictated largely by the massive amount of information already known about the material, which was necessary for establishing baseline properties, and by its availability in large amounts and at modest cost. A standard specimen configuration would be used by all laboratories, constructed from 4-mm sheet and consisting of a single butt strap type, with the sheets joined with 24 cadmium-plated high-lock fasteners in countersunk holes, as shown in Fig. 1. Such a specimen represents a common joint found in aircraft.



Proposed Specimen Configuration (Dimensions in mm)

The test environment is to be a 5% NaCl salt spray acidified with H_2SO_4 to pH of 4. A common design of an inexpensive test chamber currently in use at the Naval Air Development Center will be made available to all participating laboratories. A major concern in such an apparatus is to avoid metallic contact with the specimen, which would establish a local galvanic cell and associated localized corrosion.

Baseline tests will be carried out at constant amplitude with a stress ratio R of +0.1 (R = minimum stress intensity/maximum stress intensity) and two different stress levels, chosen to obtain different lifetimes. Individual laboratories will have the option of extending the program to consider spectrum loading. A test schedule incorporating various combinations of pre-exposure and fatigue has also beeen specified as follows: 1) exposure to salt spray and fatigue in air; 2) exposure to salt spray and fatigue in salt spray; 3) fatigue in air; 4) fatigue in salt spray.

The most difficult area for agreement was on the type of protection system to be used, since this can be considerably different in the US and Europe. The following minimal scheme has been adopted: Use of a common lot of material and fastening; chromic acid anodizing or chromate conversion coatings after shearing; the use of an inhibited epoxy polyamide primer; and subsequent drilling and countersinking to expose bare metal. This last step would tend to insure that the damage would be concentrated at or near the holes, a commonly found situation in practice. Assembly of the specimen would then follow, with subsequent painting with an alyphatic polyurethane topcoat. Finally, low temperature pre-stressing would be used to crack the paint to reexpose the metal in the area of the fastener.

This is obviously an ambitious program, whose success requires close cooperation among the coordinators, the participating laboratories, and AGARD. It is our opinion that to maximize the chances of obtaining meaningful and useful data, the politics of attracting as many laboratories from as many NATO countries as possible must be balanced with the need to involve only reliable and knowledgeable investigators in the corrosion fatigue area. It might be wise to separate the results from less experienced labs, thus giving them needed experience, without compromising the data.

The status of this approximately two-year program will be discussed at the next Structure and Materials Panel of AGARD in Aalborg, Denmark in April 1978.

PROGRAM

Specialists' Meeting
NON-DESTRUCTIVE INSPECTION RELATIONSHIPS TO AIRCRAFT DESIGN AND MATERIALS

Conference Committee Chairman

Dr. C.P. GALOTTO
FIAT, Centro Ricerche
Orbassano (Torino)
Italy

Meeting Chairman

Mr. W.G. HEATH
Hawker Siddeley
Aviation Ltd.
Woodford - UK

TUESDAY 27 SEPTEMBER

SESSION I - GENERAL   Chairman: Prof. T. GAYMANN - GE

"NDI Techniques in Aerospace"
Dr. E. BOLIS
Aeritalia, Torino - Italy

"Critical Review of Various Structural Safety Concepts Taking into Account NDI Methods"
by Prof. E. ANTONA
Scuola Ingegneria Aerospaziale
Politecnico di Torino - Italy

"The Economic Implications of Non-Destructive Evaluation Opportunities and Payoff"
by D.M. FORNEY, T.D. COOPER & R.R. ROWAND
AFML, Wright-Patterson AFB - USA

"Unfulfilled Needs of Non-Destructive Inspection of Military Aircraft"
by W/C H.M. KENT, RAF
Ministry of Defence, London - UK

Rapporteur: J.A. DUNSBY
National Aeronautical Establishment
Ottawa, Canada

SESSION II - METALLIC MATERIALS AND STRUCTURES

Part 1 - TECHNIQUES   Chairman: Mr. Tore NAESS - NO

"Application of Small Angle Neutron Scattering to NDI of Materials and Manufactured Components"

TUESDAY 27 SEPTEMBER (Cont'd)

by Dr. P. PIZZI
FIAT Centro Ricerche, Orbassano - Italy

"Surface Corrosion Evaluation by Relative Magnetic Susceptibility Measurements"
by Dr. H. WALTHER
FIAT Centro Ricerche, Orbassano - Italy

"Application of X-Ray Diffraction Stress Measuring Techniques"
by Dr. D. KIRK
Lanchester Polytechnic, Coventry - UK

"X-Ray Diffraction from Structural X-Ray Diffractography to X-Ray Oscillographic Diffractoscopy"
by L/C Dr. A. TRONCA
Aeronautica Militare, Roma - Italy

Rapporteur: R.J. SCHLIEKELMANN
Fokker-VFW
Schiphol-Oost - Netherlands

WEDNESDAY 28 SEPTEMBER

SESSION II

Part 2 - APPLICATIONS Chairman: L/Col S. SIGNORETTI - IT

"Dynamic Non-Destructive Testing of Materials"
by Dr. E.M. UYGUR
Middle East Technical University, Ankara - Turkey

"NDI Methods on Full-Scale Fatigue Tests and Their Service Usage"
by Richard SCHÜTZ
IABG mbH, Ottobrunn - Germany

"Critical Inspection of Bearings for Life Extension"
by Dr. R.T. SMITH, J.R. BARTON & F.N. KUSENBERGER
Southwest Research Institute, San Antonio - USA

Rapporteur: Marc van AVERBEKE
SABENA, Zaventem - Belgium

WEDNESDAY 28 SEPTEMBER

SESSION III - COMPOSITE MATERIALS AND STRUCTURES

Part 1 - TECHNIQUES Chairman: Mr. G. JUBÉ - FR

"NDI of Composite Materials for Aircraft Structural Applications"
by Dr. D.E.W. STONE
Royal Aircraft Establishment, Farnborough - UK

"The Resonance-Impedance Method as a Means for Quality Control of Advanced Fibre Reinforced Plastic Structures"
by R.J. SCHLIEKELMANN
Fokker-VFW, Schiphol-Oost, Netherlands

"Inspection of Carbon Fibre Parts after Fabrication and During Service"
by M. KAITATZIDIS
Dornier GmbH, Friedrichshafen - Germany

"Detectability of Flaws in Boron and Carbon Composite Parts"
by G. TOBER
VFW-Fokker GmbH
Lemwerder - Germany
and
H. Schnell
VFW-Fokker GmbH
Bremen - Germany

Rapporteur: Dr. W.N. REYNOLDS
AERE Harwell - UK

Part 2 - APPLICATIONS Chairman: Mr. T.F. KEARNS - US

"Etat Actuel et Evolution en France des Techniques de Contrôle de Qualité des Structures en Matériaux Composites"
by M.I. TRECA
Aérospatiale, Suresnes (Paris) - France

"Contrôle Non-Destructif des Structures Bobinées et Reception des Matiéres Premiéres"
by J.P. MAIGRET
Aérospatiale-Aquitaine, St Médard en Jalles - France

"Detection of Flaws in Metallic and Non-Metallic Composite Structures Using Liquid Crystal Technology"
by Dr. Shelba P. PROFFITT (BROWN)
US Army Missile R&D Command, Redstone Arsenal - USA

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Rapporteur: H. SCHNELL
VFW-Fokker, Bremen - Germany

SHORT CONTRIBUTIONS

"Crack Detection in Bolted Joints"

by Dr. Lars JARFALL
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Sweden

Åke MAGNUSSON
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"On the Detection and Measurement of Cracks in Critically Loaded Holes"

by Sven MALMQVIST
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