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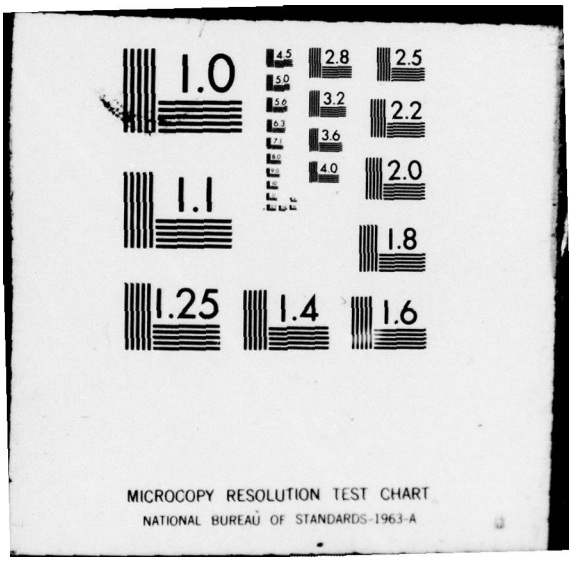
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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD ADVISORY REPORT No. 133

Technical Evaluation Report on the 52nd Symposium of the Propulsion and Energetics Panel on Stresses, Vibrations, Structural Integration and Engine Integrity (Including Aeroelasticity and Flutter)

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

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6 TECHNICAL EVALUATION REPORT

on the

52nd Symposium of the

PROPULSION AND ENERGETICS PANEL (52nd)

on

STRESSES, VIBRATIONS, STRUCTURAL INTEGRATION AND ENGINE INTEGRITY (INCLUDING AEROELASTICITY AND FLUTTER)

by

10 L.Beitch

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A070 950

The Proceedings of the 52nd Symposium of the Propulsion and Energetics Panel which was held in Cleveland, Ohio, USA on 23-27 October 1978, are published as AGARD Conference Proceedings CP-248, March 1979.

400 043

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Published March 1979

ISBN 92-835-1314-2

Set and printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London, W1P 1HD

PREFACE

A Symposium on "Stresses, Vibrations, Structural Integration, and Engine Integrity (including Aeroelasticity and Flutter)" was held in Cleveland, Ohio, during the week of 23-27 October, 1978. This Symposium was the 52nd Meeting of the AGARD Propulsion and Energetics Panel (PEP). Except for an afternoon tour of the NASA-Lewis Research Center on 25 October, all other technical and administrative activities were conducted at the Bond Court Hotel.

The Symposium was divided into eight sessions ~~as follows~~ concerned with the following subjects:

Session I – Experimental Stress Analysis;
Session II – Stress Analysis Techniques, Life Prediction;
Session III – Stress Analysis Techniques, Life Prediction
Session IV – Engine Structural Integrity, Vibration, Containment;
Session V – Engine-Airframe Integration/Compatibility
Session VI – Engine-Airframe Integration/Compatibility;
Session VII – Aeroelasticity and Flutter
Session VIII – Aeroelasticity and Flutter.

The Technical Evaluation Report (TER) on this Symposium has been prepared by Dr L.Beitch, Manager of Engineering Mechanics and Life Management, General Electric Company, Cincinnati, Ohio. The TER provides a very complete summary and understanding of the technical sessions and recommends topics to be covered in future activities. In particular, Dr Beitch's comments emphasize the need for better technical tools to be applied to life-prediction techniques.

Judging by the attendance at the Symposium and the discussions which followed most of the presentations, the meeting met its objectives and is regarded as a success. It is hoped that the activity provided a baseline to stimulate further work on the critical subjects covered.

The committee is pleased to have had the opportunity to conduct this Meeting. In addition, the effort by Dr Beitch in providing this TER is gratefully acknowledged. His work in support of the Panel will be a valuable assistance in preparing future AGARD programs.

John Acurio

JOHN ACURIO
Chairman,
52nd Meeting of PEP

CONTENTS

TECHNICAL EVALUATION REPORT

L.Beitch*

1. INTRODUCTION

The 52nd meeting of the Propulsion and Energetics Panel was held at the Bond Court Hotel in the city of Cleveland, Ohio, USA, on the week of 23-27 October, 1978. The purpose of the meeting was to hold a symposium on "Stresses, Vibration, Structural Integration and Engine Integrity (including Aeroelasticity and Flutter)". The meeting theme was to address a wide spectrum of topics associated with engine development, engine-aircraft integration and engine operation. The topics were to include:

- Experimental analysis of stress and vibration.
- Analytic stress analysis techniques considering advanced finite element methods.
- Special emphasis was to be placed on structural integrity, life prediction and component operational deterioration.
- A major part of the program was to address to the subject of engine-airframe integration.
- The subjects of aeroelasticity and flutter were also to be included.

2. SUMMARY AND COMMENTARY

The goals of the basic purpose, theme and individual topics were largely achieved in the presentation of 33 papers in 8 sessions. The availability of published preprints of the papers presented and the capabilities of the language interpreters helped to make the meeting proceed smoothly. The arrangements were particularly well suited for the, always important, informal technical interchanges between the attendees. The NASA tour and the address by the US national delegate, Dr Lovelace, enhanced the general atmosphere of the conference.

Session chairmen were apparently carefully selected since the presentations and the question and answer periods were well handled. The papers were almost all well prepared, with good visual material. The subject material did reflect the meeting theme. Overall, there were some papers that bordered on advanced state-of-art technology. For the most part, however, the symposium was a status of current and, perhaps in a few cases, older techniques. This was, nevertheless, consistent with the meeting theme. Many of the papers addressed to real engines and real engine problems. There were, however, a large number that failed to relate directly. Very few actually showed failed engine parts, and correlation between analysis and test or field experience was included in only a few of the papers.

The subject of the meeting was quite broad, including several topics that would each require a symposium of the extent of this meeting to fully explore both the advancing state-of-art and the additional requirements needed within the field. For the charter of the Propulsion and Energetics Panel, which is also quite broad, the type of meeting held was proper, that is, basically a survey of the current state-of-art in the several topics. However, it is not possible through such a symposium to specifically determine those factors that limit the progress associated with engine development, engine-aircraft integration and engine operation. Of greatest interest here is the ability of the aircraft industry to control the durability and life management of aircraft gas-turbine engines. This has become, perhaps, the overriding concern of the current aircraft engine systems. The topics of this symposium were all connected with this but were not detailed enough to address the core of the problem.

3. RECOMMENDATIONS

The recommendation, then, is for the Propulsion and Energetics Panel or the Structures and Materials Panel, or a joint meeting of the two panels, to hold a symposium to explore, in depth, several of the technologies, in their advanced state, that deal with engine durability and life management. The topics should include:

- The aircraft mission and the design and test duty cycle used to design the engine.
- The state of the available and developing numerical analyses for heat transfer, stress, vibration and life.
- The role of, and the dependence on, the computer in establishing the durability of the engine prior to and during fleet operation.

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* The writer wishes to acknowledge the assistance of the following people who have contributed to this technical evaluation: A.Coles, D.H.Ellis, R.L.McKnight and F.E.Sagendorph.

- The verification and validation of the durability predictions through testing.
- The characterization of the current and advanced engine materials, for its dependence on the vast number of environmental factors, that contribute to engine life prediction.
- The development of design practices that would minimize the use of life-limiting designs.
- The logistics aspects of providing cost effective spare parts to keep the fleet in operation.
- The development of an engine life management philosophy.

4. DISCUSSION

The symposium consisted of 33 papers presented in 8 sessions. The subjects of experimental and analytic stress and vibration analysis were well covered by some 13 papers directly and several others indirectly. The subjects of aeroelasticity and flutter were also well represented by 8 papers specifically oriented that way and indirectly in a number of others. The specific concerns of fatigue, life prediction and life management were contained in 4 papers. Burst containment was addressed in 2 papers, and the remainder considered such topics as engine deterioration, foreign object damage and general design considerations.

Session I

The theme of Session I was experimental stress analysis. Paper 3 is devoted primarily to that theme, covering virtually all the current techniques used in experimental stress analysis for engines. Applications to specific engine components and problems are prevalent throughout the paper, giving a valuable perspective to the approach. This includes the modern use of the old technology of photoelasticity. Paper 4 is devoted primarily to that subject and shows that with the newer equipment and techniques, photoelasticity is indeed a valuable and contributing tool to engine design analyses. Paper 1 discusses the use of holography, primarily as a correlating technique with numerical predictions. Both Papers 1 and 2 emphasized the analytic predictions but did discuss the correlation with test aspects. A lengthy discussion ensued following Paper 1 concerning the capabilities of the computer program used (NASTRAN) and its proper application.

Sessions II and III

These two sessions were addressed to the subject of stress analysis techniques and life prediction. The sessions contained 9 papers addressing to various aspects of the subject. From the analysis point of view, both finite elements and the boundary integral equation approach are discussed in 5 of the papers. Two of the papers address to broader topics of fatigue life. One paper (Paper 11) discusses the methods of correlation between analysis and testing. Paper 12 presents a comprehensive discussion on the aeroelastic instabilities in the design/operation of helicopters. The limited time for presentation of that paper prevented the full appreciation of this subject at the meeting.

The complexities of analyses of engine parts and the development and limitations of current methods are discussed in Papers 6, 8, 9, 10 and 14. Paper 6 highlights the nonlinear aspects of the approach. Three-dimensional finite-element techniques are reviewed in both Papers 8 and 9. Paper 8 presents an alternative analytic method for stress interpretation applied to a rocket motor case, while Paper 9 treats turbine blade vibration modes. Paper 9 stimulated a great deal of discussion with a large audience participation on a variety of subjects. This included: the reasons for the change in blade resonant frequencies with rotor speed; boundary conditions used and the adequacy of the finite-element model; the use of statistics in the predictions; and the mathematical formulation of the approach. The paper presents useful correlation techniques but is somewhat lacking in explanation of differences that exist between analysis and test.

Boundary integral equation analysis (BIE) is the subject of Papers 10 and 14. The BIE method was presented in Paper 10 with the consideration of nonlinear effects. Paper 14 uses the BIE approach in conjunction with finite elements, although not in a dependent way. The paper did not "oversell" the BIE method but offers it as the best approach in some cases and an alternative in some others. The indications were for a more extensive use of this approach. The presentation of the paper could have been somewhat more explicit on the limitations of the method, which was the subject of discussion after the presentation.

The remaining two papers at the sessions addressed the wider concerns of life prediction. Paper 7 mentions many of the considerations in the engine life management process. Verification of predictions, primarily through photoelasticity, is a part of this. The paper also discusses crack propagation, considering some of the impact on design that this causes. Paper 13 also discussed some of the life management considerations but emphasized the service usage and the need to understand this through recorded flight data. This paper stimulated a great deal of discussion from several members of the audience. These questions pointed out the need for further development and understanding in many life-oriented areas. The questions included: the effects of temperature and multiple strains; the processing of flight data where the use of onboard computers versus large stationary computers were contrasted; the accuracy and usefulness of such flight data and whether correlation now exists; the advantage of this approach as a replacement or in conjunction with existing methods; and linear damage rules, combinations of high- and low-cycle fatigue and uniaxial versus multiaxial states of stress.

These combined sessions, due to the subject matter and the discussions they stimulated, were one of the most important parts of the symposium.

Session IV

The subject of this session was engine structural integrity, with emphasis on vibration and containment. Five papers were presented; and although they were not, perhaps, totally addressed to the core problems of structural integrity, they were, nevertheless, interesting and useful discussions of real engine concerns.

Two papers were addressed to the subject of rotor burst. Paper 15 contains an interesting survey of this subject and the approaches considered to reduce the incidences of occurrence and the consequences of happening. Paper 19 discusses a program of testing to better understand how to design for protection. Discussions after presentation indicated concerns over whether the analytic and testing results properly represent real engine conditions and if the results here needed supplementary understanding.

Paper 16 provided a marked contrast of a small engine manufacturer addressing actual problems and detailing analysis and experimentation. Admitting to more easily handling the containment problem with smaller parts, the paper freely discusses disk bursts and blade failures. The subject of structural integrity was well covered here.

Paper 17 deals with the mechanics of damping and presents a good technical understanding of film damped bearings. The paper contains associated experimental studies. Paper 18 discusses the modal approach by means of impact excitation. Such an approach is suggested for structures that do not lend themselves too readily to analytic evaluation. Questions after presentation were mainly concerned with the techniques of application.

Sessions V and VI

The subject of Sessions V and VI was engine/airframe integration and compatibility. The subject was covered by 8 papers in the two sessions. The introductory paper gave a general understanding of the engine-airframe integration needs, but none of the papers specifically addressed to the overall problem where all the involved parameters were listed, for example. Each of the papers was concerned with an engine problem that could be considered to be related to engine-airframe integration, but the topics of these papers could also have fallen into categories of structural integrity and aeroelasticity.

Paper 20 presented a strong case for the need to have such an integrated system. The paper reviewed the technical problems and showed results of current efforts. Of greatest concern here was the structural integrity of the system as opposed to the independent analysis of the engine and airframe separately. Included here were dynamic, deformation and stress considerations. The presentation included film clips that made the points intended quite clear. It was a general interest presentation.

A specific integration problem is discussed in Paper 21 relating to the design of air intakes for a fighter aircraft. Failure analysis, theoretical analysis and engine test details were presented. This highlighted the limited test facilities for this purpose in the industry.

Paper 22 was also concerned with a specific problem related to a small fleet with old engines. The paper discusses the problem of engine deterioration and the remedial steps taken to cope with it. The testing was good but the techniques used were unique to the need and do not present a generalized approach.

Paper 23 shows compatibility data for a range of the engines discussed including propeller whirl flutter data, oil cooling details, bearing life engine deflections and response frequencies. The advanced techniques involved reflect the experience of the manufacturer.

Paper 24 presents dynamic calculations showing the effects of loss of a rotor blade on the engine and the supporting pylon structure. Most of the results were analytical and based on normal mode expansions, but some actual correlating data was shown. The importance of cooperation between the airframer and the engine manufacturer for this analysis was stressed.

Paper 25 examines possible weight, performance gains and cost reductions which might be possible through designs utilizing a high degree of engine to airframe integration. The specific example treated the design considerations for a "divided duct" system whereby the top half of the engine bypass duct forms the inner lining of the fuselage structure. The conclusions as presented indicate that integrated design concepts such as this can provide significant benefits with little increase in technical risk.

A planned test facility capable of performing engine testing under maneuver loadings was the subject of Paper 26. The Turbine Engine Loads Simulation (TELS) was described in considerable detail, and its unique capabilities and potential use were highlighted. During the discussion following the presentation, the cost and timing schedules were discussed. Current indications are that the test facility construction may be funded in 1981.

Paper 27 concerned the ability of different engine designs to withstand foreign object damage (FOD). The paper presents certain fundamental concepts about FOD as well as the existing safety regulations which must be adhered to in the design. It was pointed out that all engine manufacturers, because of noise-level regulations, are actively working in acoustic reduction programs even with the associated weight penalty, but no similar concerted effort is underway for FOD protection.

Following the paper, an extremely interesting film covering test facilities at C.E.Pr. was shown. Very interesting high-speed photographs of actual tests were also included.

Special Paper

The planned special paper was not available at the meeting. Instead, and perhaps as a hurried substitute, a review of the method of Strain Range Partitioning (SRP) was presented (Paper No.33) by M.H.Hirschberg from the NASA Lewis Research Center. It was an excellent presentation of a current topic on the advanced understanding of life prediction.

The paper discusses the extensive program sponsored by NASA that has provided the industry with advances in the field of low-cycle fatigue prediction. Although the paper presents some important concerns for the approach, the effort has been successful in that: it has provided a new method for testing, especially in Europe; and it provides a broad base of experience data. In the research for the understanding of life prediction, the SRP method is a significant step in the right direction. Universal acceptance does not exist, but the major laboratories are continuing an evaluation.

Sessions VII and VIII

The general topic for these sessions was aeroelasticity and flutter. Because the analysis methods used in this area are quite complex, it is difficult for people not actively working in this field to appreciate the theoretical work. Most papers did, however, present experimental data as well, and these physical results were helpful.

Paper 29 provides state-of-the-art insight regarding the flutter influences of density and distortion. Numerous correlation curves of analysis with experimental data were presented to aid in understanding the physical nature of the problem.

Paper 30 also addressed the problem of correlating unsteady flow phenomena with steady-state inlet distortion. In this paper, the data was obtained for two different axial compressor stages with the same overall dimensions but quite different pressure ratios. Experimental results were discussed in considerable detail.

Paper 31 presented a theoretical model for a one stage axial compressor under rotating stall. Correlation with experimental data is good, considering the complexity of the problem. The analysis provides a perspective for viewing some of these complexities.

The design of and the data obtained from a linear cascade facility are the subjects of Paper 32. The data presented was used to establish flutter boundaries, but the problem of actual correlation between linear cascades and the real engines requires further consideration.

Paper 34 presents experimental data obtained in the unstalled supersonic flutter regime. The area is known to be difficult and the experimental setup appears well controlled. The range of testing is, perhaps, not well defined in relation to the range of airfoil design. The successful fabrication of the composite airfoils with integrated instrumentation is a significant achievement.

Paper 35 is a study utilizing available analyses to study trends in flutter boundary in terms of various design parameters. Separate conclusions are reached regarding high and low back-pressure conditions, and they agree well with known design experience.

5. CONCLUSIONS

The symposium successfully addressed to topics of structural integrity and integration for engine development and operation. The large number of technologies involved makes the effort a complex one. A focusing of the required efforts toward an understanding of the basic problems is necessary. Underlying all the discussions here is the requirement to predict the engine part lives with an accuracy that can only be proven by years of actual engine operation. Inadequacies with methods used can have long-range undesirable effects on safety and curtailment of fleet operations.

Continued emphasis needs to be placed on structural integrity and engine durability. A more detailed understanding of the core problems in these areas is essential to directing efforts toward the required solutions. The industry has not agreed to an overall engine life philosophy. This complicates the apparent needs and diffuses the resources.

AGARD should play a role in establishing such a philosophy and focusing on the required technologies. This would best be done by having an AGARD meeting addressed specifically to defining the basic problems involved with the prediction of engine durability and the implementation of engine life management plans.

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-133	ISBN 92-835-1314-2	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title TECHNICAL EVALUATION REPORT on the 52nd Symposium of the PROPULSION AND ENERGETICS PANEL on STRESSES, VIBRATIONS, STRUCTURAL INTEGRATION AND ENGINE INTEGRITY (INCLUDING AEROELASTICITY & FLUTTER)

7. Presented at

8. Author(s)/Editor(s)	9. Date
L. Beitch	March 1979

10. Author's/Editor's Address	11. Pages
General Electric Company Mail Drop K221 Evendale, Ohio 45215, USA	12

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Aeroealsticity
Flutter
Dynamic structural analysis
Aircraft engines
Vibration
Stresses
Loads (forces)

14. Abstract

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