DAMAGE TOLERANCE IN AIRCRAFT STRUCTURES

A symposium presented at the Seventy-third Annual Meeting AMERICAN SOCIETY FOR TESTING AND MATERIALS Toronto, Ontario, Canada, 21-26 June 1970

ASTM SPECIAL TECHNICAL PUBLICATION 486

List price $19.50
04-486000-30

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race Street, Philadelphia, Pa. 19103
Foreword

The Symposium on Damage Tolerance in Aircraft Structures was conducted in two sessions at the Seventy-third Annual Meeting of the American Society for Testing and Materials, held in Toronto, Ontario, Canada, 21–26 June 1970. The symposium was sponsored by ASTM Committee E-9 on Fatigue. M. S. Rosenfeld, of the Naval Air Development Center, served as symposium chairman, with P. C. Paris, Del Research Corp., Hellertown, Pa., and R. J. Hebert, Canadair, Ltd., Montreal, Ontario, presiding as chairmen of the first and second sessions, respectively.
Related
ASTM Publications

Structural Fatigue in Aircraft, STP 404 (1966), $18.50

Fatigue at High Temperature, STP 459 (1969), $11.25

Effects of Environment and Complex Load History on Fatigue Life, STP 462 (1970), $22.00
Contents

Introduction vii

The Dependence of Fatigue Crack Propagation on Strain Energy Release Rate and Crack Opening Displacement—J. M. BARSOM 1

Effect of Thickness on the Fracture Toughness of 7075 Aluminum in the T6 and T73 Conditions—F. C. ALLEN 16

The Influence of Curvature on Stress Intensity at the Tip of a Circumferential Crack in a Cylindrical Shell—N. J. I. ADAMS 39

Evaluation and Prediction of the Residual Strength of Center Cracked Tension Panels—C. E. FEDDERSEN 50

Fatigue Crack Propagation in Stiffened Panels—C. C. POE, JR. 79

Material Toughness and Residual Strength of Damage Tolerant Aircraft Structures—A. F. LIU AND J. C. EKVALL 98

An Approach to Predicting the Growth to Failure of Fatigue Cracks Subjected to Arbitrary Uniaxial Cyclic Loading—T. R. BRUSSAT 122

Initiation and Growth of Fatigue Cracks in and Residual Strength of the F-100 Wing—W. D. GRAZIANO AND G. E. FITCH, JR. 144

Development of the Fail-safe Design Features of the DC-10—T. SWIFT 164

The Ballistic Damage Characteristics and Damage Tolerance of Wing Structural Elements—J. E. JENSEN 215

The Significance of Fatigue Crack Closure—WOLF ELBER 230

Crack Propagation in Helicopter Rotor Blades—M. J. RICH 243
Introduction

In the past aircraft were designed for maximum performance, with particular attention given to range, altitude, speed, and payload. Structural concepts and materials which provided minimum weight were used with little consideration for damage tolerance or, in the case of military aircraft, structural vulnerability. The current emphasis on safety, with longer intervals between maintenance periods to increase aircraft availability, has required more intensive consideration on the part of the designer of crack propagation characteristics and residual strength of flight structures.

Information on the growth of cracks in engineering structures and the residual strength of cracked structures is necessary for the prediction of service lives of structures subjected to fatigue loading and for the establishment of safe inspection intervals. This symposium provided an effective means of exchanging technological advances in fatigue crack propagation and fracture theory. The specific objectives of the symposium were

1. To review the state of aircraft structural analysis for structures with propagating cracks.
2. To present recent advancements in research into basic mechanisms of crack propagation and residual strength of aircraft structures.
3. To provide a review of fracture mechanics as applied to the assessment of structural vulnerability and residual strength of materials and structures.

Because of the limited time available in a symposium of this nature, emphasis was placed on discussions of theoretical considerations that influence damage tolerance design of aircraft structures. Although material characteristics can influence crack growth behavior and residual strength of structures, this aspect of the problem was not emphasized. The role of material in the attainment of damage tolerant structures should be the subject of a separate symposium.

The papers presented can be separated into four distinct categories: (1) basic concepts in fatigue crack propagation, (2) effects of panel geometry, (3) influence of panel stiffeners, and (4) application of fracture mechanics and crack propagation to the design and test of aircraft structures.

In the first category, Elber considers the effect of crack closure on crack propagation, Barsom reviews crack propagation laws and concludes that the primary factor affecting fatigue crack growth behavior is the strain energy release rate, and Brussat presents a semiprobabilistic approach for predicting fatigue crack growth under variable amplitude uniaxial cyclic loading.

In the second category, the effects of geometry are discussed in papers by Allen, who discusses the effect of panel thickness, by Adams, who considers
the influence of panel curvature on the stress intensity at the tip of a crack, and by Feddersen, who considers the residual strength of center cracked tension panels. Feddersen also proposes a simple and direct empirical method for relating gross stress, stress intensity factor, and crack length over the full range of crack lengths and panel widths. This method defines the residual strength characteristics of panels using a minimum of experimental data.

Moving further up the ladder of increasing structural complexity, Poe and Liu and Ekvall discuss the effects of stiffener strength, geometry, stiffness, and spacing on the crack propagation characteristics of flat panels.

The fourth category of papers deals with the application of fracture mechanics and crack propagation concepts to the design of modern aircraft structures. Graziano and Fitch discuss the crack growth behavior in a wing designed with no consideration given to fatigue and crack growth, and Swift discusses the extensive analytical and experimental considerations being given crack growth in the design of a commercial transport of the immediate future.

Further, Jensen presents the results of investigations into the ballistic damage characteristics and ballistic damage tolerance of various panel configurations used for tension skins in multispar wing boxes. In a related paper not presented at the symposium, Rich discusses the propagation of cracks in helicopter rotor blades.

Grateful acknowledgment is made of the contributions of the authors, the session chairmen, those who reviewed papers prior to the meeting, the Toronto coordinator, and the discussion participants.

*M. S. Rosenfeld*  
research aerospace engineer  
Aero Structures Department  
Naval Air Development Center  
Warminster, Pa. 18974  
symposium chairman