(2)

ARL-STRUC-TM-579 AR-006-654

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aircraft Structures Technical Memorandum 579

REPORT ON VISIT TO CALTECH AND CERRA/ICASP6 RELIABILITY CONFERENCE, JUNE 1991

by

D.G. FORD

Approved for public release

OCTOBER 1991

AR-006-654

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORY

Aircraft Structures Technical Memorandum 579

REPORT ON VISIT TO CALTECH AND CERRA/ICASP6 RELIABILITY CONFERENCE, JUNE 1991

by

D.G. FORD

SUMMARY

This memo describes discussions with three materials researchers at the California Institute of Technology, Pasadena, and the Sixth International Conference on Applications of Statistics and Probability in Civil Engineering, Mexico City, June 17-21 1991 at which the author presented a paper about predicting fatigue life distributions with FRAN.

DSTO ARL MELBOURNE

POSTAL ADDRESS: **Director, Aeronautical Research Laboratory**
506 Lorimer Street, Fishermens Bend 3207
Victoria Australia

CONTENTS

1. INTRODUCTION

In June 1991 the author presented a paper [Ford] at the Sixth International Conference on Applications of Statistics and Probability in Civil Engineering, (CERRA-ICASP 6) Mexico City. Before his Recall to Duty he also took the opportunity for discussions as described below with researchers at the California Institute of Technology, Pasadena. Two other technical visits were planned but one became irrelevant and another unnecessary when Dr B.N. Cox of Rockwell Science Center came to ARL.
All of the author's presentations concerned sampling or fatigue integrations implemented in the program FRAN (Fatigue and Reliability Analysis).

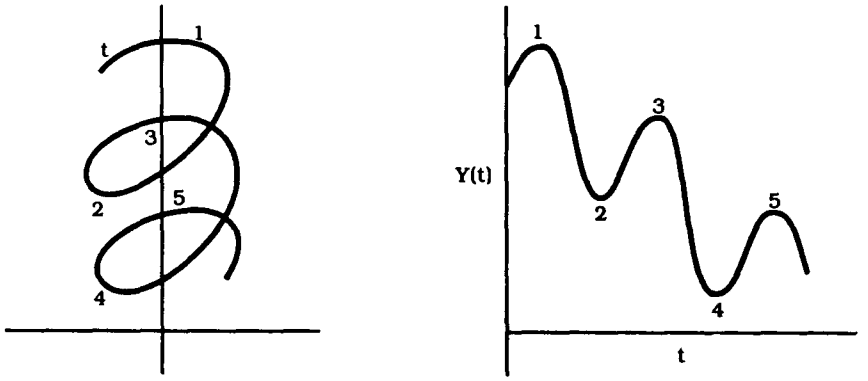
2. CALIFORNIA INSTITUTE OF TECHNOLOGY

The three researchers below work on materials science in the Guggenheim Aeronautical Laboratory (GALCIT).

Professor Wolfgang Knauss 4th June 1991

Dr Knauss spoke of his interest in the fatigue of polymers and his work on delamination of composites. The first subject led to my talking of range-pairs (rainflow) whilst his current interest in delamination was in its extension through creep buckling (presumably local) particularly under a minimum sustained stress. I mentioned the allied case of bolt or rivet holes joining to metal structure and he said that these may be exacerbated by local matrix effects dominating near a surface and by the chance of environmental effects.

With the range-pair tutorial I began with the relation between circles and sinusoids and generalised this to the "circular scribble"



or more correctly without loss of generality

$$Y(t) = M(t) + R(t) \sin (2\pi t).$$

After this I described our ARL-RAE results on reconstitution tests and said that the continuation into crack growth of the descriptive power of range-pair or rainflow analysis lay in the large numbers of turning points occurring while a crack tip traverses a particular plastic zone; $100 < (da/dn)/r_y < 10^4$ for constant amplitude growth.

I went on to the box test, the Rychlik definition and the automation of the box test to three-point one-pass counting. I also mentioned the roughly 3:1 speed up by first using structures with **drop** and **drip** pointers as well as level, corresponding to the original work by Matsuishi and Endo and promised some references from ARL.

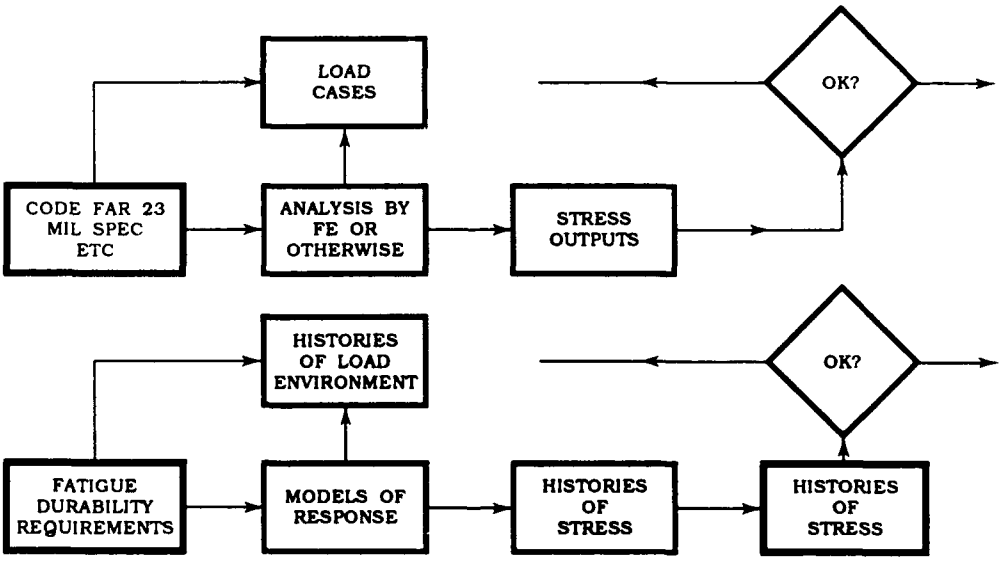
Dr Ravi-Chandar 4th June 1991

Dr Ravi-Chandar seemed to work more on fatigue than Knauss but his main interest was in ceramics, including those zirconium stabilised, for which the Australian Company set up by CSIRO had started to operate in the USA. These are extremely weak in tension and fully flaw dependent.

This led to my ICASP 6 paper and I spoke of the sampling and data structures described in the first half. He found this interesting and favoured the abstract approach above some Swedish work which involved nonlinear structural modelling of fatigue striations. He agreed that FRAN could in fact model ceramics as well as metal structures.

Ravi mentioned some of the recent work on crack growth of which I said my program coding had left little time to peruse. Some of this had been summarised by Subra Suresh (also see Knauss and Rosakis), including non-metallics, and he mentioned Jean Lemaitre (also in Knauss and Rosakis) to whom Chaboche seems to be a junior partner.

Firstly I suggested that a convenient multi-crack fatigue tool would change the nature of stress analysis. The sketch shows single-case type of analysis where most of the information in K^{-1}, the inverted stiffness matrix, is wasted, though some FE packages retain it. Any serious stressing is done because it is required by safety or law as exemplified in a standard code but this fact is too obvious to include in FEA or the conscious knowledge of analysts.



COMPARISON OF STATIC AND FATIGUE ANALYSES

However, in the case of fatigue the same principle means that stress analysis coding is called as a subroutine in a wider process of simulation. Naturally this is a tremendous load on even the best computing resources and creates a need for condensed presentations of K^{-1}. For pure elasticity the obvious answer is a constant stress concentration factor K_T and, in general, historical dependence complicates this but the need remains. It is qualitatively analogous to vibration modelling with reduced degrees of freedom.

Dr Ares Rosakis 5th June 1991

Professor Rosakis was interested in my paper also so I left a copy and repeated some of the presentation to Ravi but expanded more on damage theory reliability, initial cracks and looping through times in FRAN. There was not time to hear of his work but ARL receives the related GALCIT reports.

3. CERRA-ICASP 6 CONFERENCE

Maria Isabel Sheraton Hotel, Mexico City 17-21 June, 1991

This conference is held every four years under the auspices of the International Association for Civil Engineering and Risk Analysis Reliability (CERRA), alternating with the ICOSSAR series.

Eight of the sixteen conference topics had some relation to general structures and I was especially interested in Material Behaviour, Determination and Updating of Structural Reliability and Continuous-Time Processes. The general topics and individual papers are listed in the Appendix.

Each session was arranged in an unusual way, starting

> "with the participation of an invited General Reporter, who will present an integrated, critical summary of the papers scheduled for that session. This will be followed by brief contributions (up to five minutes for each paper) from the authors, who should limit their participation to clarifying ideas and adding relevant concepts not treated by the General Reporter. A free discussion will finally take place with the participation of the audience".

This system worked well for some sessions but some individual authors lapsed into full presentations leaving others without enough time. I was one of these but arranged afterwards to correspond with my Reporter, Professor Casciati from the University of Pavia, who found the range-pair integration interesting.

4. DISCUSSION

The CERRA-ICASP series is one of the two leading forums for developments in reliability and safety, the other being ICOSSAR. The visit was therefore stimulating and the interest in the presentation [Ford] was pleasing and can lead to further developments.

Discussions at the CALTECH Guggenheim Laboratory also produced different viewpoints about fatigue analysis.

There is a continuing emphasis on Monte Carlo procedures for reliability of structural systems and indeed one of my own conclusions was that FRAN could not treat more than 15 cracks without this type of sampling. However as one of the leading speakers, Rudiger Rackwitz, said new sampling developments are becoming fewer and the number of basic variables allowed is nowhere near the needs claimed by some workers. It would therefore appear that the order of the problems should first be reduced by non-statistical considerations, starting from the general stress analysis. Similar problems can develop for aircraft and such order reductions are also needed for practical applications of FRAN.

REFERENCES

1. Chaboche, J.L. Continuum Damage Mechanics: Present State and Future Trends. **ONERA TP** No. 1986-53.

2. Ford, D.G. (1991) Systematic Extreme Sampling in Multicrack Fatigue and Reliability, Sixth International Conference on Applications of Statistics and Probability in Civil Engineering **(CERRA-ICASP 6)**, Mexico City, June 17-21, 1991.

3. Knauss, W.G. and Rosakis, A., editors (1991) **"Non Linear Fracture - Recent Advances** " Kluwer.

4. Lemaitre, Jean (1990) **International Journal of Fracture** 42 pp. 41-46.

5. Matsuishi, M. and Endo T., (1968) Fatigue of metals subject to varying stress, Paper presented to **Japan Soc. Mech. Engrs**, Jukvoka, Japan.

6. Rychlik, I., (1987) A new definition of the rainflow cycle counting method. **International Journal of Fatigue 9**, pp. 119-121.

7. Suresh, (1991) Subra **Fatigue of Materials**, Cambridge.

APPENDIX

CERRA/ICASP 6 CONFERENCE

Table of Contents

Volume 1

I Uncertainty analysis and mathematical models

II Material behaviour and its models

III Probabilistic models of structural components

IV Determination and updating of structural reliability

V Response and reliability for dynamic excitations

VI Seismicity and seismic hazard

VII Continuous time - processes and random fields

Volume 2

VIII Combination of simultaneous load processes

IX Exploration and Sampling

X Geotechnical properties

XI Foundations

XII Dams, embankments and natural slopes

XIII Bridges

XIV Hydrology, hydraulic and marine systems

XV Offshore structures

XVI Decisions and optimization

XVII Reliability based design

XVIII Probabilistic analysis in the operation of industrial and public systems

DISTRIBUTION

AUSTRALIA

Department of Defence

Defence Central

Chief Defence Scientist)
AS, Science Corporate Management)shared copy
FAS Science Policy)
Director, Departmental Publications
Counsellor, Defence Science, London (Doc Data sheet only)
Counsellor, Defence Science, Washington (Doc Data sheet only)
Scientific Adviser, Defence Central
OIC TRS, Defence Central Library
Document Exchange Centre, DSTIC (8 copies)
Defence Intelligence Organisation
Librarian H Block, Victoria Barracks, Melb (Doc Data sheet only)

Aeronautical Research Laboratory

Director
Library
Chief Structures Division
Divisional File - Aircraft Structures
Author: D.G. Ford

Navy Office

Navy Scientific Adviser (3 copies Doc Data sheet only)

Army Office

Scientific Adviser - Army (Doc Data sheet only)

Air Force Office

Air Force Scientific Adviser
Director General Engineering-Air Force
HQ Logistics Command [DGELS]

HQ ADF

Director General, Force Development (Air) - OFFOPS

SPARES (10 COPIES)

TOTAL (32 COPIES)

AL 149 DEPARTMENT OF DEFENCE

DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER	1b. ESTABLISHMENT NUMBER	2. DOCUMENT DATE	3. TASK NUMBER
AR-006-654	ARL-STRUC-TM-579	OCTOBER 1991	AIR 89/080

4. TITLE
REPORT ON VISIT TO CALTECH AND CERRA/ICASP6 RELIABILITY CONFERENCE, JUNE 1991

5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), LIMITED (L) UNCLASSIFIED (U)).

DOCUMENT	TITLE	ABSTRACT
U	U	U

6. NO. PAGES
18

7. NO. REFS.
7

8. AUTHOR(S)
D.G. FORD

9. DOWNGRADING/DELIMITING INSTRUCTIONS
Not applicable

10. CORPORATE AUTHOR AND ADDRESS
AERONAUTICAL RESEARCH LABORATORY
506 LORIMER STREET
FISHERMENS BEND VIC 3207

11. OFFICE/POSITION RESPONSIBLE FOR:
SPONSOR RAAF
SECURITY -
DOWNGRADING -
APPROVAL CSTD

12. SECONDARY DISTRIBUTION (OF THIS DOCUMENT)
Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DSTIC, AI MINISTRATIVE SERVICES BRANCH, DEPARTMENT OF DEFENCE, ANZAC PARK WEST OFFICES, ACT 2601

13a. THIS DOCUMENT MAY BE ANNOUNCED IN CATALOGUES AND AWARENESS SERVICES AVAILABLE TO . . . .
No limitations

13b. CITATION FOR OTHER PURPOSES (IE. CASUAL ANNOUNCEMENT) MAY BE [X] UNRESTRICTED OR [ ] AS FOR 13a.

14. DESCRIPTORS
Fatigue life
Reliability engineering
Visit reports

15. DISCAT SUBJECT CATEGORIES
2011

16. ABSTRACT
This memo describes discussions with three materials researchers at the California Institute of Technology, Pasadena, and the Sixth International Conference on Applications of Statistics and Probability in Civil Engineering, Mexico City, June 17-21 1991 at which the author presented a paper about predicting fatigue life distributions with FRAN.

PAGE CLASSIFICATION
UNCLASSIFIED
PRIVACY MARKING

THIS PAGE IS TO BE USED TO RECORD INFORMATION WHICH IS REQUIRED BY THE ESTABLISHMENT FOR ITS OWN USE BUT WHICH WILL NOT BE ADDED TO THE DISTIS DATA UNLESS SPECIFICALLY REQUESTED.

16. ABSTRACT (CONT):

17. IMPRINT

AERONAUTICAL RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. COST CODE	20. TYPE OF REPORT AND PERIOD COVERED
Aircraft Structures Technical Memorandum 579	24 208F	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

23. ADDITIONAL INFORMATION (AS REQUIRED)