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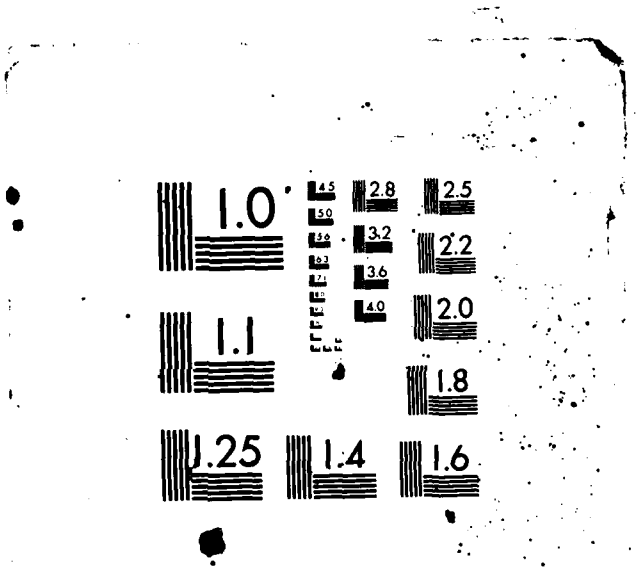

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KOZIN BOGDANOFF & ASSOCIATES, INC.

WEST LAFAYETTE, IN 47906

JUNE, 1985

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1. Introduction

The purpose of this report is to summarize the last year's activity under this contract, to supply copies of publications supported under this contract and to indicate those lines of investigation terminated at the end of this contract.

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1.2. Summary of Work Accomplished

Detailed statistical analysis of FCG data partially reported in Item A, Section 2 and continued in Item E, Section 2 has increased our interest in FCG modeling and the acquisition of suitable additional data with high replication number. The available data indicates that:

a) The "weakest link" concept of FCG is not valid,
b) The Weibull distribution, which is based on the "weakest link" concept, is not appropriate for the description of the distribution of the time to cross a given crack length interval,
c) The first extreme value distribution, which is based on the "strongest link" concept is appropriate for description of the distribution of the time to cross a given crack length interval (Item F, Section 2), and
d) The "strongest link" concept appears appropriate for the FCG mechanism (Item F, Section 2).

We are the first group to have a statistical analysis on which to base these remarks. More specifically, the data analysis indicates that:

i) The mechanism of FCG is essentially the same over all crack length intervals except for scale and location effects,
ii) the coefficient of skewness, is approximately equal to 1, and,
iii) The process is history dependent. Items A, E, H, J of Section 2 and Items B, D, F, G of Section 3) are directed at the modeling problem. Items B and G Section 3, point out that diffusion process based models cannot include i)-iii), which is not too surpising since FCG is not a diffusion process as some seem to think.

Preliminary investigations (Item H of Section 2 and Item D of Section 3, plus others not reported) indicate that the time transformation of a stationary B-model and a stationary vector B-model may provide a straight-forward approach that includes i)-iii). This is a significant step since, while it is easy to find models that include only one or possibly two of the features i)-iii), it is not easy to find models even with the potential for including these features. The practicality of these two models has not been assessed from the viewpoint of parameter estimation. At this time, a 2-dimensional vector stationary B-model appears somewhat superior, which is interesting since it suggests that crack length alone as an observable does not define the FCG process.

A history dependent deterministic FCG equation is proposed in Item J, Section 2 for the evaluation of the mean time to reach a specified crack length. This model is the result to a simple, but new, extension of the usual data analysis in which it was observed that the time to cross a given short crack length interval depends on the starting time; put another way, it was observed that the $\Delta n/\Delta a$ values depend on the value of the time of the start across the increment Δa. The simple deterministic history dependent model proposed followed, and the practical significance of this model in accurately predicting future crack growth and the data required to obtain this accuracy (not present in current models) were discussed.

Any model constructed to determine inspection procedures to insure a specified reliability in the operation of a fleet of units is based upon assumed information about operation available prior to operation, and is very unlikely to be correct for the actual operational conditions. Information about actual fleet operation can be obtained at inspections where number of units replaced is noted, states of damage in components may be assessed, etc.. B-models present a setting in which it is possible to adaptively update the model based on inspection or service information in a simple, practical manner. The updated model there is used to provide a more accurate time duration estimate to the next inspection, while keeping close to the prescribed reliability, than can be obtained with a non updated model. Items I of Section 2 and A and E of Section 3, discuss this adpative updating procedure using B-models. As far as we know, this appears to be the first time an adaptive control model has been suggested in which the observation is on a probability distribution. Papers Item I, A and E of Section 3 indicate some of the interesting convergence problems that can occur and note the gains in accuracy that can be acheived by employing a detailed and carefully executed inspection procedure. Much remains to be done, however.

Two years ago, we came upon data on the fatigue life in tension of sized polyester/viscose yarn employed in the weaving industry. These life data are most interesting for several reasons; first, yarn is essentially one-dimensional; second, its method of organization and of detaining tensile strength is very different from that of metals; third, there are essentially one hundred replications at each test condition; and, finally, besides many tests at one length (100 cm.), tests also were conducted with variable lengths (30 cm. 40 cm., 50 cm., 60 cm., 70 cm., 80 cm., 90 cm.,).

Edf's of all tests were plotted on linear scales and visually examined. It was observed that in some of the tests at 100 cm. length an abrupt change in slope (increase) occurred about half-way up the edf. Item B, Section 2 examined this unusual effect.

It was found in Item B, Section 2 that a stationary B-model with a nonlinear time transformation was required to describe the edf selected for examination. Thus, the process of damage accumulation appears nonstationary. An opinion based on physical reasoning was advanced to explain the singular shape of this edf.

The effect of the length of a component on fatigue life has recently become a hot topic. Fortunately, we have already studied this topic in some detail and reported on it in Item D, Section 2. Since we have appropriate life data, our views have the advantage of being based on fact for at least our material.

We demonstrated in Item D, Section 2 that the "weakest link" concept among sublengths Δl whose fatigue lives are regarded as independent random our variables is not consistant with the facts. In particular, as length increases, the edf's seem to stop moving to the left, well away from the ordinate axis, indicating that a decrease in fatigue life due to an increase in length gradually stops. We demonstrated how a "weakest link" concept model can be specially modified to bring it into agreement with the facts. Further, we proposed a B-model, with physical appeal, that accounts for the effect of length on fatigue life. Finally, we have recently made a preliminary study of the general topic of size effect leased on this B-model, but no report has been written.

Our entire effort in the modeling of cumulative damage has been guided by one principle: "if there is not life data or data on the evaluation of damage accumulation at high replication number, modeling effort is of little or no value." To distinquish among competing models, good definition of the tails of the distributors is essential, as Freudenthal pointed out long ago. (Put another way, at low replication number just about any unimodal distribution looks good). To secure good tails definition, high replication number is essential. Once a class of comprehensive coherent models has demonstrated it's accuracy in description and prediction, the number of replications needed for engineering purposes can be sharply reduced.

To date, we have found B-models practically useful engineering tools for cumulative damage. This is largely due to the fact that these models are dynamical processes with a very rich content.

2. Publications (Printed and in Preparation)

A) J.L. Bogdanoff & F. Kozin, "Probalistic Modeling of Fatigue Crack Growth" II, Engin. Fract. Mech., Vol. 20, No. 2, 1984, pp 255-270.

B) J.L. Bogdanoff & F. Kozin, "A Statistic Model of Failure Applied to Yarn Fatigue Data", in review process.

C) J.L. Bogdanoff & F. Kozin, "Probablistic Models of Cummulative Damage", John Wiley & Sons, N.Y., April, 1985.

D) J.L. Bogdanoff & F. Kozin, "Effect of Length on Fatigue Life of Yarn", in preparation, but now suspended for lack of funds.

E) F. Kozin & J.L. Bogdanoff, "Probablistic Modeling of Fatigue Crack Growth" III Data Analysis, in progress.

F) F. Kozin & J.L. Bogdanoff, "On Use of 1st Extreme Value Distribution in Fatigue Life Analysis", in preparation, but now suspended for lack of funds.

G) J.L. Bogdanoff & F. Kozin, "On the Use of Stationary Vector Mark of Processes in Fatigue Crack Growth & Fatigue of Composites", in preparation, but now suspended for lack of funds.

H) F. Kozin & J.L. Bogdanoff, "On Parameter Estimation for Time Transformations in Fatigue Crack Growth", in preparation, but now suspended for lack of funds.

I) J.L. Bogdanoff & F.Kozin, "Dynamic Updating of Cummulative Damage Models for Reliability and Maintenance Based Upon Service Informaiton" II, in preparation, but now suspended for lack of funds.

J) F. Kozin & J.L. Bogdanoff, "On Deterministic History-Dependent Fatigue Crack Growth", First draft finished, but now suspended for lack of funds.

3. Conference Publications

A) J.L. Bogdanoff & F. Kozin, "Dynamic Updating of Cummulative Damage Models for Reliability and Maintenance Based Upon Service Information: Prob. Methods in the Mechanics of Solids and Structures, IUTAM Symposium, Stockholm, 1984, Editors: S. Eggwertz, N.C. Lind, Springer-Verlag, Berlin, 1985, (by invitation).

B) F. Kozin & J.L. Bogdanoff, "Analysis of Stochastic Equation Models in Fatigue Crack Growth", Prob. Methods in the Mechanics of Solids and Structures", IUTAM Symposium, Stockholm, 1984, Editors: S. Eggwertz, N.C. Lind, Springer-Verlag, Berlin, 1985, (by invitation).

C) F. Kozin & J.L. Bogdanoff, "Review of B-Models Applied to Cummulative Damage Processes", Proc. Bi-annual Conference on Pressure Vessels and Piping, ASME, San Antonio, June 1984.

D) J.L. Bogdanoff & F. Kozin, "Use of Time Transformation Methods in Fatigue and Fatigue Crack Growth", Proc. on Random Vibration, ASME, AMD - Vol. 65, Dec. 1984, Edited by T.C. Huang & P.D. Sparnios.

E) F. Kozin & J.L. Bogdanoff, "Adaptive Updating of Fatigue Model for Reliability and Maintenance Based Upon Service Information", 40th MFPG (NBS), Proc/. Gaithersburg, April, 1985.

F) F. Kozin & J.L. Bogdanoff, "On the Statistic Modeling of Cummulative Damage in Composites", ICOSSAR"85", Proceedings, Vol. Kobe, 1985.

G) F. Kozin & J.L. Bogdanoff, "On Probablistic Modeling of Fatigue Crack Growth", ICOSSAR"85", Proceedings, Vol. Kobe 1985.

4. Conference Presentations (March 84 - May 85 Period)

A) International Union Theoritical & Applied Mechanics (IUTAM) Weibull Memorial Smyposium 18 - 21 June,(1984), Stockholm.
J.L.B. & F.. invited to present papers and publish in Symposium Proceedings (see 3(A), (B))

B) ASME Bi-Annual Conference on Pressure Vessels and Piping, 18 - 21, June (1984), San Antonio.

J.L.B. & F.K. invited to include paper in Proceedings even though unable to attend (to present) due to previous commitment A), (See 3(C)).

C) Invited lecture (FK), Naval Postgraduate School, 19, July (1984), Monteray.

D) ASTM Conference

16 - 22, October (1984), Dallas

Present paper on Deterministic Past-Dependent Model of FCG to E24, 06.04 Comm. (JLB)

E) ASME Winter Annual Meeting
10 - 14, December (1985), New Orleans

JLB presented invited paper included in Symposium on "Random Vibration" (See 3(D)).

F) MFPG Conference on New Technology in Material Failure Preservation, 15 - 17 April, (1985), Gaithersburg, NBS.

FK presented paper on Updating (See 3(E)).

G) Int. Conf. On Struct. Safety and Reliability"85" (ICOSSR"85"), 27 - 29, May (1985).

JLB & FK invited to present papers for inclusion in Proc. (See 3(F) & (G)).

Note: Items F) & G) contracted for before being informed by AFOSR that contract would not be renewed.

5. Patents

No patents have evolved as a result of this contract.

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