2.6 Computer Codes

2.6.1 Structural Analysis

FRANC2D/L is a highly interactive finite element program for the small deformation analysis of two-dimensional structures. As such, it is useful for engineering calculations or for instruction in finite element and fracture courses. Linear elastic fracture mechanics analyses can be performed with automatic remeshing as the crack grows. The layered capability allows the user to model riveted and adhesively bonded structures, such as lap joints and bonded repairs. Elastic-plastic material behavior is also available. This allows the user to model tearing with the critical crack tip opening angle approach. This provides the full capability of growing a fatigue crack and calculating residual (tearing) strength as a function of crack length.

FRANC2D/L is an extension of FRANC2D, which was originally written by Paul Wawrzynek at Cornell for the analysis of crack growth. A key concept in his work was the use of a winged-edge data structure to describe the geometry. This greatly facilitates automatic remeshing during crack growth.

2.6.2 Life Prediction

2.6.2.1 NASGRO Fracture Analysis Software

NASGRO Fracture Analysis Software is a suite of programs based on fracture mechanics principles. NASGRO can be used to analyze crack growth, perform assessments of structural life, compute stresses, and process and store fatigue crack growth properties. The package includes a large set of crack growth rate and fracture data.

NASGRO was originally developed at NASA Johnson Space Center to perform fracture control analysis on NASA space systems. Later, after the NASA/FAA/USAF Aging Aircraft Program was formed and began supporting the development effort, NASGRO was developed further for use in damage tolerance analysis of aircraft, including that required for FAA certification.

The software is comprised of the following three modules:

- NASFLA - Life Assessment
- NASBEM - 2-D Boundary Element
- NASMAT - Database of da/dN & fracture test results

NASFLA is part of the NASGRO 3.0 suite of programs Stress Intensity Factor -These are computed for the crack geometry and loading chosen from the NASFLA library of models, and displayed in tabular or graphical form.

NASBEM is part of the NASGRO 3.0 suite of programs. It is a two-dimensional boundary element program used to perform the following analyses:

- Stress Intensity Factors - These can be calculated for any geometry and loading. Tables of stress intensity factors and corresponding crack lengths can be generated for use by the NASFLA module in performing life assessments.
- Stress Fields - These can be calculated for any collection of points in the two-dimensional uncracked object being modeled including its boundary.

NASMAT is used to store, retrieve and curve fit crack growth and fracture toughness data. It has a database containing over 9000 sets of data. This includes over 3000 sets of fatigue crack growth data and over 6000 fracture toughness data points. These data can be searched, plotted, and fitted to either the NASGRO crack growth rate equation or a user specified growth rate equation, or they can be entered into a growth rate table.

2.6.2.2 AFGROW Fracture Analysis Software

http://fibec.flight.wpafb.af.mil/fibec/afgrow.html

2.6.2.3 Cracks2000 Structural Integrity Software

The CRACKS2000 program is based on the Linear Elastic Fracture Mechanics (LEFM) approach for estimating the fatigue life of a component with a crack. The LEFM approach uses the stress intensity factor parameter, as the driving factor for crack growth. The Cracks2000 program has considerable flexibility in the analytical modeling of crack growth analysis problems.

The program can solve both constant amplitude and variable amplitude crack growth analysis problems, with the user choosing the stress intensity factor, the type of loading spectrum, the type of retardation model, and the type of crack growth rate behavior description.

Cracks2000 has fifty-one stress intensity factors solutions. There are closed form equations for stress intensity factor solutions for 25 geometries. Many of these solutions are the early Newman-Raju solutions, which are retained for comparisons with older analysis. For the latest stress intensity factor solutions, tables of β-factors are generated from the equations; the tables are used for the life analysis, and can be printed and plotted for β-factors comparison

Additional information on the Cracsk2000 software can be found at:

http://www.udri.udayton.edu/cracks/

or contact

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2.6.3 Risk/Probabilistic

PRobability Of Fracture (PROF)

PROF is a computer program that was specifically written to interface with the data that are available as a result of ASIP. PROF runs in the Windows environment using an Excel spreadsheet interface with ASCII data files and two C^{++} calculation modules. The two calculation modules estimate the probability of failure as a function of flight hours due to either

fatigue crack growth at a stress riser and the probability of failure due to discrete source damage in a load path.

The PROF input requirements for estimating failure probability due to fatigue crack growth are:

- crack growth versus flight hours (a versus T) for the expected stress sequences;
- a versus K/σ at the stress riser;
- distribution of critical stress intensity factors at the stress riser;
- distribution of maximum stress per flight experienced at the stress riser;
- distribution of crack sizes at the stress riser;
- probability of detection as a function of crack size, POD(a), function for the inspection system used at inspections;
- distribution of equivalent crack sizes at repaired stress risers; and
- flight hour intervals between inspections.

PROF projects the crack size distribution using the a versus T relation from the deterministic damage tolerance analysis of ASIP. At an inspection, PROF changes the distribution of crack sizes in accordance with the POD(a) function and the equivalent repair crack sizes. The post-inspection/repair crack size distribution is then projected for the next usage interval. Single flight probability of failure is calculated using the Irwin abrupt fracture criterion. That is, the failure probability is calculated as the probability that the maximum stress intensity factor (combination of the distributions of maximum stress per flight and crack sizes) during the flight exceeds the critical stress intensity factor. This probability is obtained from a triple integration over input distributions.

For failure probability due to discrete source damage, PROF requires the additional input of residual strength as a function of crack size in the remaining critical elements of the load path. The residual strength characterization replaces the stress intensity factor input. PROF again grows the crack size distributions with modifications, as necessary, at inspections. Single flight failure probability is calculated from the distribution of maximum stress per flight, crack size distribution at the critical element and residual strength as a function of crack size. This probability is obtained from a double integration over input distributions.

The output of PROF is stored in an Excel workbook and provides both the single flight failure probability as a function of flight hours and the crack size distributions before and after an inspection. The availability of the crack size distributions permits changing the analysis due to known changes in usage. Further, multiple runs of PROF permit analyzing more complex scenarios such as multiple element damage. See Sample Problems UDRI-2, UDRI-3 and UDRI-4 for examples of the use of PROF for risk analysis of discrete source damage, multiple element damage and corrosion damage scenarios, respectively.

PROF is proprietary to the University of Dayton but is freely available for United States government applications. PROF can be obtained for United States government applications from

Mr. David Banaszak
AFRL/VASM
Wright-Patterson Air Force Base, Ohio 45433

Phone: (937) 255-6104

email: David.Banaszak@wpafb.af.mil

For applications not directly related to the United States government, a license for the use of PROF can be arranged. Contact

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DARWIN

Design Assessment of Reliability WIth INspection (DARWIN) is a risk analysis program for calculating the probability of failure in turbine engine disks. With a graphical user interface for problem setup and output, DARWIN integrates finite element analysis, fracture mechanics, non-destructive inspection, random defect occurrence and location, and other random variables to assess the risks of rotor fracture. Risk calculations incorporate both Monte Carlo and failure function/fast integration methods.

See www.darwin.swri.org