A Short History of Crack Growth Simulation Software Developed at Cornell University

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Finite Element Fracture Analysis Program (FEFAP)

- Determine how a crack can cross or terminate in a 2D element and apply a template to divide the effected elements.
Many near degenerate crack/element intersections lead to elements with poor aspect ratios.

This combined with a displacement correlation approach yields low accuracy SIF’s and tortuous crack paths.
**FEFAP-G**

- Updated version of FEFAP with an interactive graphical user interface and many enhancements.
Among the enhancements were some limited tools for locally deleting elements in the crack-tip region after crack extension and replacing them with better shaped elements.
CRACKER

- Dan Swenson (1984-1985)
- Primarily a program for dynamic crack propagation (explicit dynamics)
- Cracker generalized the FEFAP-G approach of crack-tip meshing by first deleting elements, extending the crack, placing crack-tip elements, then creating a transition mesh
CRACKER

• Cracker was an innovative and capable program, but was not a good foundation for continued development because:
  • Many features and options were specialized for dynamic crack growth and
  • It was built on conventional FORTRAN data structures (arrays) that did not lend themselves to dynamic updating.
FRANC

- FRacture ANalysis Code (FRANC) Originally Wash Wawrzynek, many subsequent contributors 1984 – present, (now FRANC2D)
- A program to manage a dynamic graph like data structure that happens to know how to do finite element analysis and a bit about fracture mechanics.

FRANC2D has had 30 years of longevity because:

1) Built around an abstract data type the hides implementation details
2) Built on a virtual graphics package (rapid porting to new graphics devices)
3) Simple to use framework for creating and managing new menus and pages
FRANC

- FRANC2D uses a “Winged-Edge” data structure to store FE mesh topology and geometry.
- It provides a set of “high level” operators that modify the data structure while maintaining data integrity and a set of queries to retrieve topological and geometrical information.
• FRANC2D uses a “delete and fill” approach to crack growth, similar to CRACKER

• Because of the topological query capabilities, the delete&fill approach is enhanced with the ability to retain structural boundary or bi-material interfaces.

FRANC2D’s biggest shortcoming is that there is no distinction between the finite element mesh geometry (discrete and faceted) and the real structural geometry.
PORFRANC

- Multi-physics (deformation, poro-elasticity, fluid flow in the fracture)
- Cohesive zone crack models
• High performance (for the time) graphical postprocessor for PORFRANC
FRANSYS / FRANC3D*

- Luiz Martha, Wash Wawrzynek, and others  1987 – 2005
- Fully 3D crack growth simulator
- Built-in solid modeling capabilities (B-Spline patches and a radial-edge topological data structure)
- Advanced (for the time) multi-window graphical user interface

* Originally named FRacture ANalysis SYStem (FRANSYS), but was rechristened FRANC3D after we received a cease and desist letter from the lawyers for ANSYS
Originally, boundary elements were used for deformation analysis. This required surface meshing only (volume meshing capabilities were not very mature in the late 80’s).
• Unfortunately, the boundary element technology we were using (a hypersingular formulation developed by Earlin Lutz – a program called BES) required that we compute SIFs using displacement correlation, which were typically in error by about 3-5% (good in 1990, not so good in 2000). Also, boundary elements do not scale well for large problems.

• Some solid finite element capabilities were added to this version of FRANC3D late in its life, but these capabilities were awkward to use and did not provide much more accuracy for SIFs than the boundary elements.
FRANC3D – thin shell

- FRANDC3D enhancements for thin shell finite elements (airframe structures)
- David Potyondy and David Chen 1991 – 1999
- Linear elastic (fatigue) and plastic tearing (residual strength)
FRANC3D – thin shell

pressure = 9.4 psi
crack length = 38.2”
magnification factor = 5.0
FRANC3D – thin shell

40 in. single long crack

long crack + 0.05 in. MSD cracks

Pressure (psi)

Lead Crack Extension (in.)

20% Loss of R.S. (Exp.)

Exp.

Num.
HYFRANC3D

- A near well-bore hydrofracture FRANDC3D derivative
- Jose Sousa and Bruce Carter 1993 – 2005
- Coupled BEM for the solid and FEM for the fluid flow in the fractures
FRANC3D / Next Generation

- A total FRANC3D rewrite, Wash Wawrzynek & Bruce Carter 2005 – present
- Developed outside of Cornell with mostly Air Force and Navy funding
- Designed to work with commercial finite element programs (ABAQUS, ANSYS, and NASTRAN are supported currently)
- Input is an uncracked finite element mesh
- Can be run with a graphical user interface or programmatically through a Python interface
- Built-in fatigue life computations
FRANC3D / Next Generation

“global” model

FRANC3D/NG remeshes a “sub-” model

FE mesh compatibility maintained

initial corner crack
FRANC3D / Next Generation

FRANC3D/NG derives a solid model from the uncracked mesh geometry

1) finite element mesh
2) fit with FE facets with cubic triangular Bezier patches
3) find “hard” edges and determine global topology

Supporting only one geometrical primitive (cubic Bezier) simplifies modeling and intersection computations

The mesh is retained on surfaces that will be joined with the global model
FRANC3D / Next Generation

- Crack size/shape parameters
- Position and orient crack
- Crack-front template parameters
A “template” of well shaped elements is generated along crack fronts automatically.

Computed SIF’s normally within 1% of reference values for typical “engineering” mesh densities.
FRANC3D Version 6 is the newest 3D fracture analysis software from FAC.

FRANC3D development started at Cornell University in the late 1980’s, evolving into a program that has been used worldwide in academia and industry for analyzing crack growth in complex 3D structures.

Version 6 has a number of significant enhancements over Version 5 and has improved support for the commercial finite element analysis programs: ANSYS\(^1\), ABAQUS\(^2\) and NA STRAN\(^3\). Typically, a user extracts a small portion of a complex 3D finite element model. FRANC3D reads this small portion, inserts one or more cracks, re-meshes, executes the analysis program, computes fracture parameters, extends the cracks, and computes a stress intensity factor history and fatigue life.
FRANC3D Version 6 (Commercial Version)
FRANC3D Version 6 (Commercial Version)
FRANC3D Version 6 (Commercial Version)
FRANC3D Version 6 (Commercial Version)

initial crack location
Over 30 license holders world-wide including:

- Pratt & Whitney
- Rolls Royce
- Honeywell
- Siemens
- Pilatus Aircraft
- Avio Aero Group
- Mitsubishi Heavy Industries
- Corning Glass
- US Air Force
- US Navy
- NASA/LaRC
Summary

- 37 years of continuous innovation in crack growth simulation software
- Each of these codes was the most advanced of its time
- These ideas and capabilities have evolved out of academia and into industry where they are slowly becoming standard practice in a number of companies