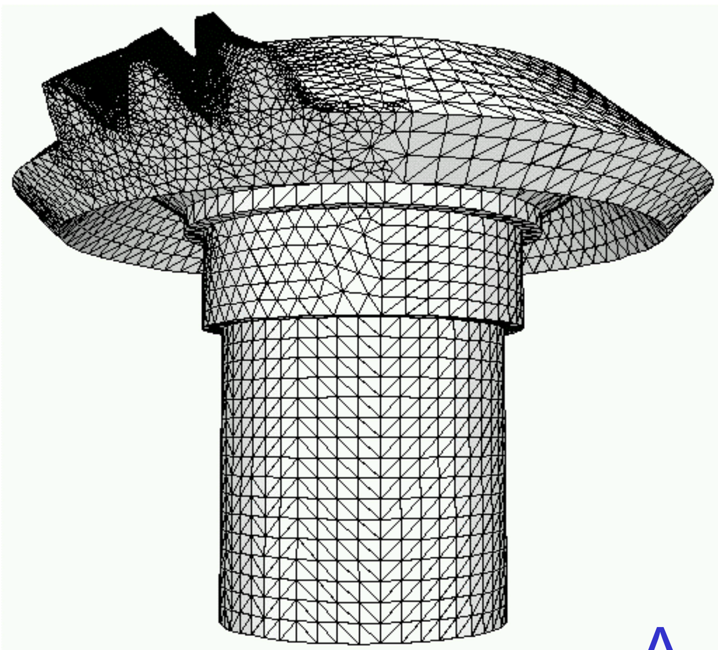
Meshing For Crack Propagation Simulation: Problems….

… from Within …

…and Without



FCM

MPM

MFEM

BCM

EIBM

SPH

EFG

A. R. Ingraffea

With a lot of help from his friends in the

Cornell Fracture Group

And

ASP/ITR Project

Outline of Presentation

- The crack propagation problem:
  Definitely evolutionary geometry, but
  need it be evolutionary meshing?

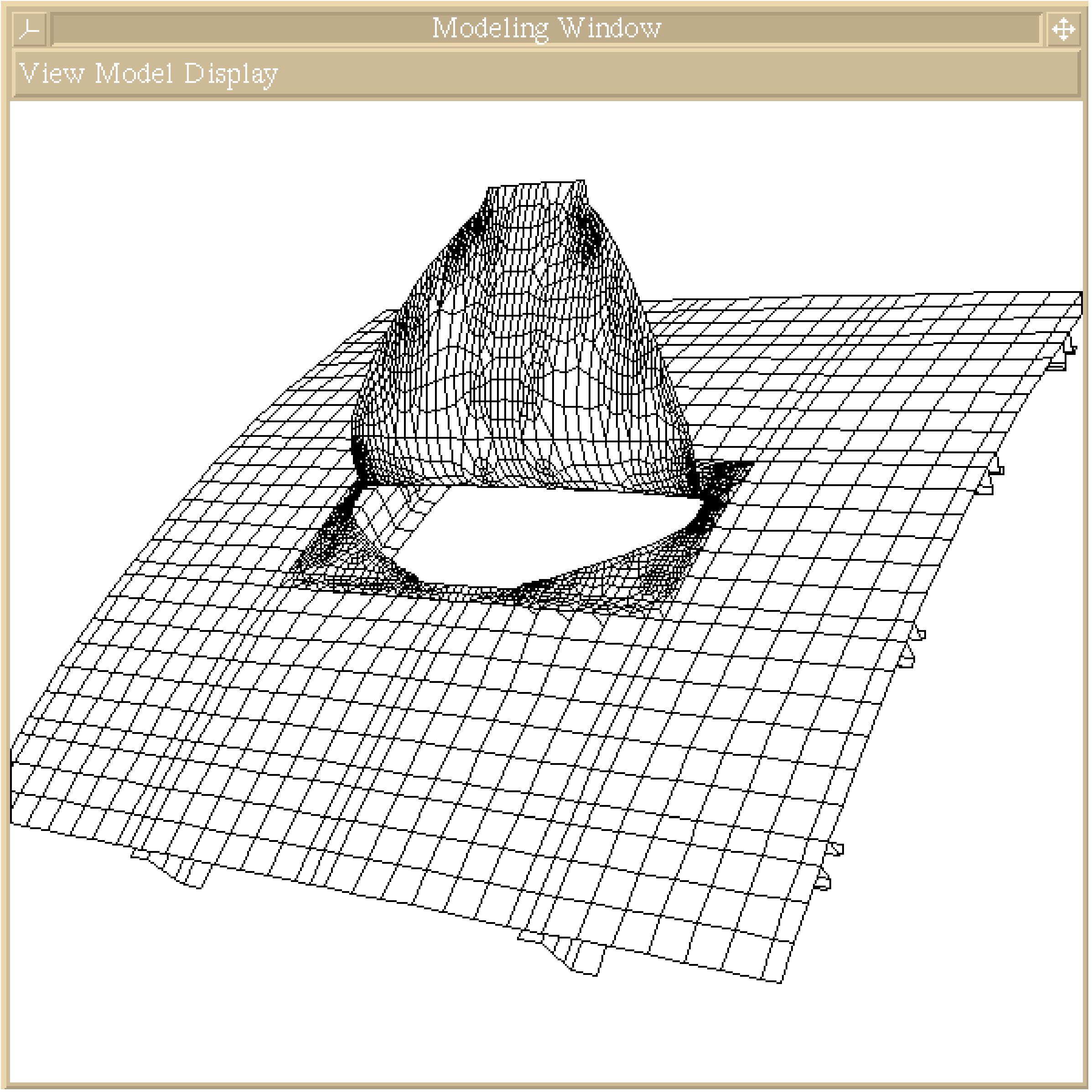
- The problem within: examples of current simulation capability.
  And shortcomings.

- The problem without:
  The meshfree methods are here, and more coming!
  Are they just a challenge, or a revolution?

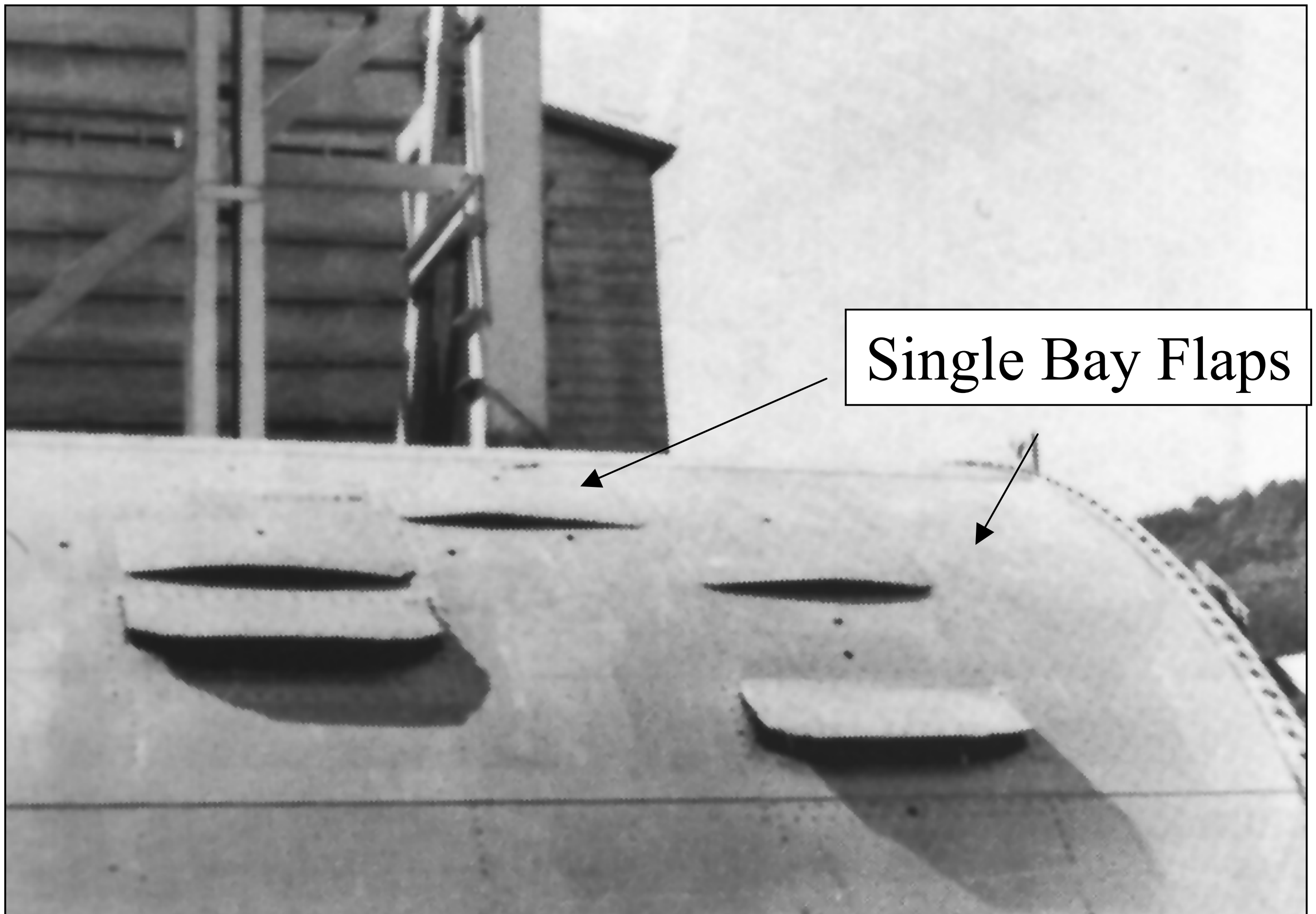
Crack Propagation is a Problem of National Significance

An aging (>40 years old) military aircraft dies…

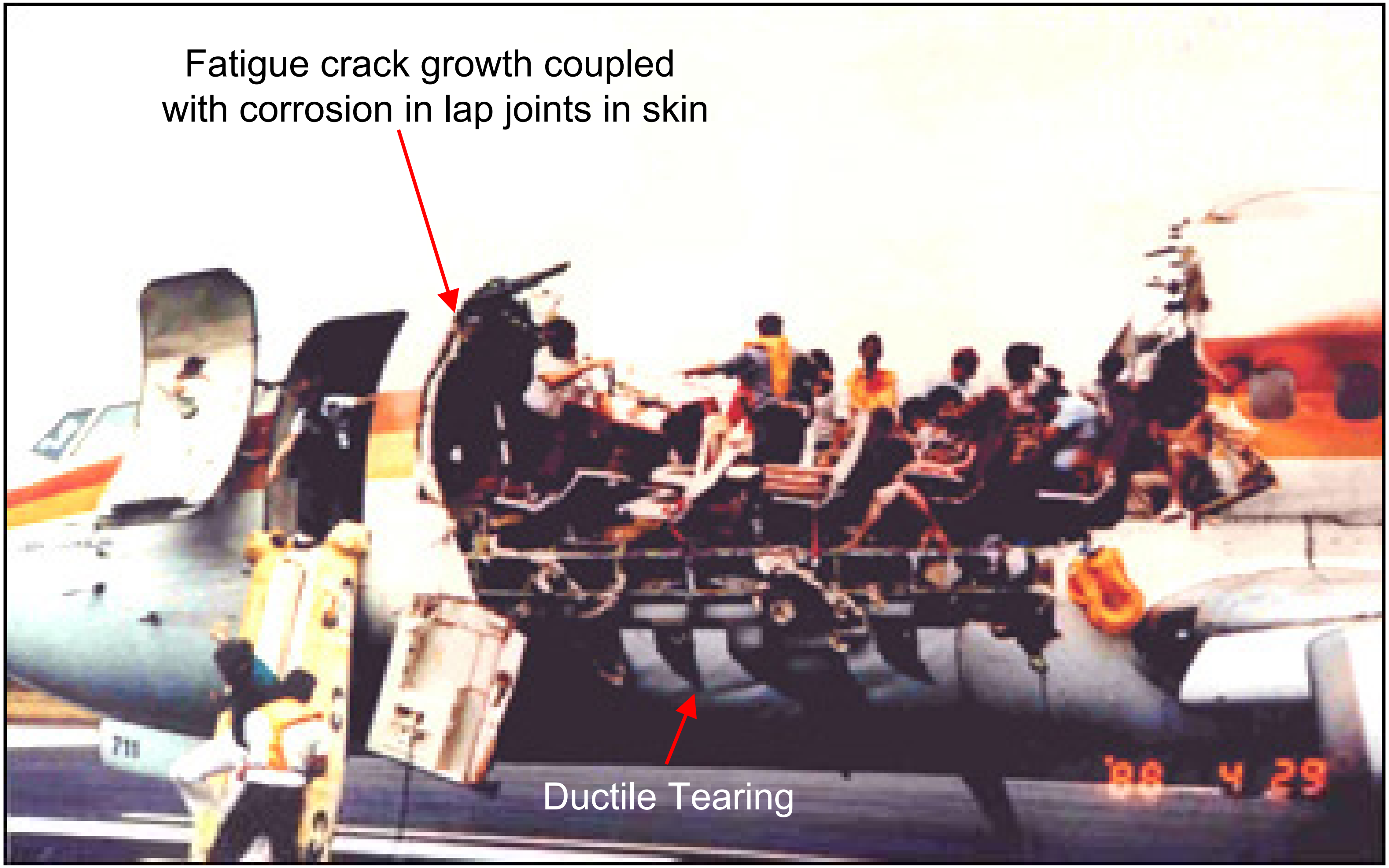
Predicted Curvilinear Fatigue Crack Growth: Adaptive Remeshing for Shell FEM



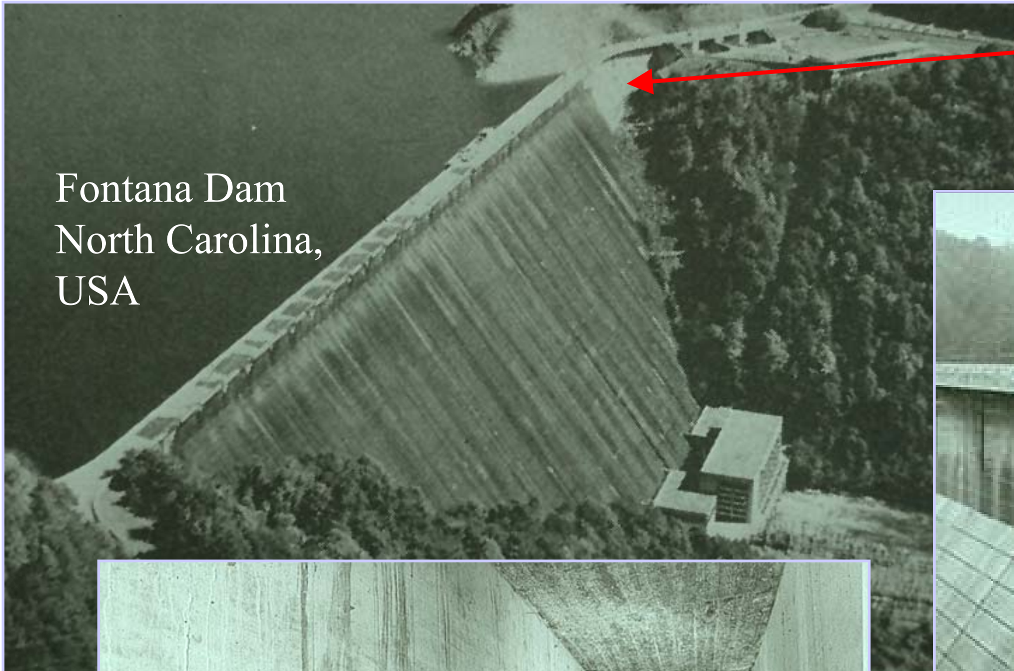
Early Damage Tolerance Testing on B-707 Fuselage

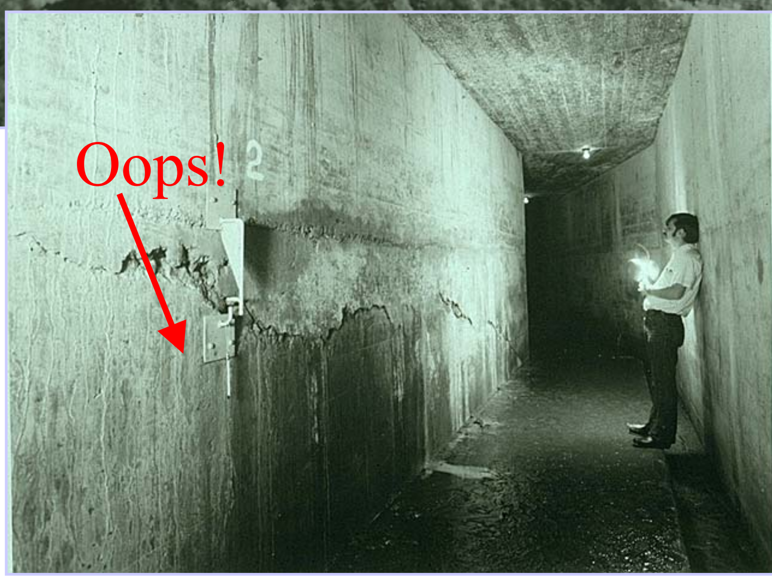


An aging (>21 years old) civilian aircraft kills…

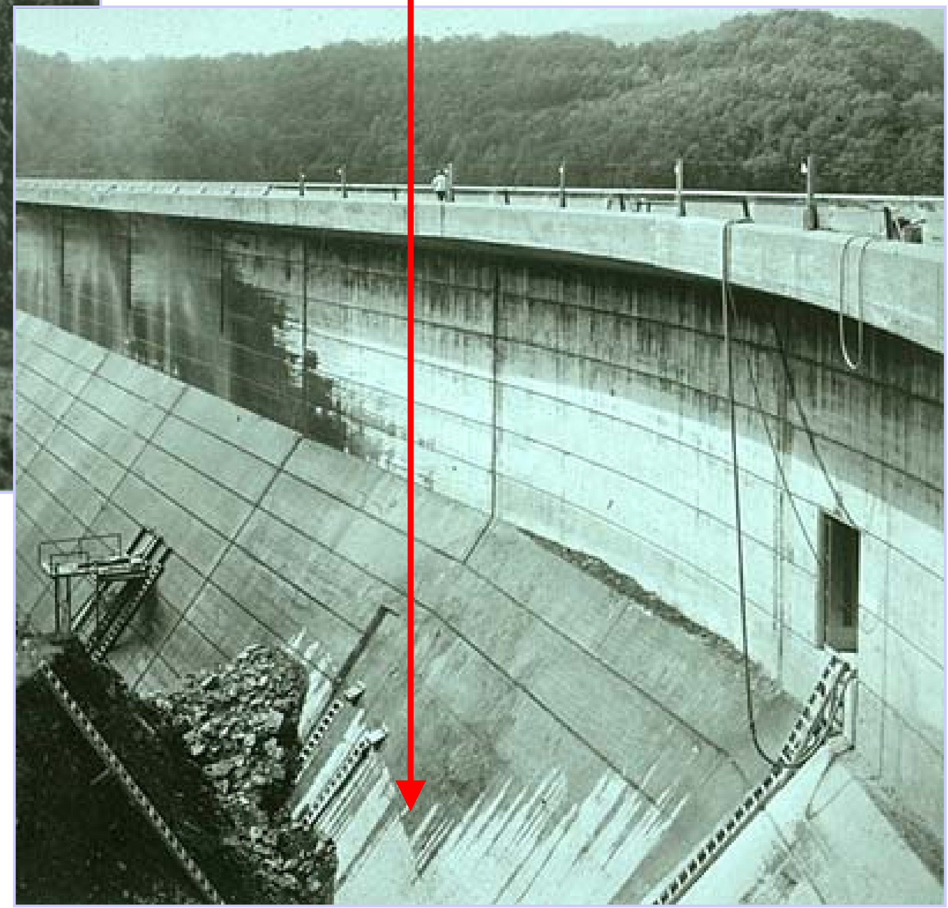


Aging Dams are Cracking

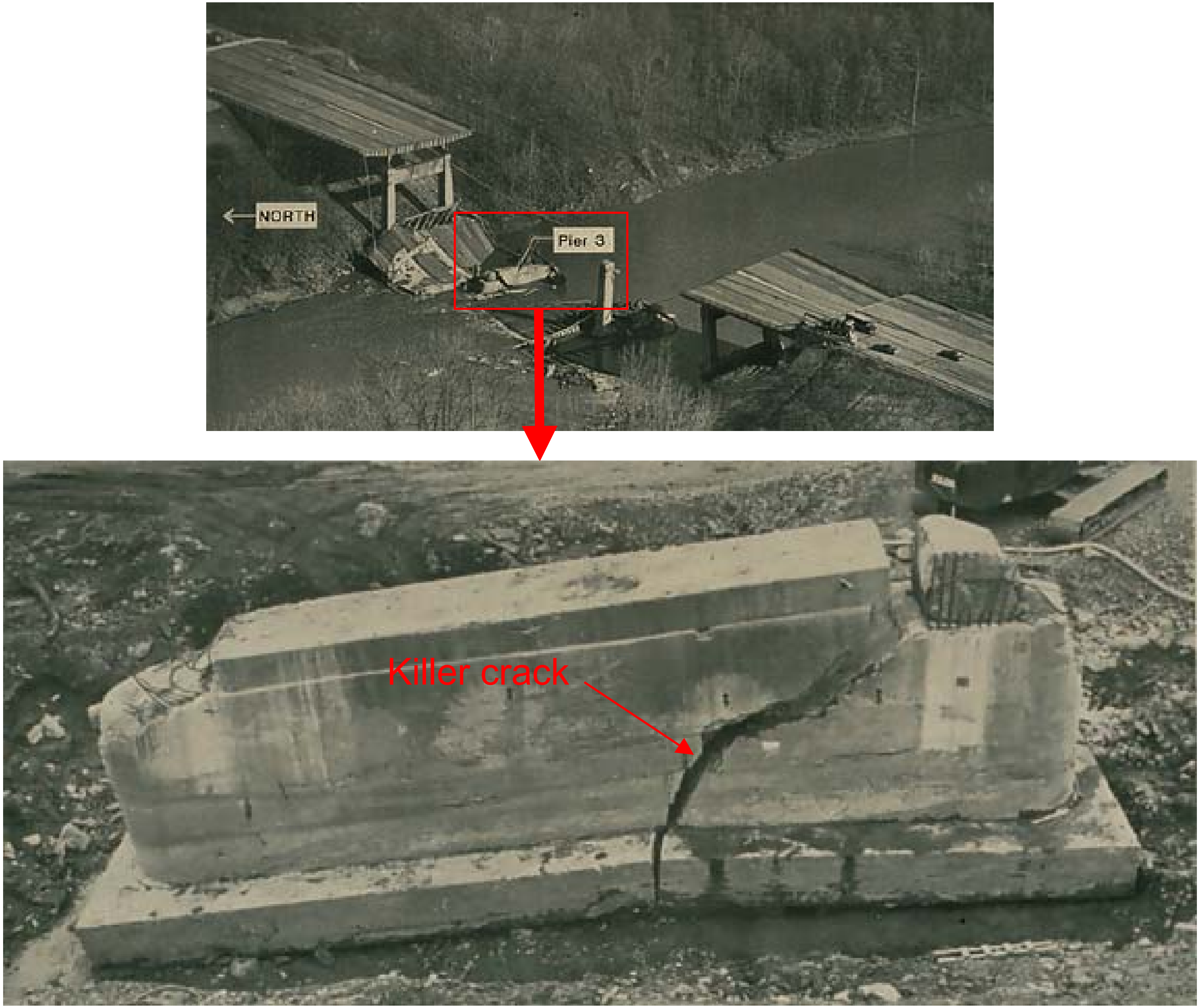




Crack on downstream face of a gravity dam?

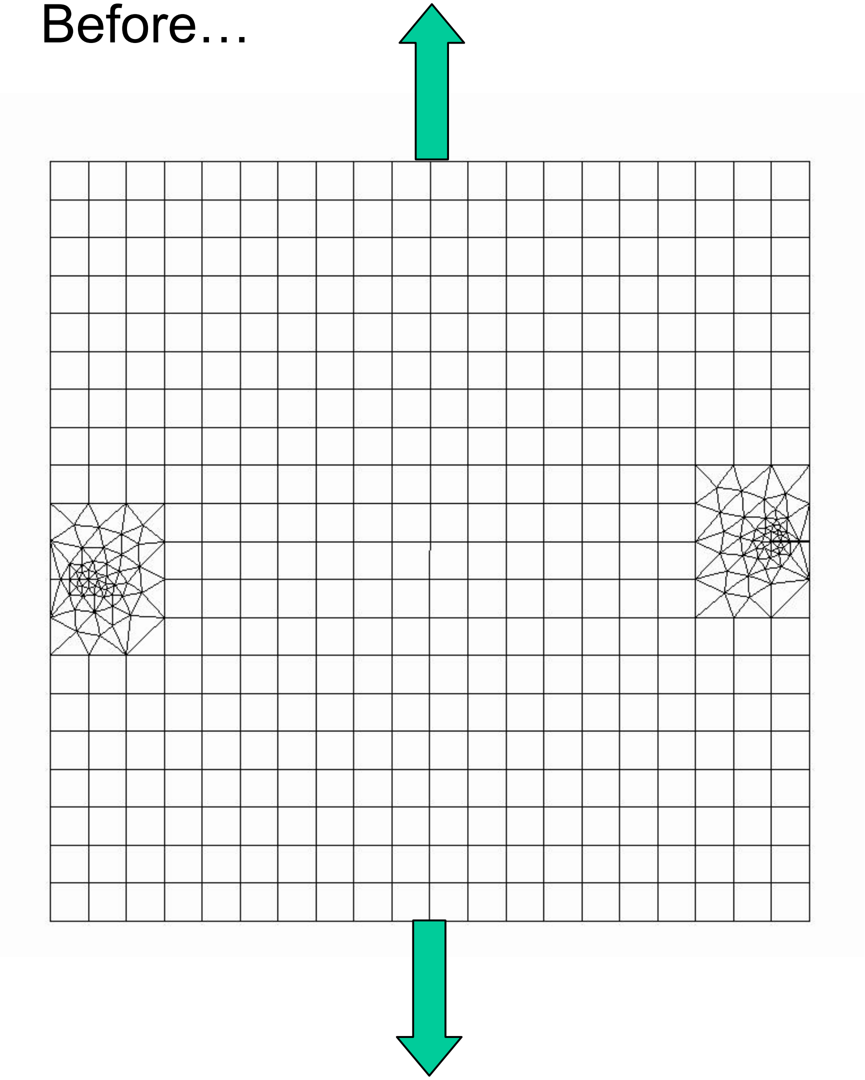


NY State Thruway, I90, Bridge Collapse

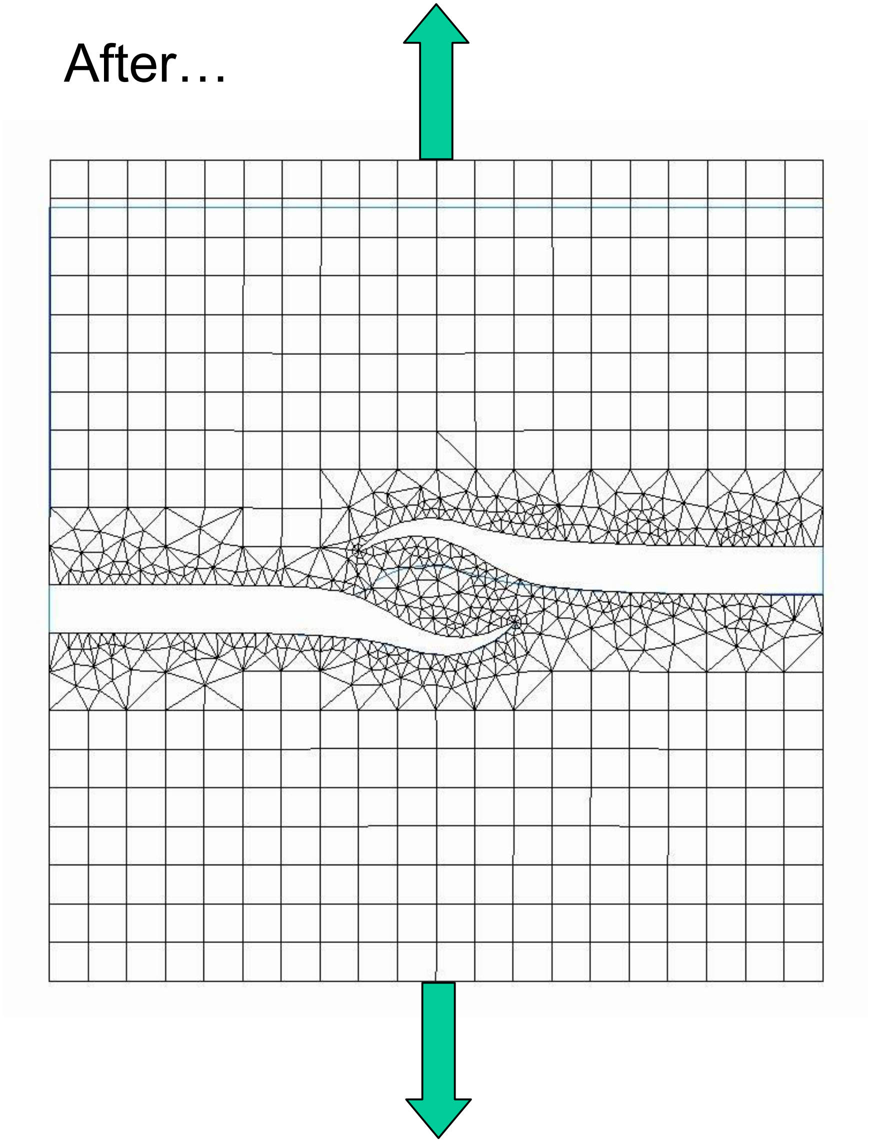

NORTH
Pier 3
Killer crack

Let's Dissect The Meshing Process with a Simple 2D Problem

Before…



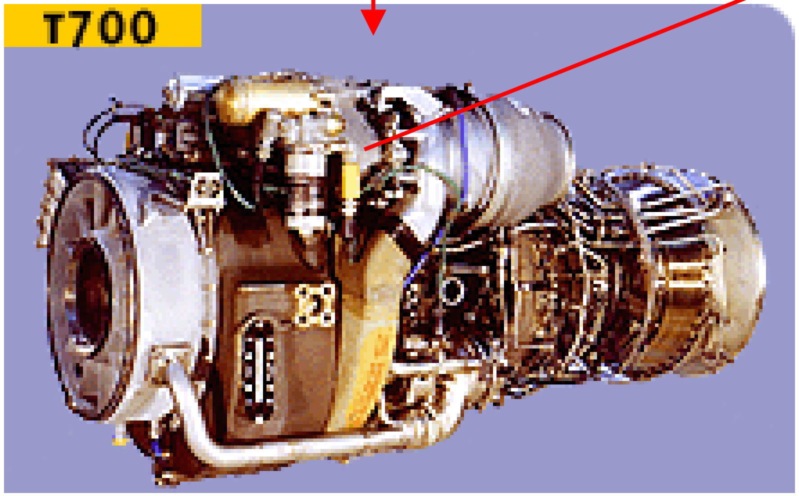
After…

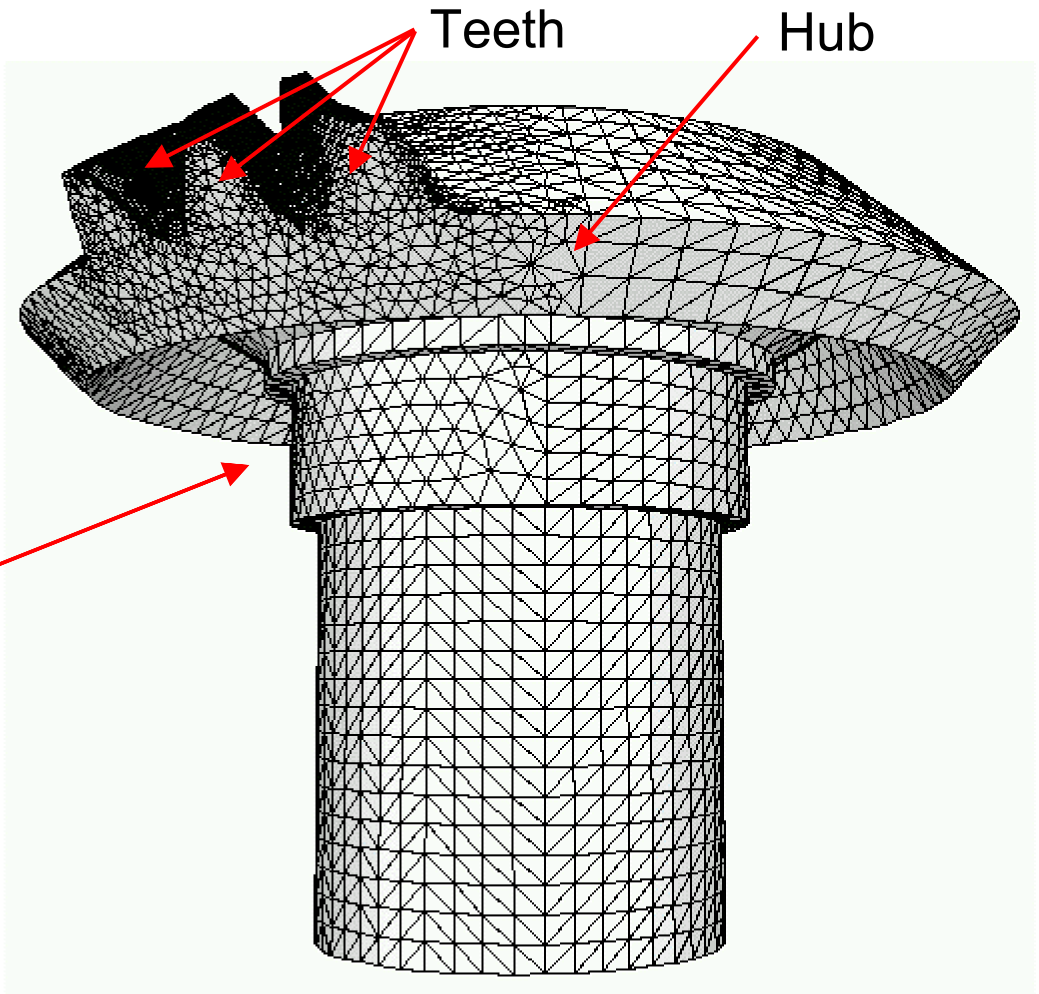


Requirements for an Advancing-Front-Based 3D Mesher for Crack Problems

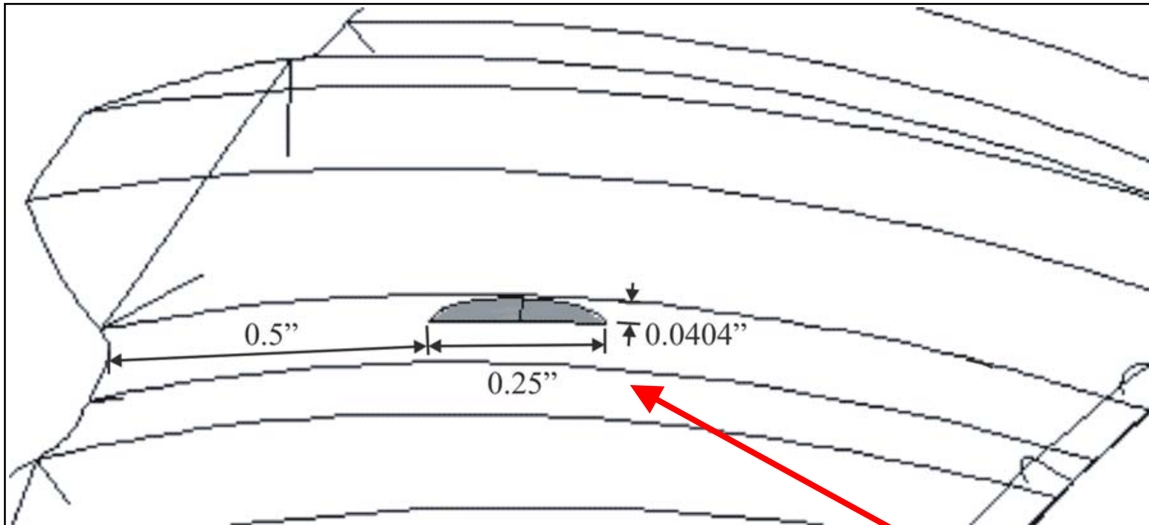
- Produce well-shaped elements
  - ✓ Of course
- Conform to an existing, triangular surface mesh on region boundary
  - ✓ Especially in small regions around extending crack front
  - ✓ Allows fast, local remeshing
  - ✓ Minimize information transfer between old and new meshes
- Transition well between regions with elements of highly varying size
  - ✓ As much as 2 orders of magnitude difference in crack problems
- Accommodate geometrically coincident, arbitrarily shaped crack surfaces
  - ✓ Discriminate between nodes on opposite crack faces

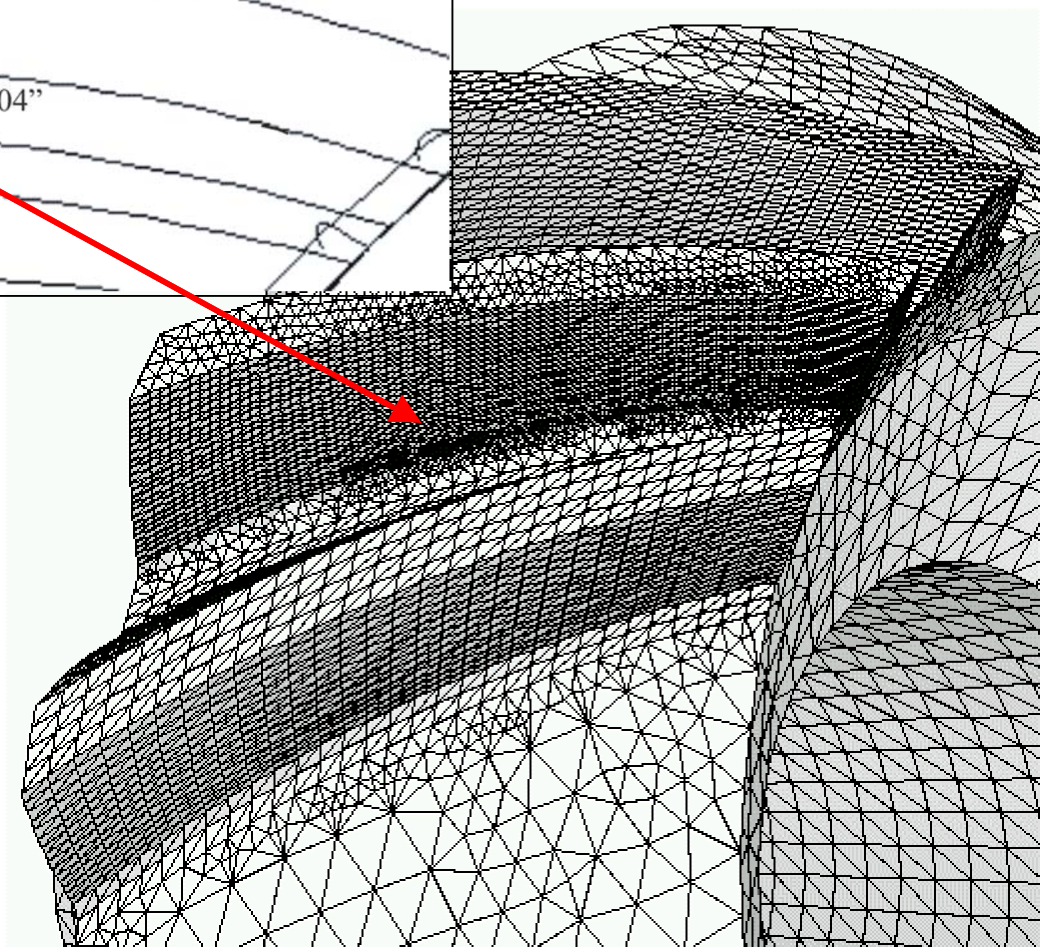
Mesh Model of SH 60 Seahawk Power Transmission Spiral Bevel Gear





Initial Flaw Size and Location



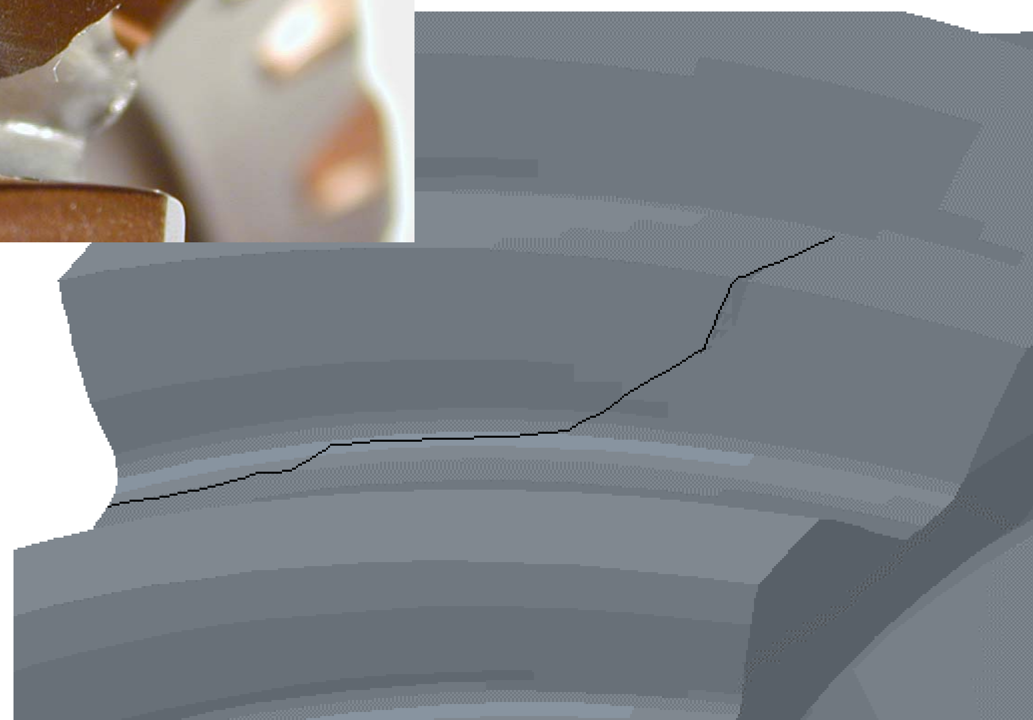


Problem Demands

ELEMENTS	214,000 - 327,000
DOF	920,000 - 1,400,000

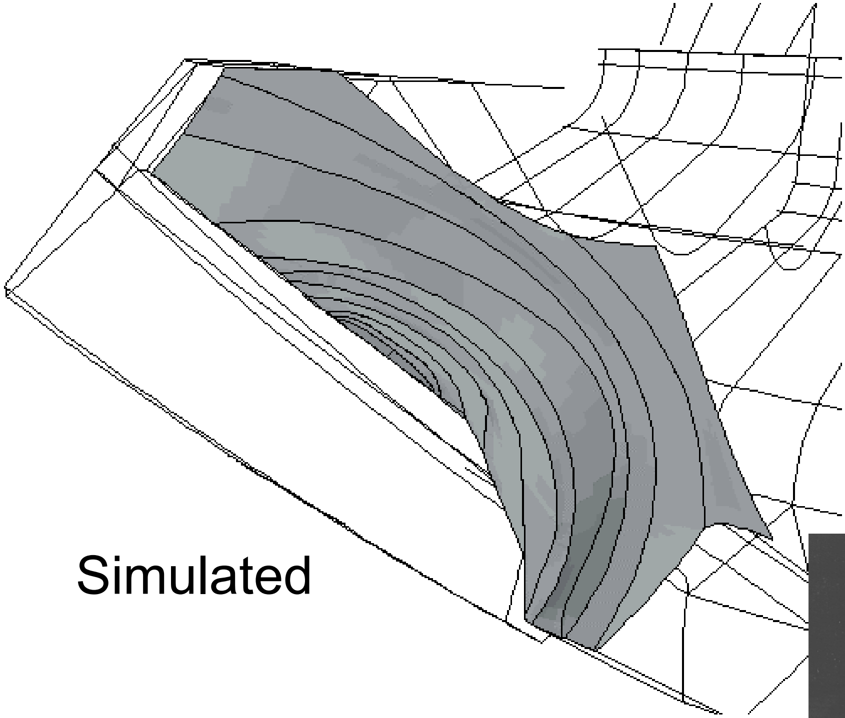
Comparison: Simulated versus Observed

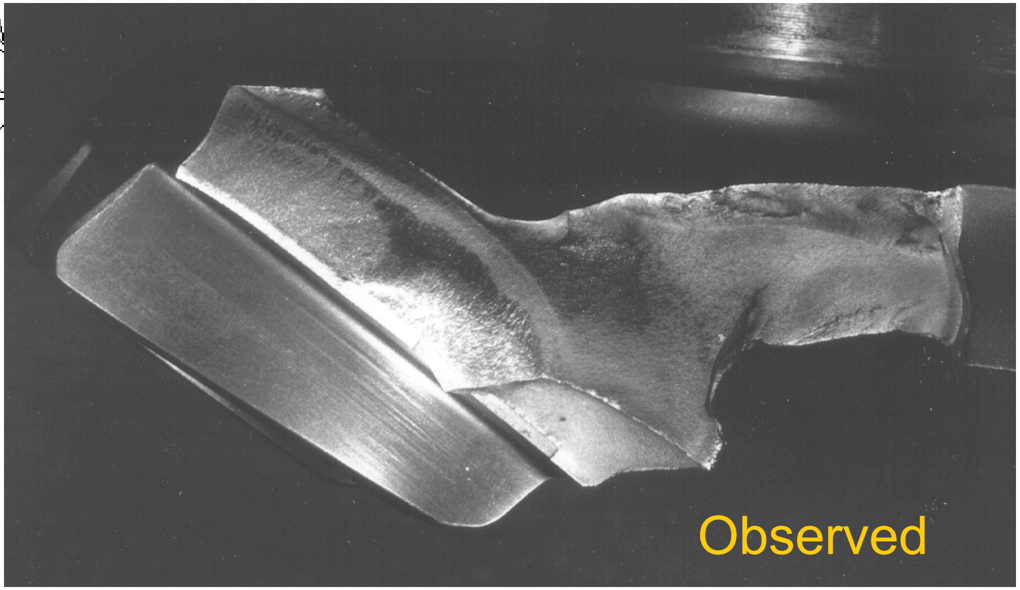
Simulated



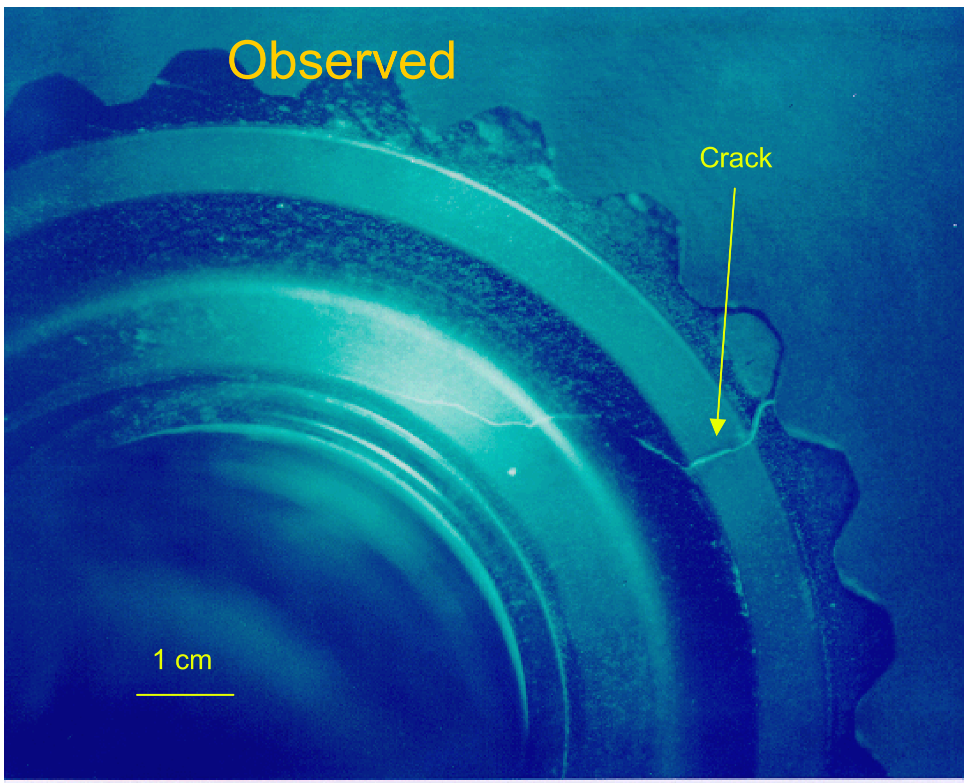
Crack Trace on the
Face of Tooth

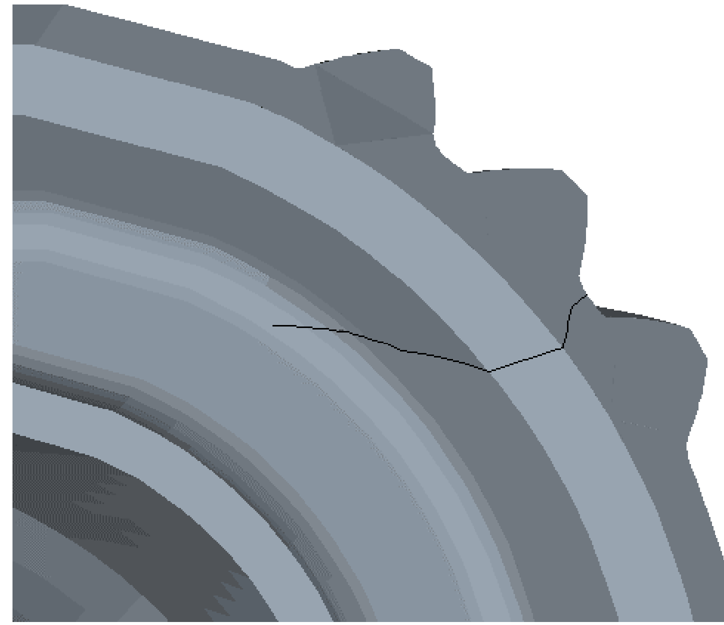
Comparison: Simulated versus Observed Fracture Surfaces





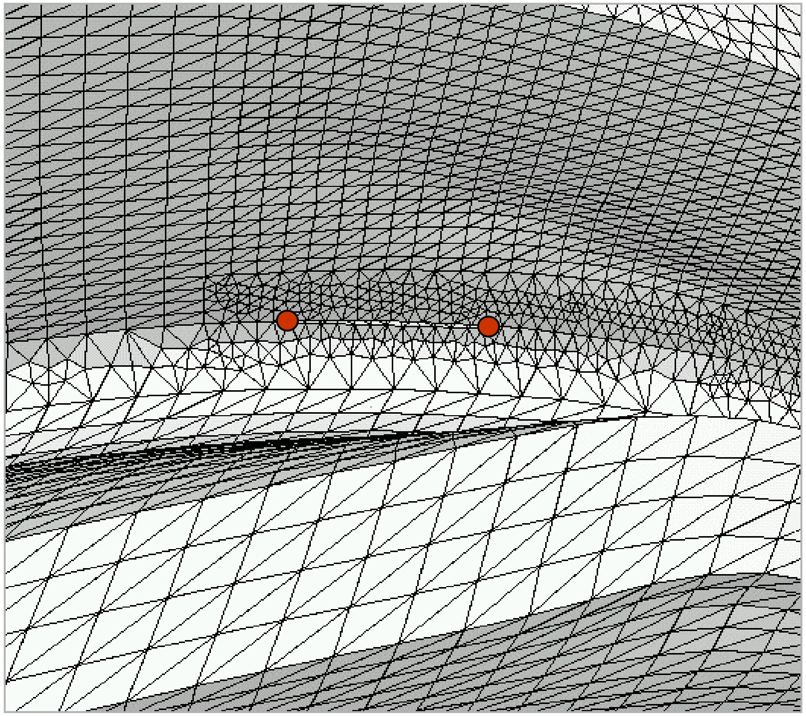
Comparison: Simulated versus Observed Crack Trace on Gear Hub





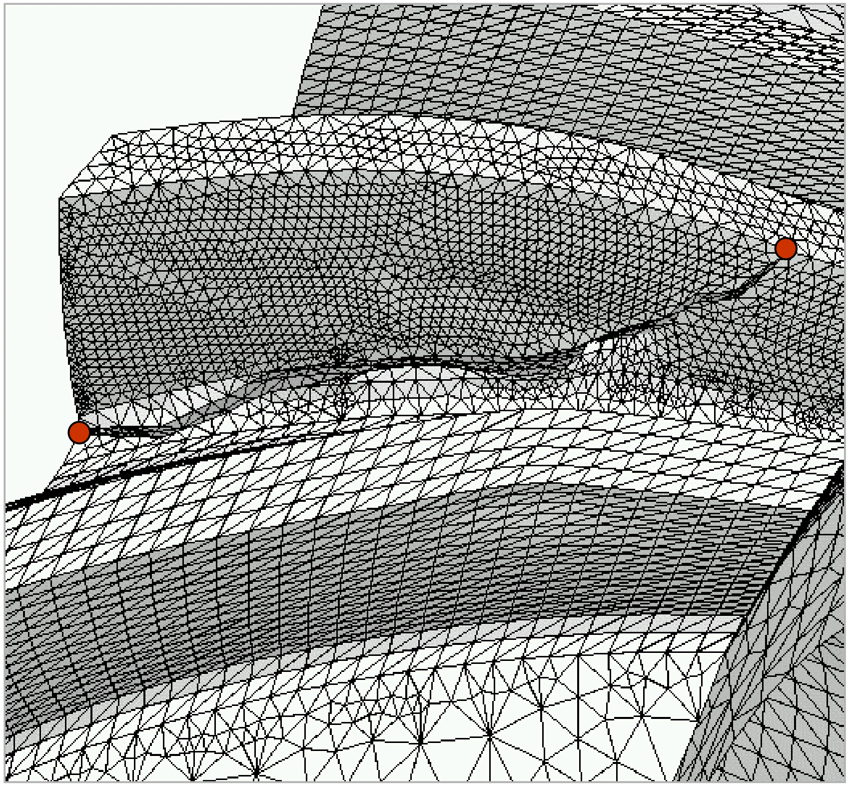
Simulated

Mesh Detail on Tooth Surface

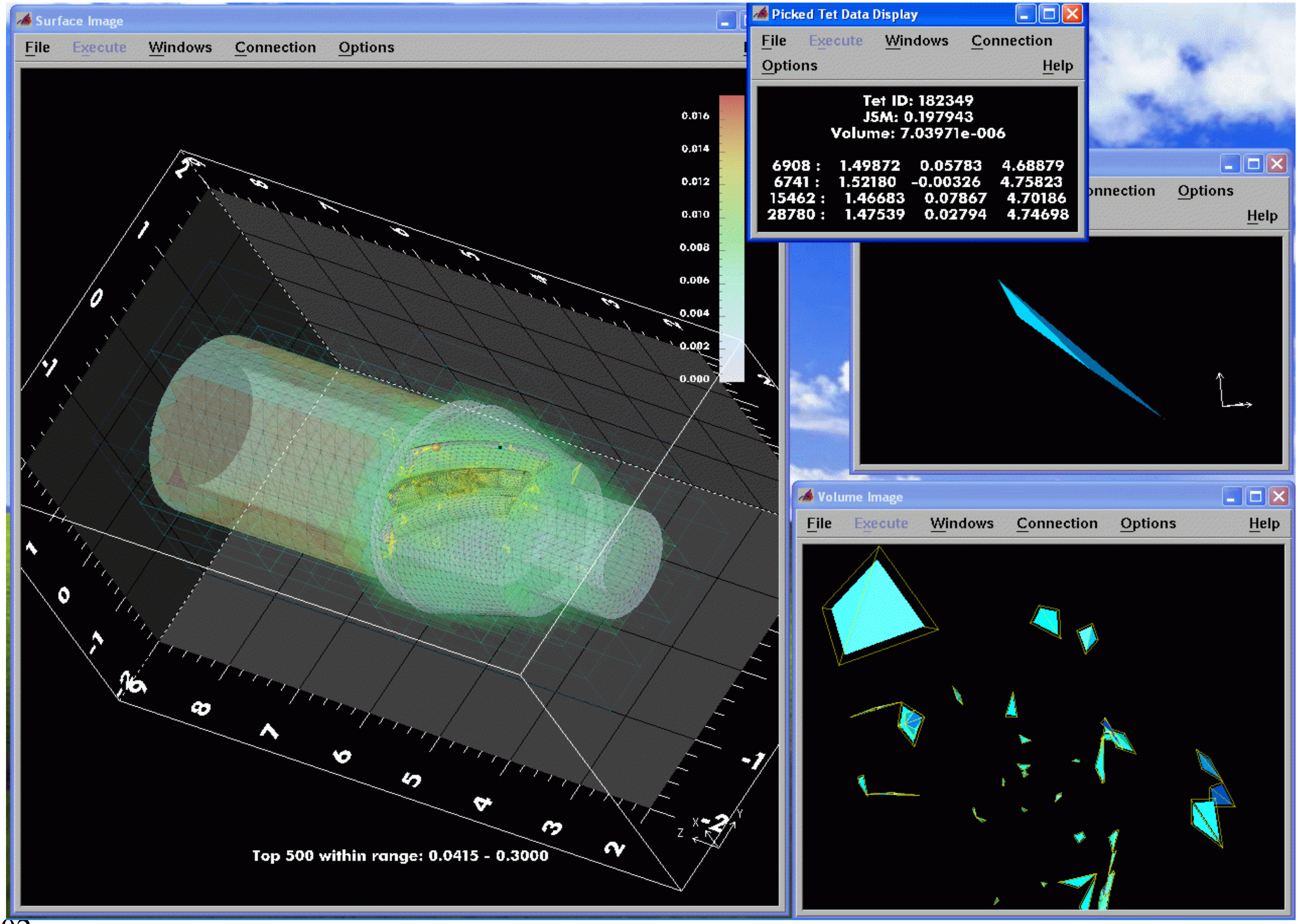


Initial Flaw/Mesh

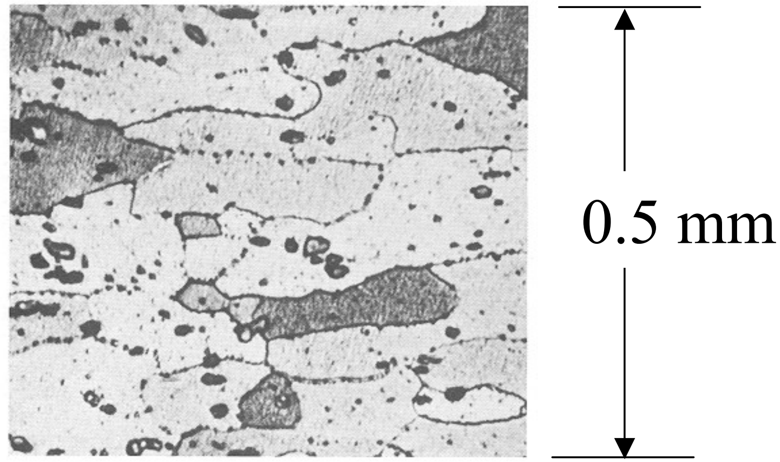
Later Stage of Simulation



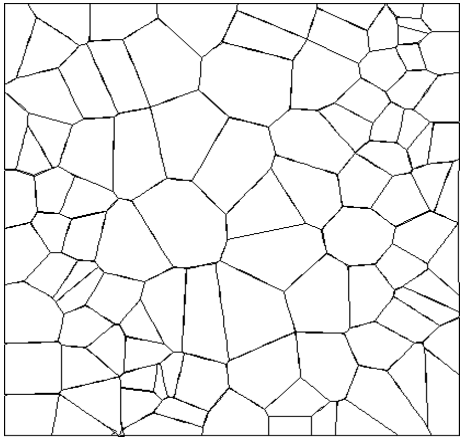
An OpenDX and SQL Server-Based Mesh Analysis Tool

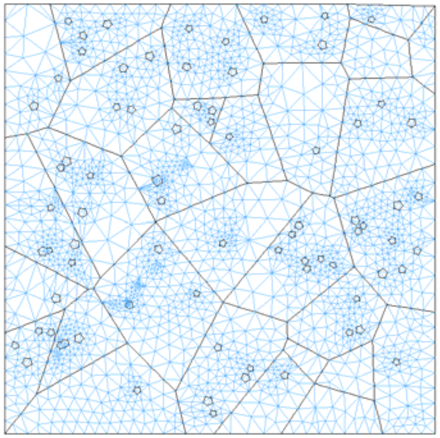


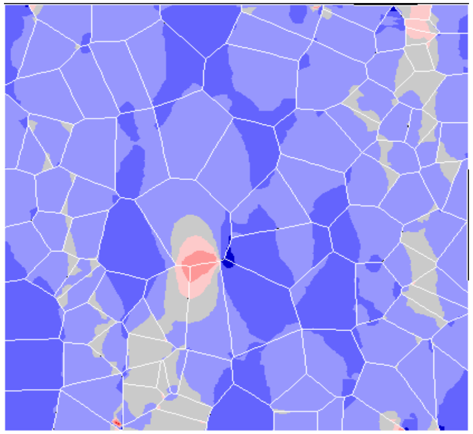
The "Nanotechnology" Revolution is Creating Interesting Meshing Demands



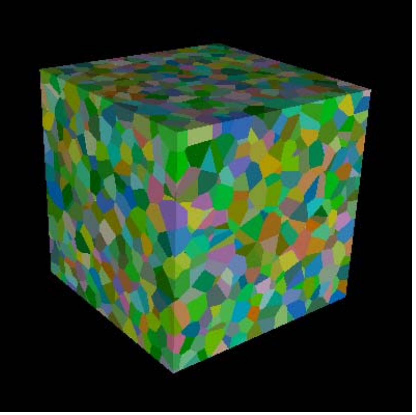
AA 2024-T3 sheet, 500X





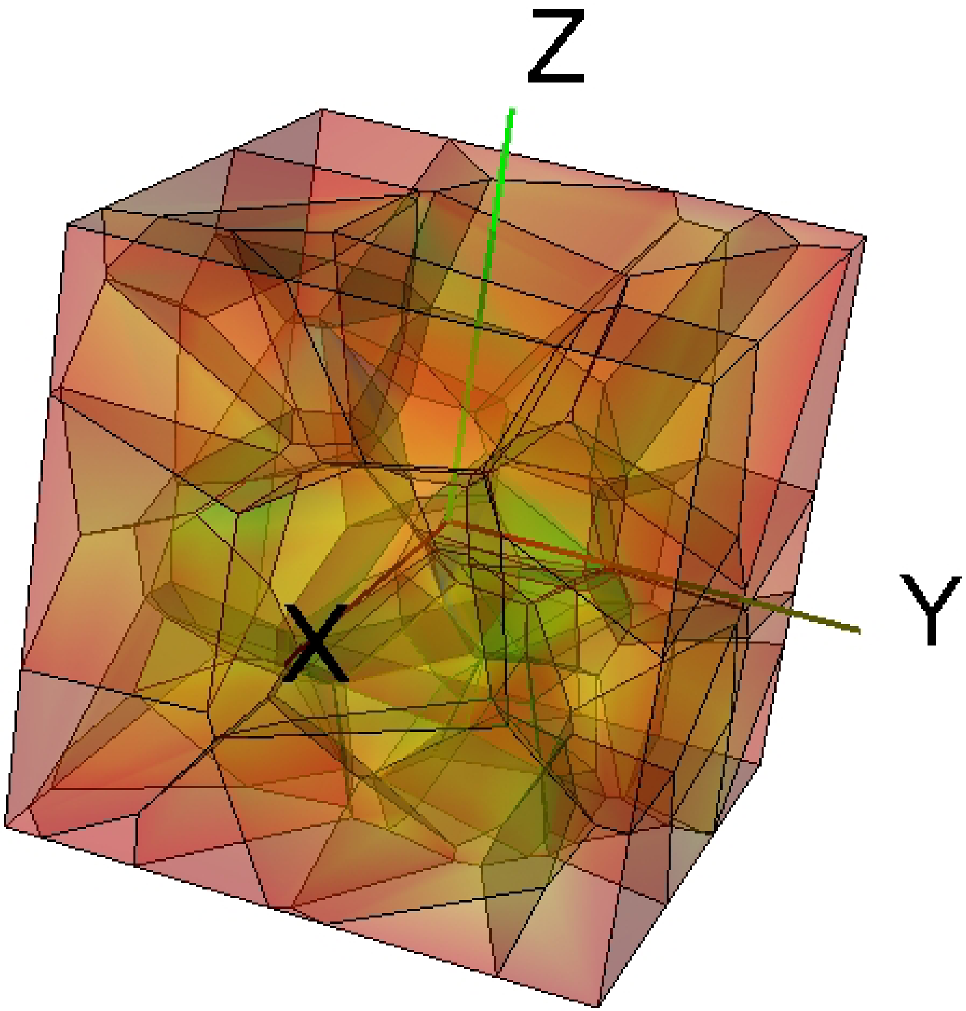


2D Representations of Crack Initiation in a Metallic Polycrystal

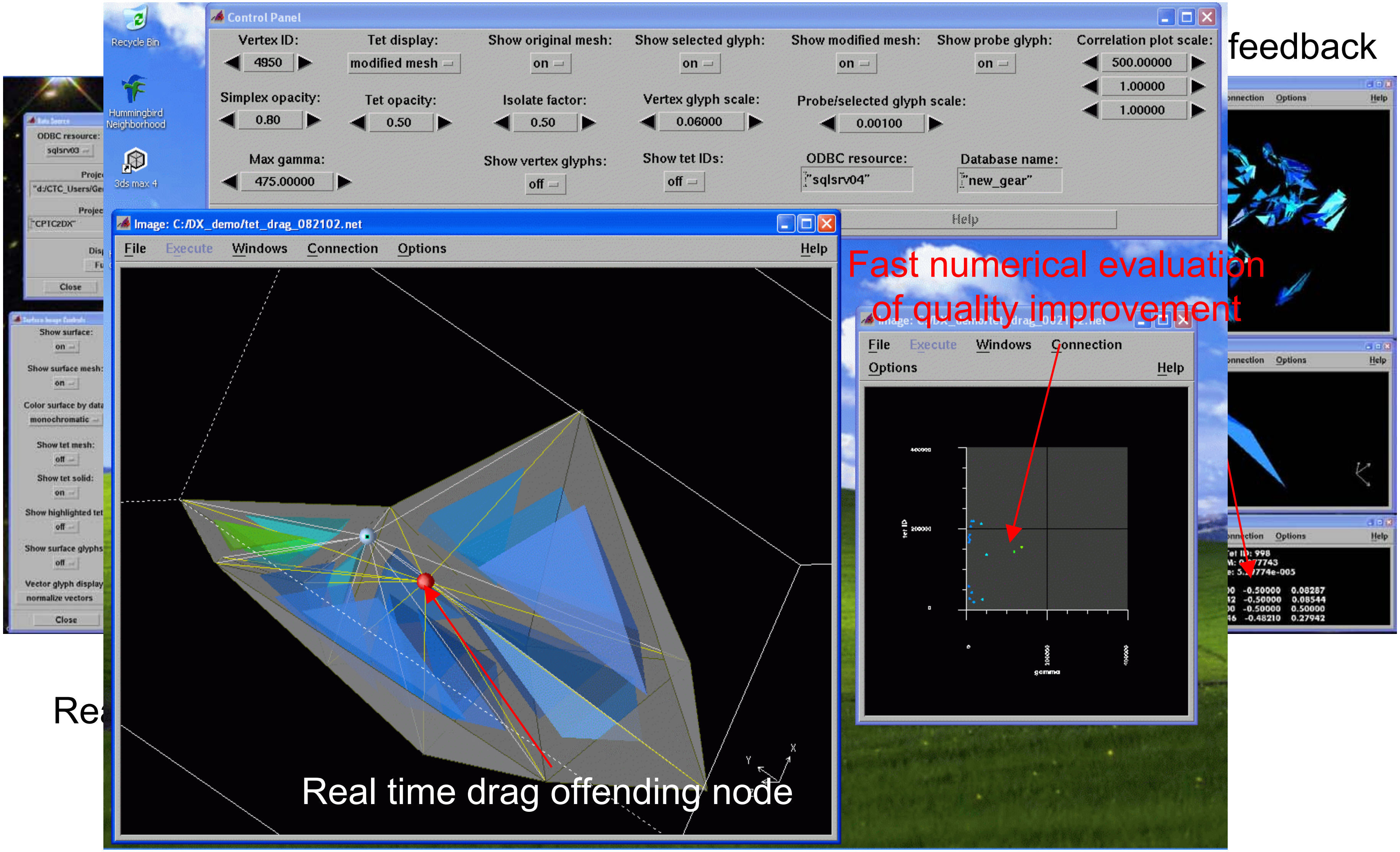


Things Get Tough in 3D

- 50 μm cube
- Only 100 Grains
- 6,271,419 DOF
- 1,519,816 10-noded tets



Mesh Analysis and Improvement Tool Even More Necessary



Problems from Without: The Meshless Methods Challenge or Is It a Revolution?

Money, interest, and PhD’s are flowing to meshless methods. Why? Can they:

- Solve problems that can’t be solved with meshed methods?
- For problems solvable with meshed methods, can meshless methods solve them:
  - More efficiently?
  - With better physics and mechanics?

Is This the BIG LIE, or ….

"…The development of a technique that does not require the generation of a mesh for complicated 3D domains is still very appealing. The problem of mesh generation is that the time remains unbounded, even using the most sophisticated mesh-generator…"

From Oñate *et al.* "Meshless Finite Element Ideas", keynote at the 5th World Conference on Computational Mechanics, Vienna, July 2002.

Sessions at 5th World Conference on Computational Mechanics on Meshless Methods: 8 Mesh Generation: 0

MPM—Material Point Method

BCM—Boundary Cloud Method

MFEM—Meshless Finite Element Method

MWLSM—Meshless Weighted Least-Squares Method

SPH—Smooth Particle Hydrodynamics

EIBM—Extended Immersed Boundary Method

FCM—Finite Cover Method

AMFDM—Adaptive Meshless Finite Difference Method

EFG—Element Free Galerkin

DPD—Dual Particle Dynamics

MFS—Method of Finite Spheres

Summary

For meshed approach with explicit representation of crack geometry:

- Work underway on guaranteed-quality, Delaunay-based, 3D, mesher, with ideal crack front features for simulation of crack propagation: DMESH
- Ditto, minus the guarantees, with an advancing-front-based approach: JMESH
- Both benefiting from a suite of quality assessment/improvement tools using a SQL Server/ OpenDX basis.

Meshfree appoaches with/out explicit representation of crack geometry:

- They are here, in droves!
- Are they a revolution, or just a challenge?