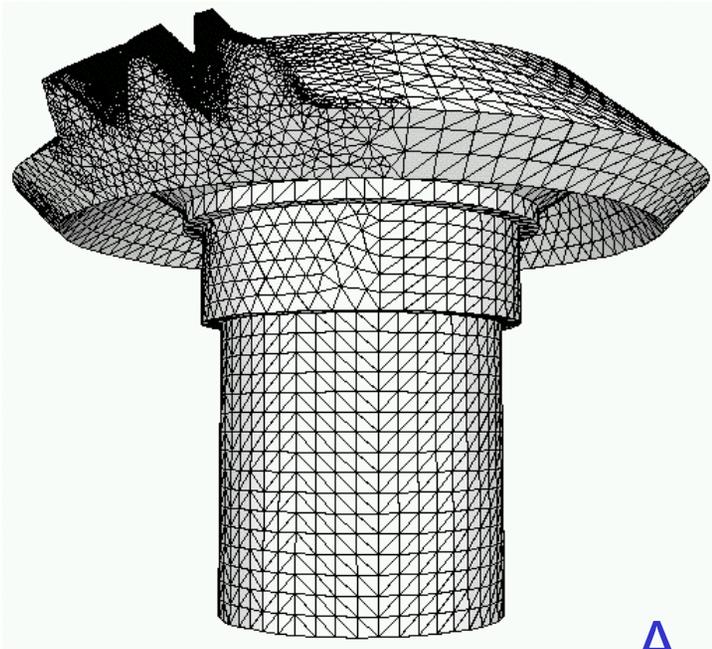


# Meshing For Crack Propagation Simulation: Problems....

... 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

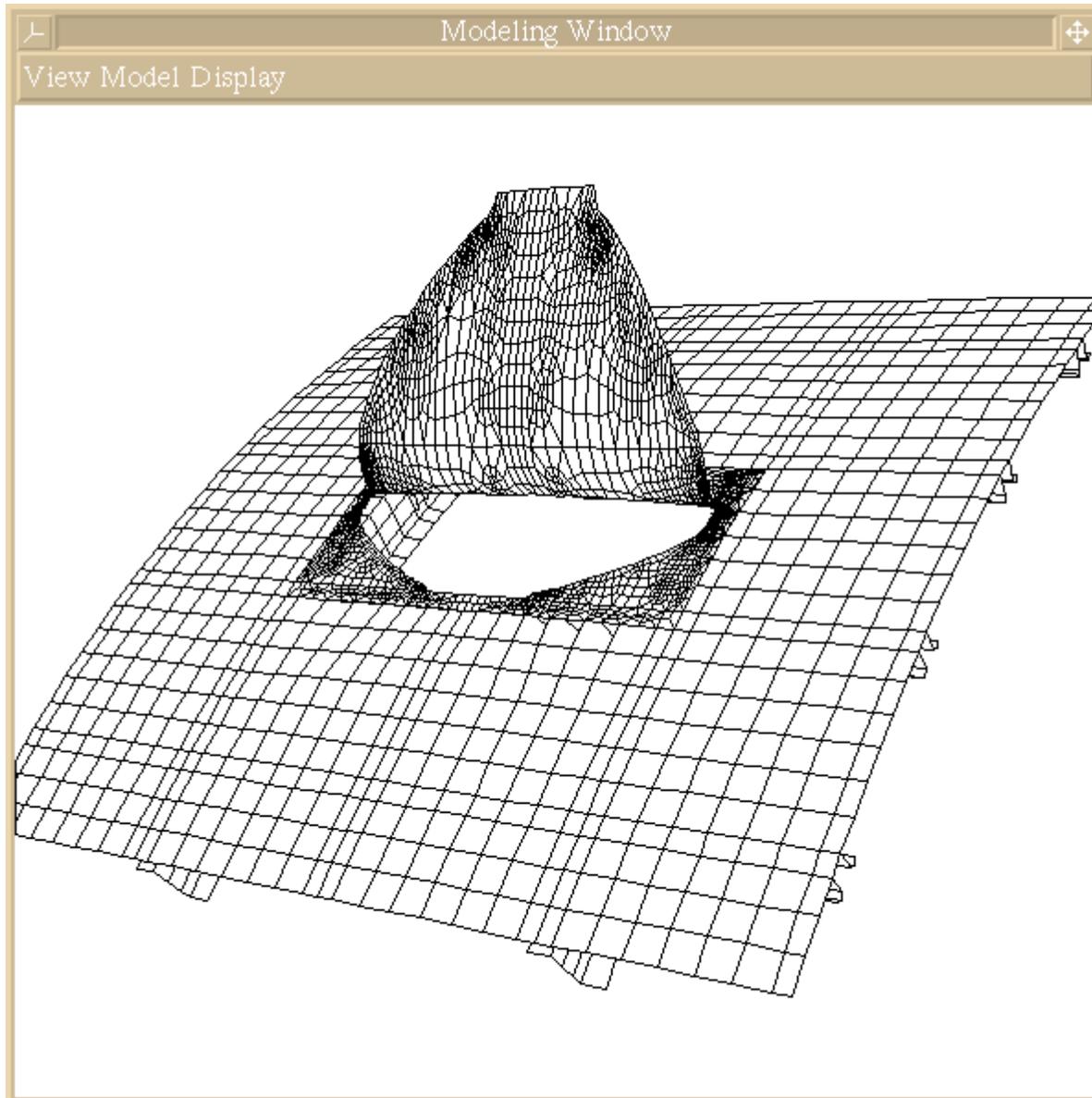
- The crack propagation problem:  
Definitely evolutionary geometry, but  
need it be evolutionary meshing?
- The problem within: examples of current simulation capability.  
And shortcomings.
- The problem without:  
The meshfree methods are here, and more coming!  
Are they just a challenge, or a revolution?

# Crack Propagation is a Problem of National Significance

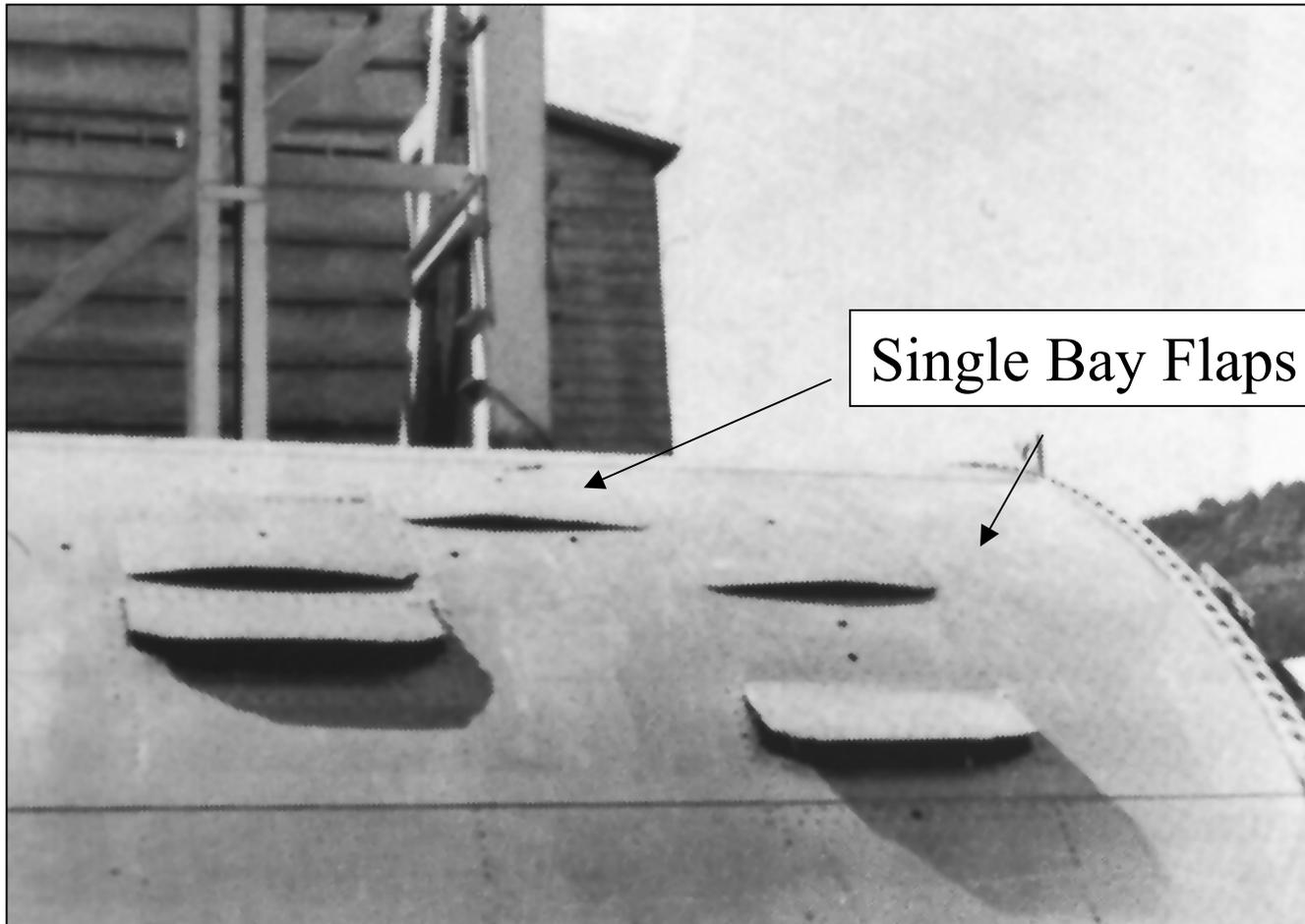


An aging (>40 years old) military aircraft dies...

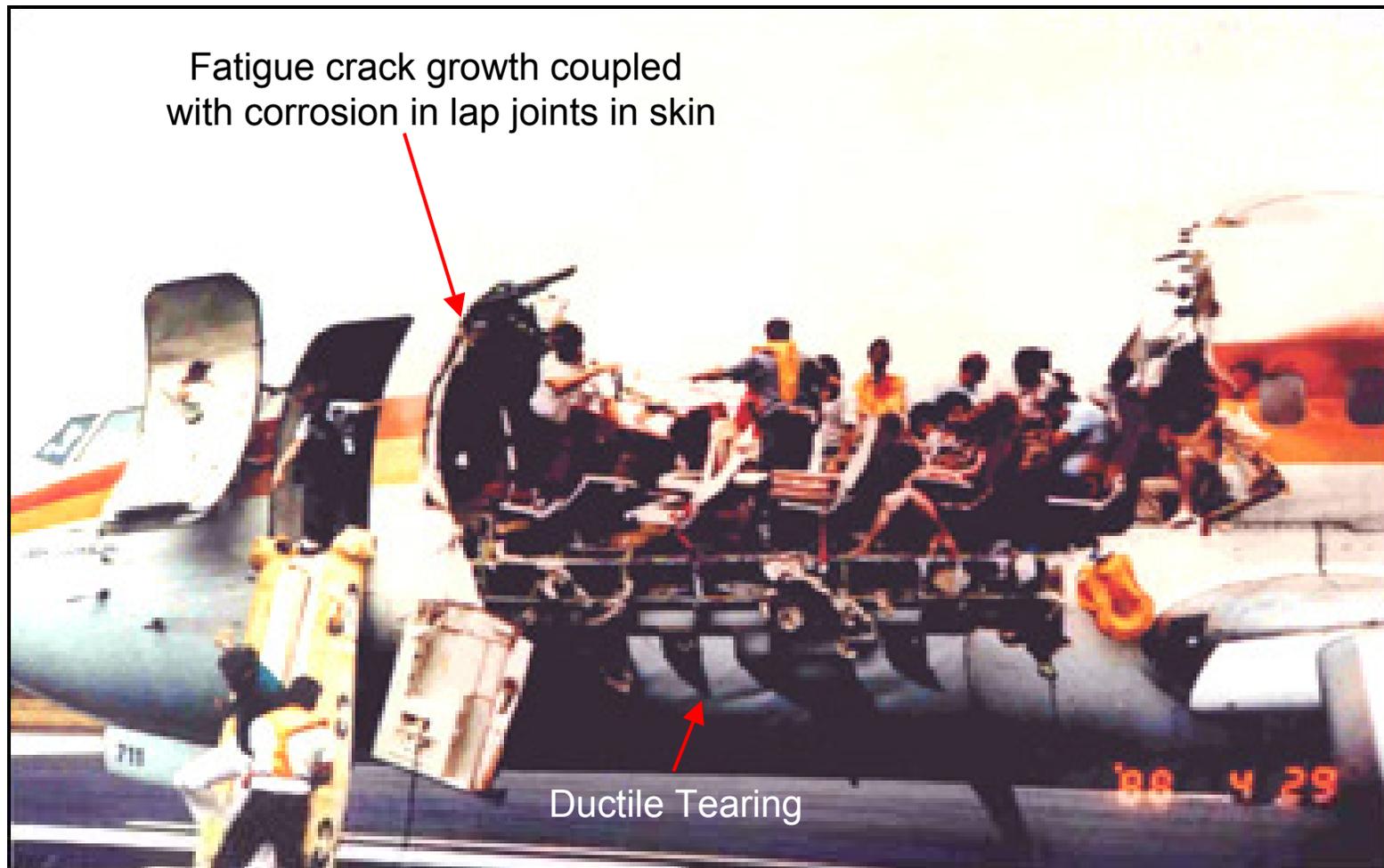
# Predicted Curvilinear Fatigue Crack Growth: Adaptive Remeshing for Shell FEM



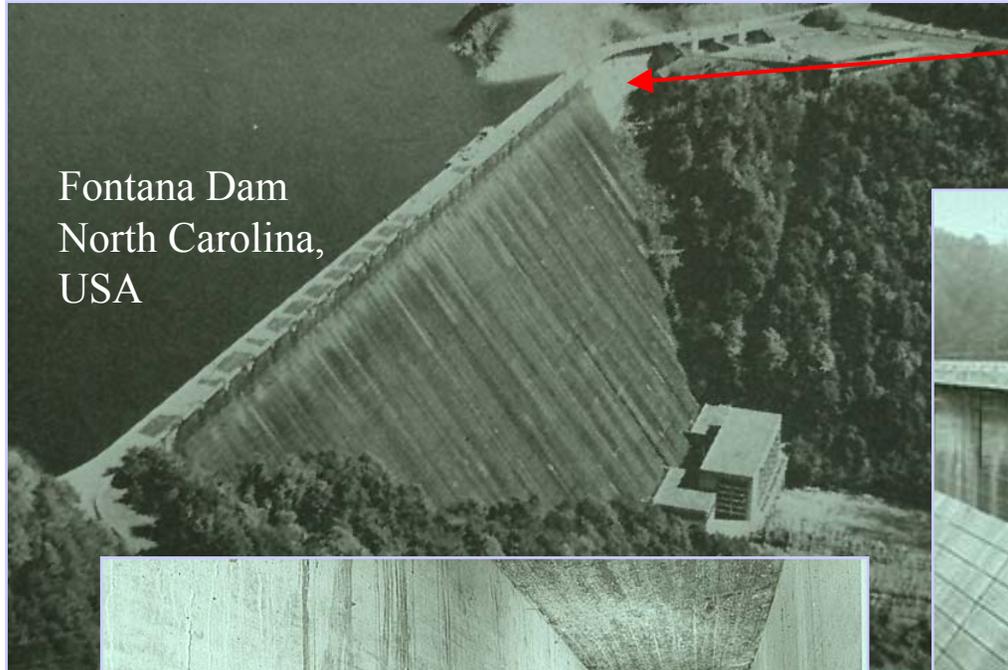
# Early Damage Tolerance Testing on B-707 Fuselage



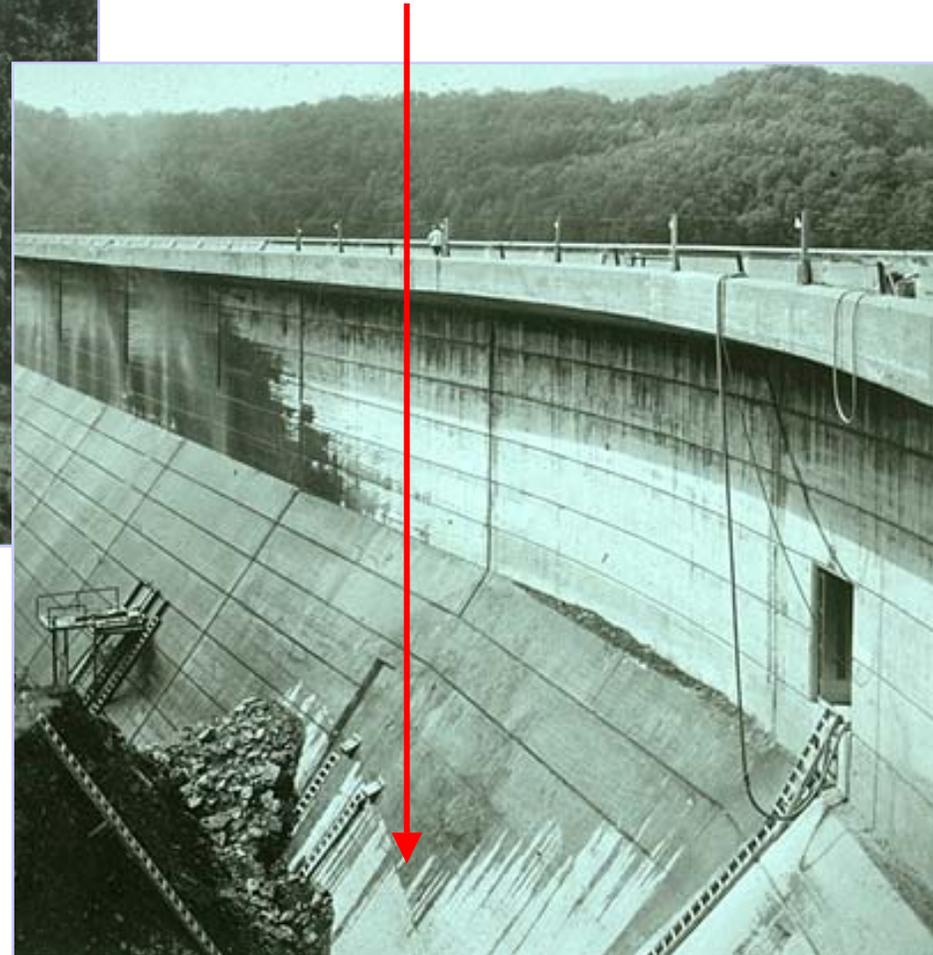
# An aging (>21 years old) civilian aircraft kills...



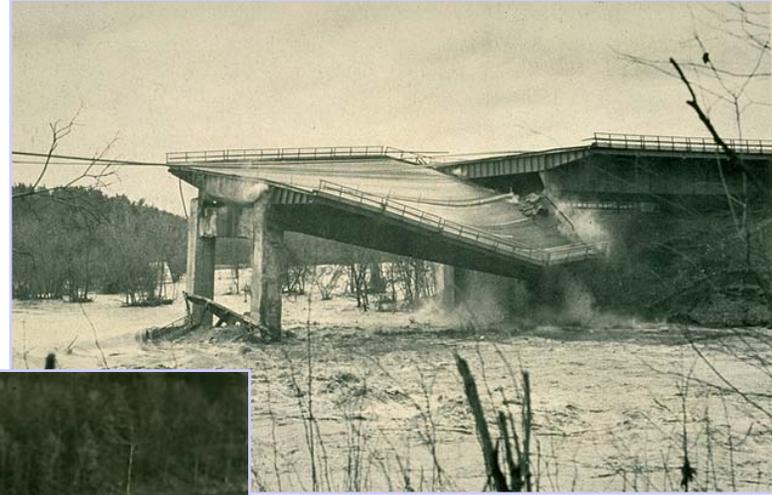
# Aging Dams are Cracking



Crack on downstream face  
of a gravity dam?



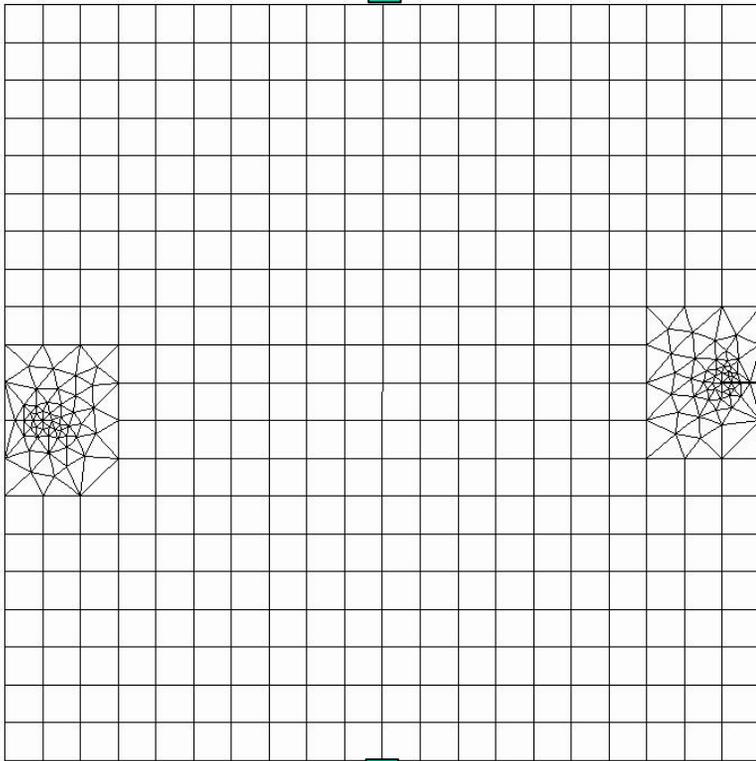
# NY State Thruway, I90, Bridge Collapse



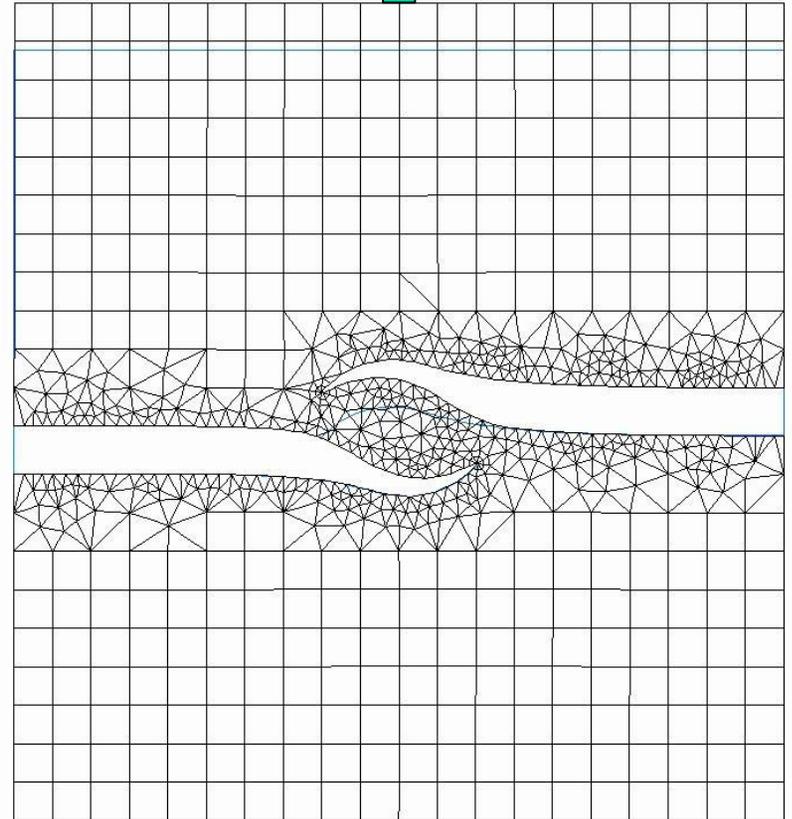


# Let's Dissect The Meshing Process with a Simple 2D Problem

Before...



After...



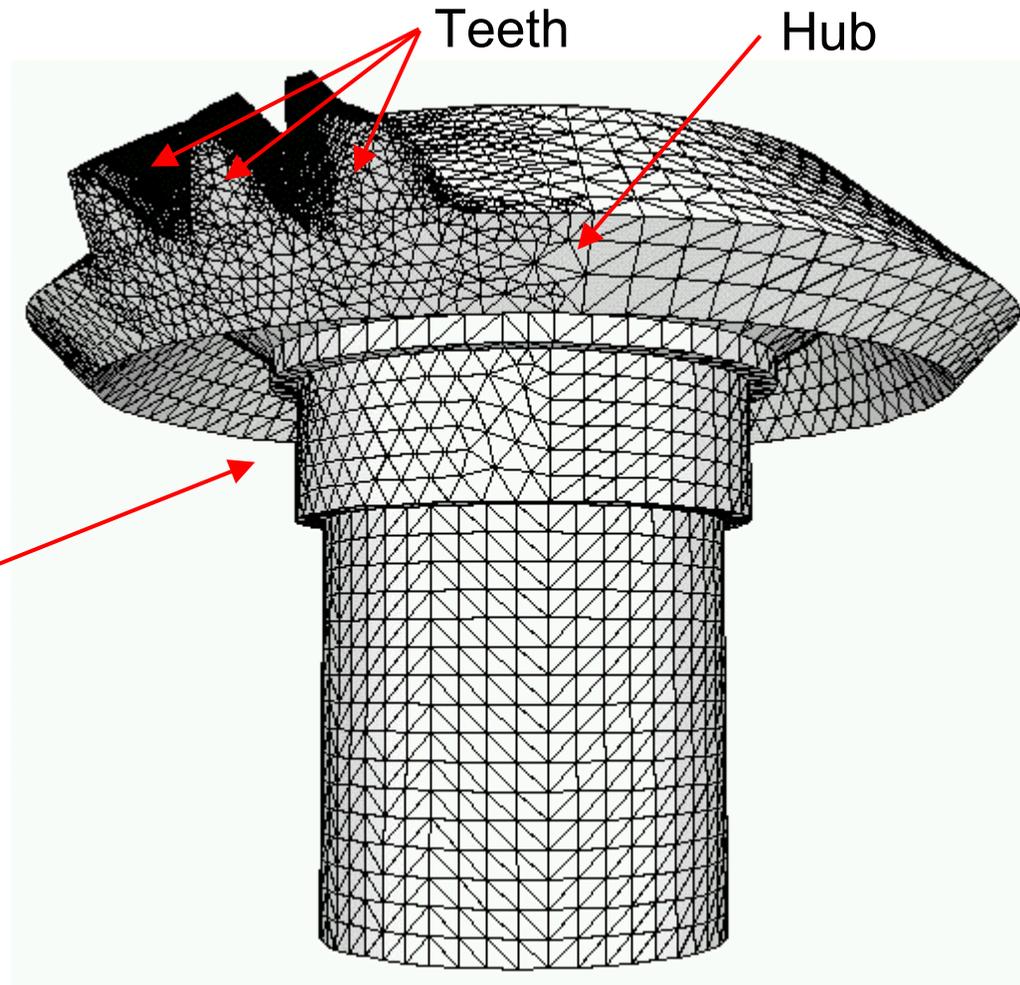
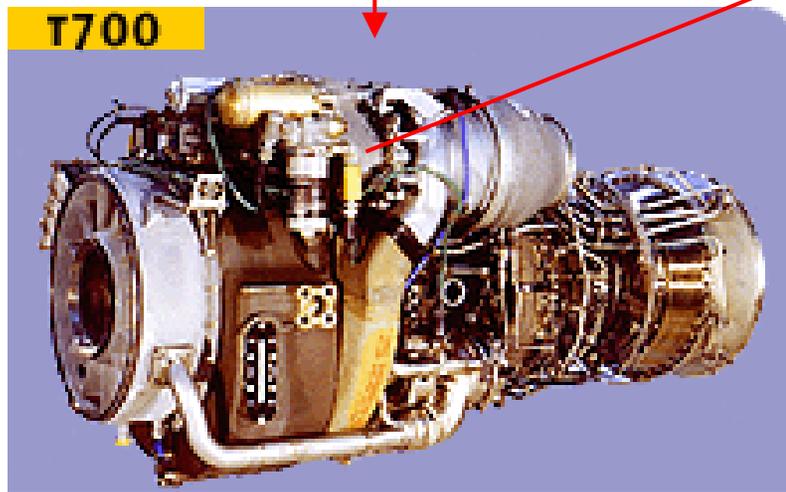
# Requirements for an Advancing-Front-Based 3D Mesher for **Crack** Problems

- 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**

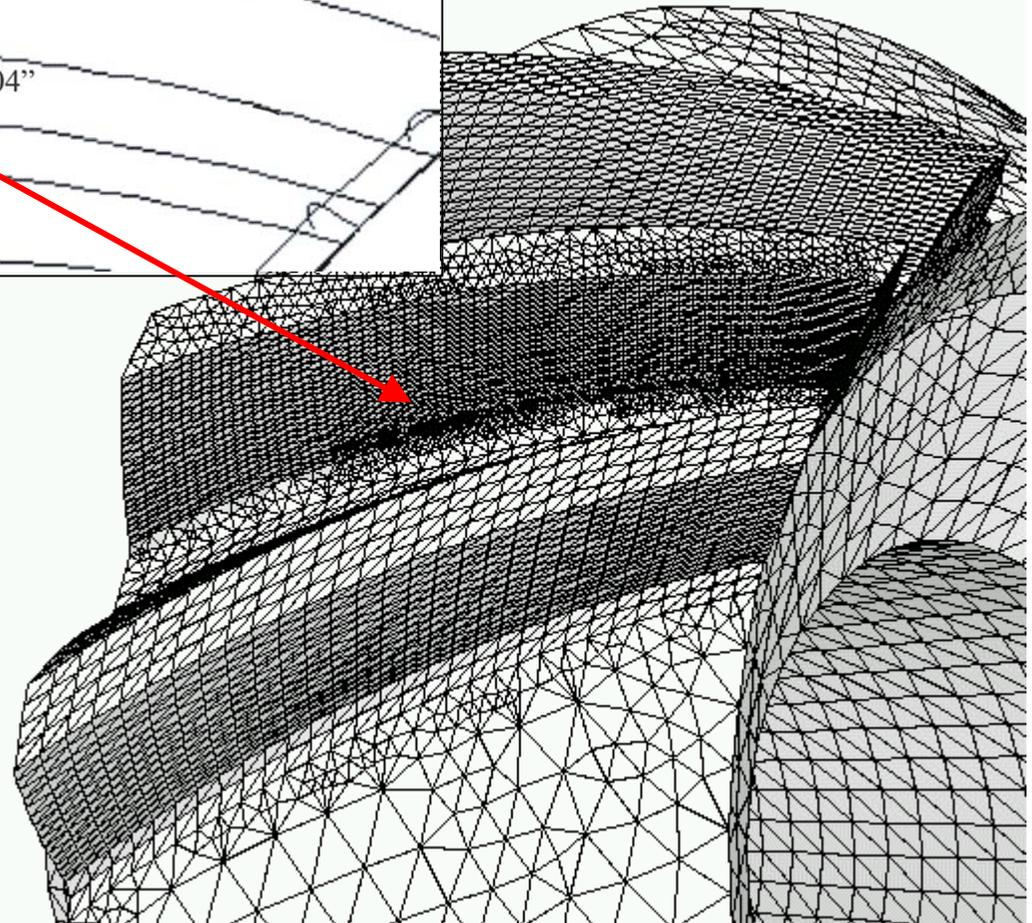
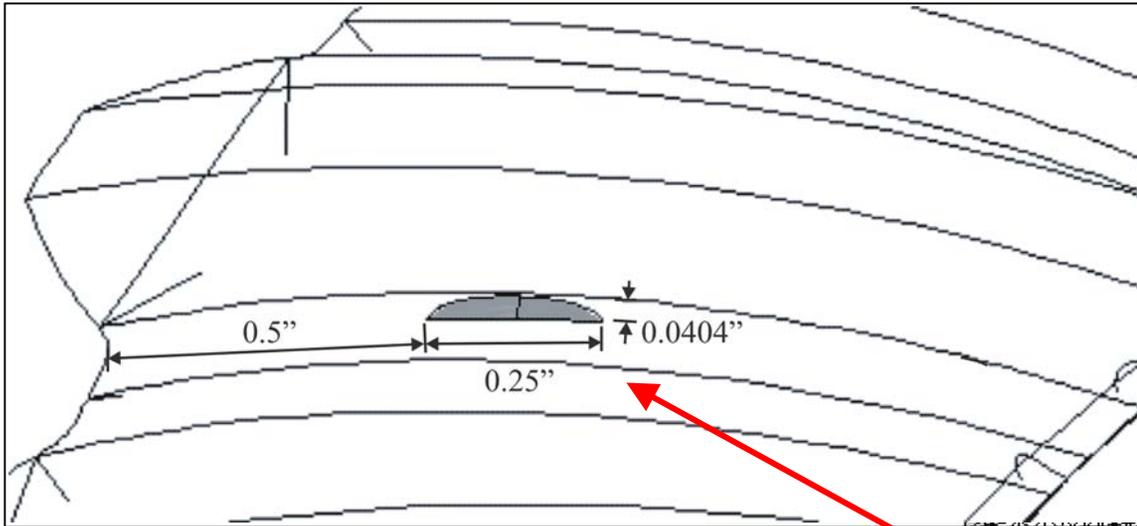
# Mesh Model of SH 60 Seahawk Power Transmission Spiral Bevel Gear



**T700**



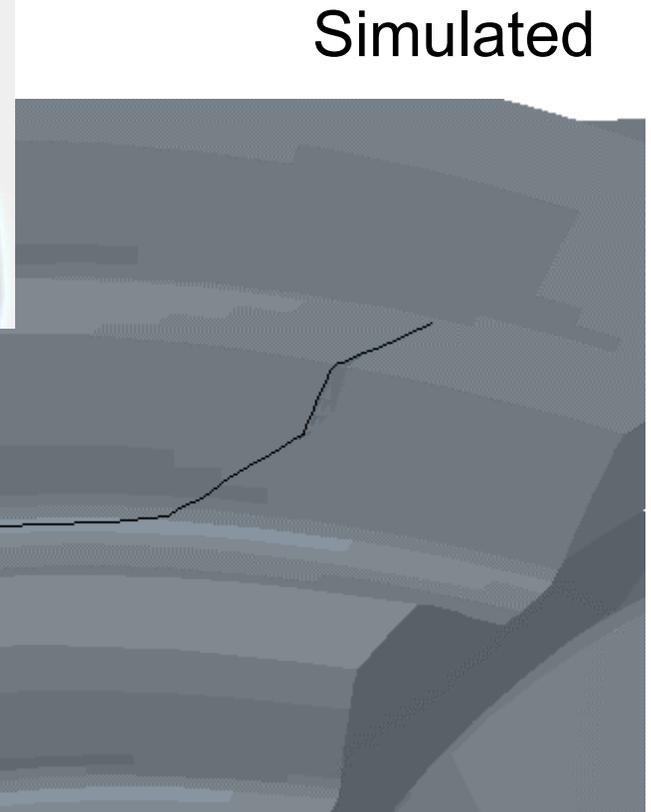
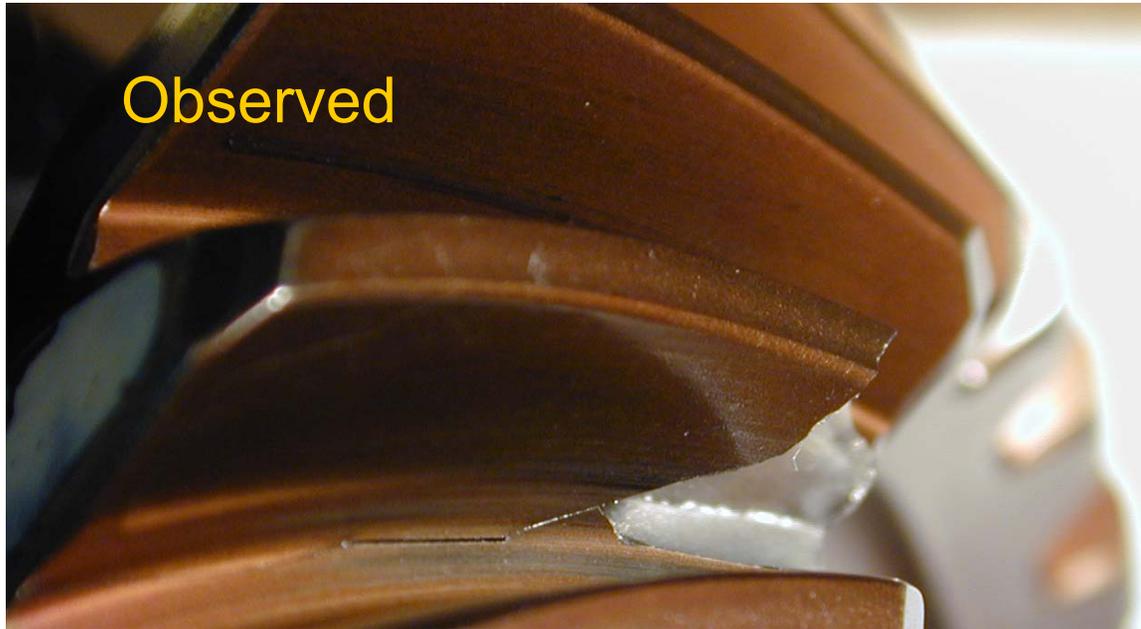
# Initial Flaw Size and Location



## Problem Demands

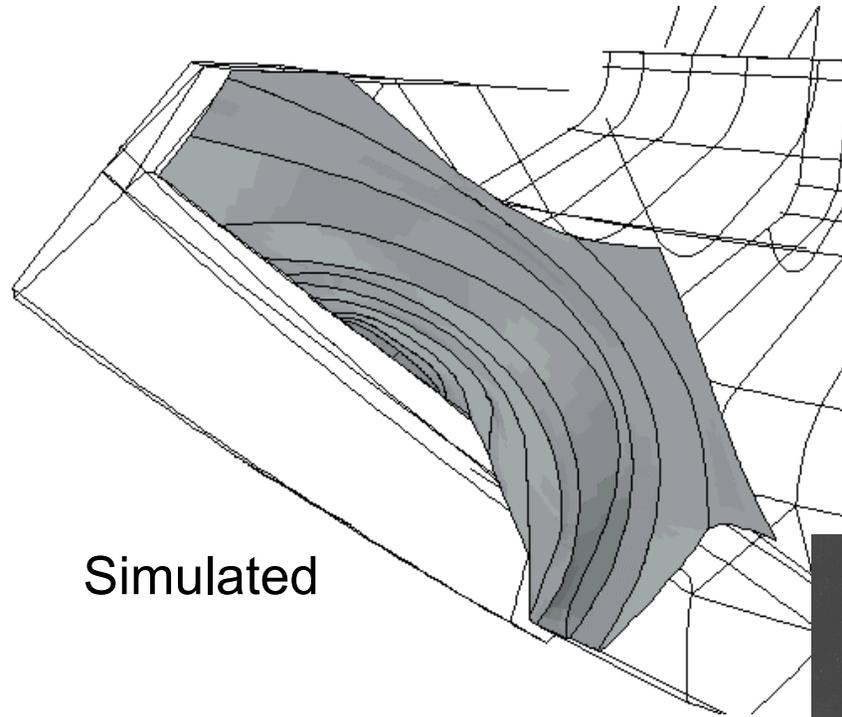
|          |                        |
|----------|------------------------|
| ELEMENTS | 214,000 -<br>327,000   |
| DOF      | 920,000 -<br>1,400,000 |

# Comparison: Simulated versus Observed

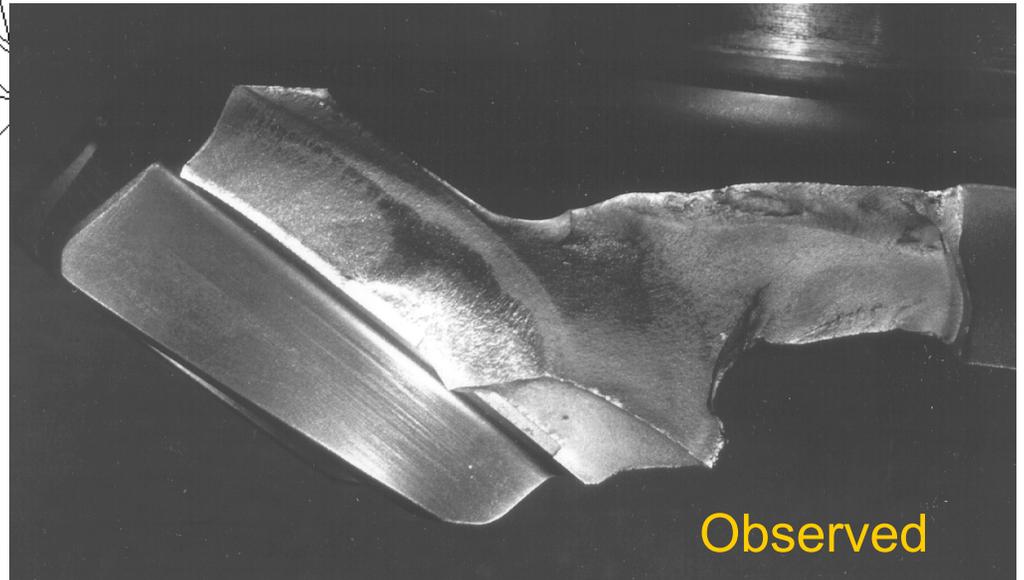


Crack Trace on the  
Face of Tooth

# Comparison: Simulated versus Observed Fracture Surfaces

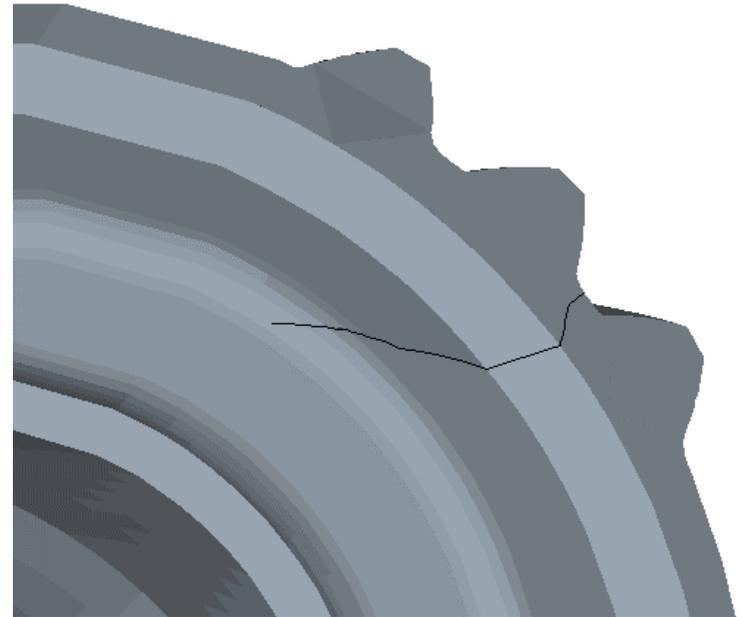
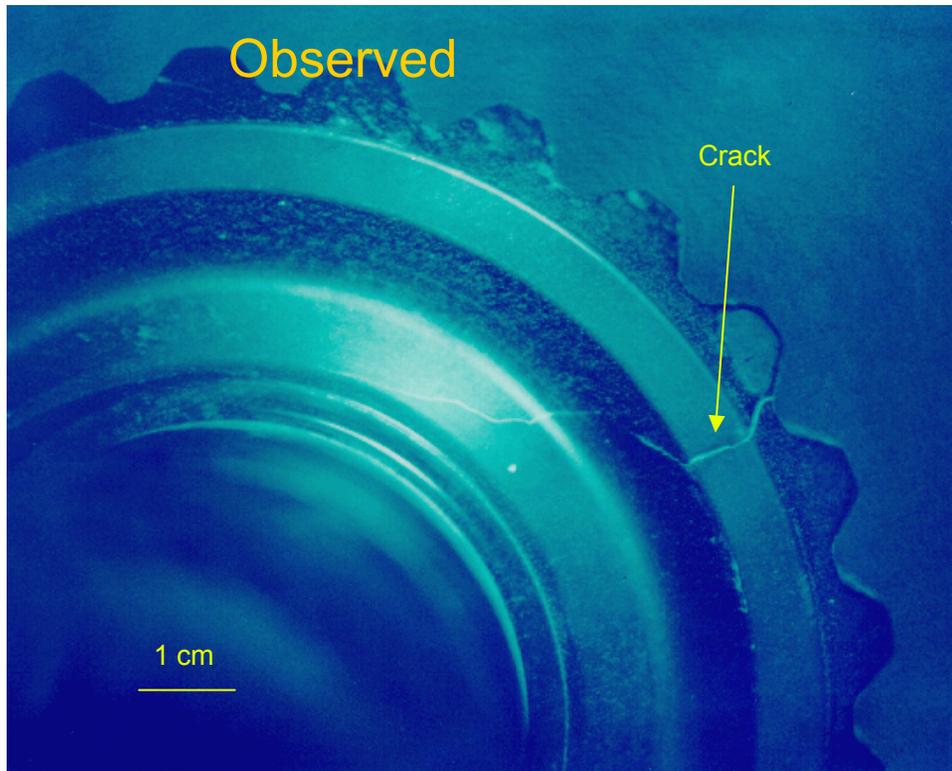


Simulated

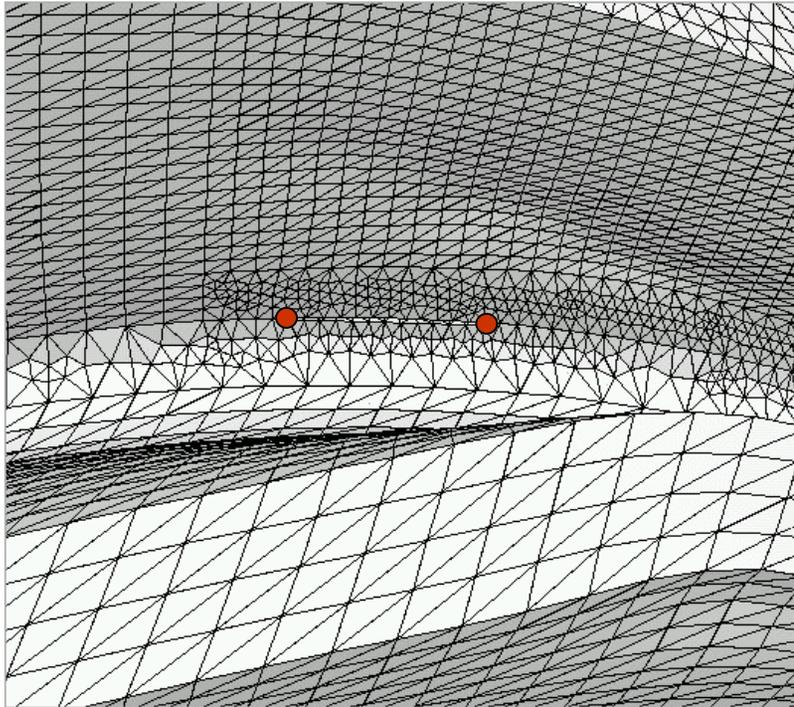


Observed

# Comparison: Simulated versus Observed Crack Trace on Gear Hub

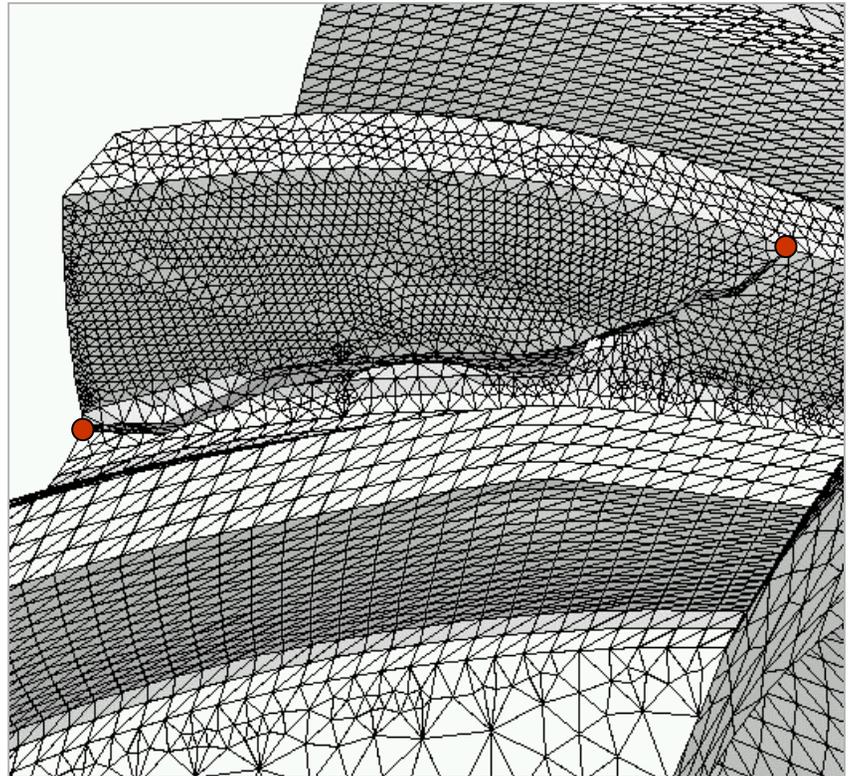


# Mesh Detail on Tooth Surface

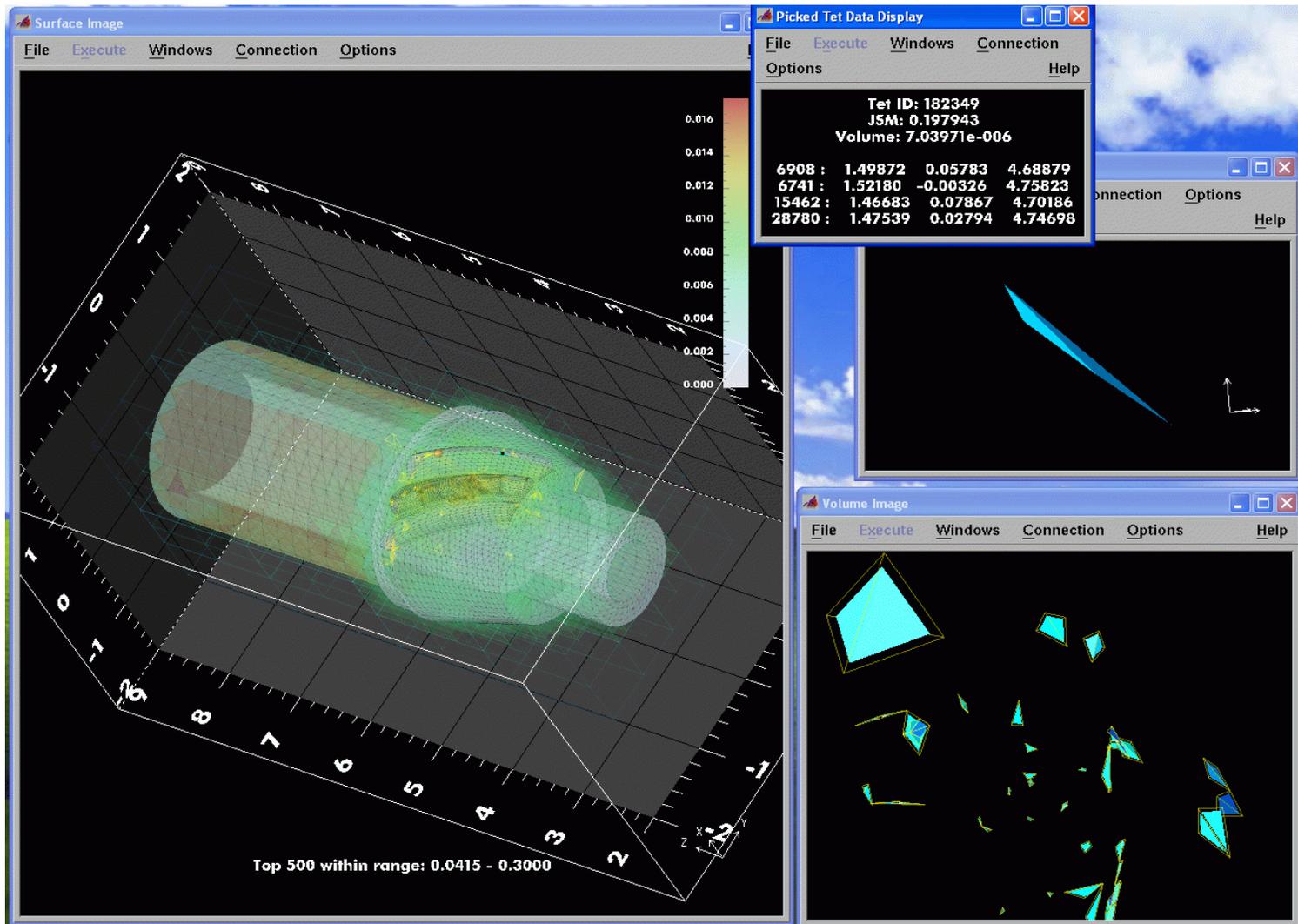


Initial Flaw/Mesh

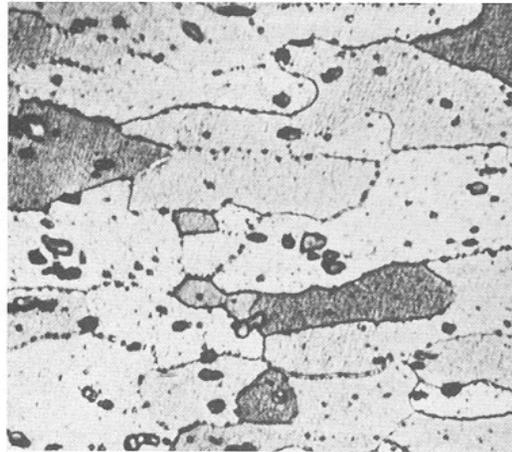
Later Stage of Simulation



# An OpenDX and SQL Server-Based Mesh Analysis Tool

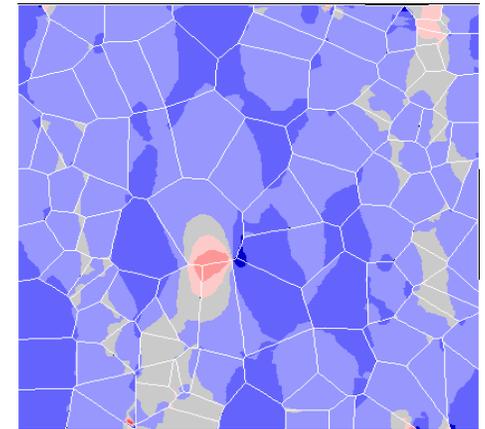
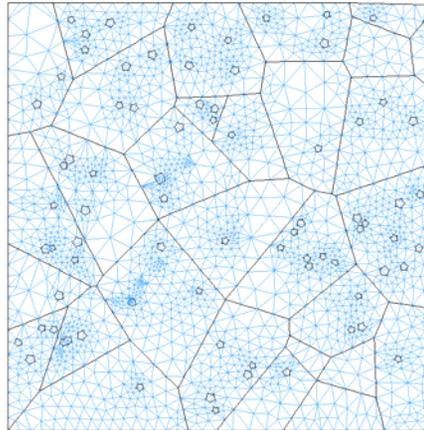
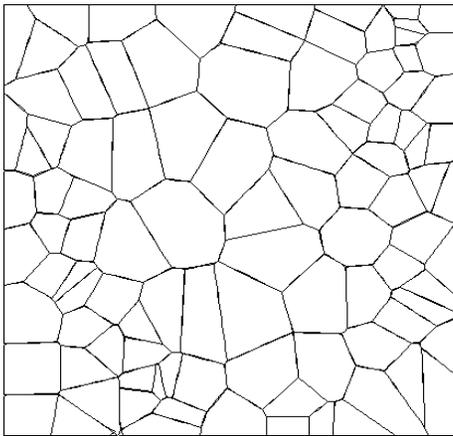


# The “Nanotechnology” Revolution is Creating Interesting Meshing Demands



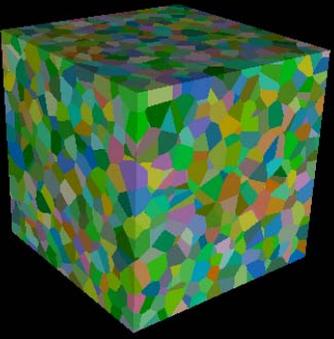
0.5 mm

AA 2024-T3 sheet, 500X

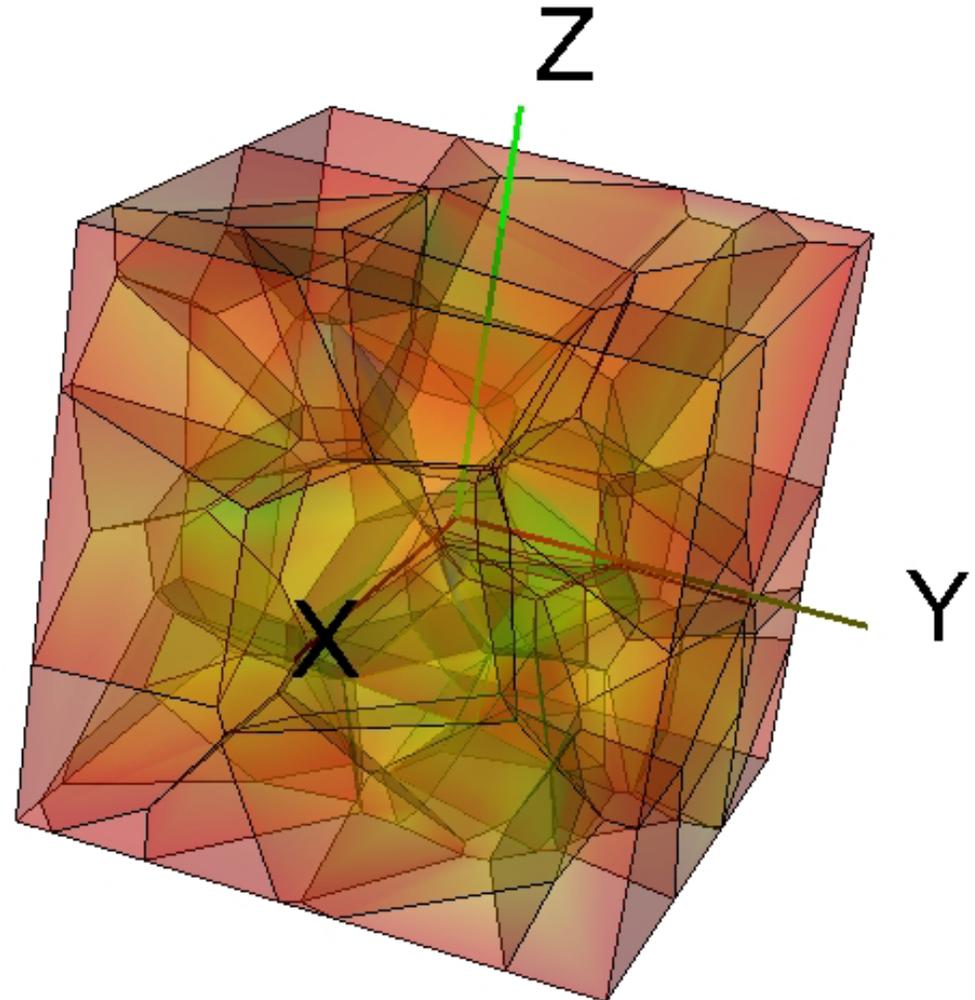


## 2D Representations of Crack Initiation in a Metallic Polycrystal

# Things Get Tough in 3D



- 50  $\mu\text{m}$  cube
- Only 100 Grains
- 6,271,419 DOF
- 1,519,816 10-noded tets



# Mesh Analysis and Improvement Tool Even More Necessary

The image displays a software interface for mesh analysis and improvement. The main window shows a 3D model of a gear with a mesh overlay. A red dot on the mesh indicates a node being dragged in real-time. The interface includes a control panel with various settings and a correlation plot.

**Control Panel Settings:**

- Vertex ID: 4950
- Tet display: modified mesh
- Show original mesh: on
- Show selected glyph: on
- Show modified mesh: on
- Show probe glyph: on
- Correlation plot scale: 500.00000
- Simplex opacity: 0.80
- Tet opacity: 0.50
- Isolate factor: 0.50
- Vertex glyph scale: 0.06000
- Probe/selected glyph scale: 0.00100
- Max gamma: 475.00000
- Show vertex glyphs: off
- Show tet IDs: off
- ODBC resource: sqlsrv04
- Database name: new\_gear

**Correlation Plot:**

The plot shows the relationship between gamma and tet ID. A red arrow points to a specific data point on the plot.

| tet ID | gamma    |         |
|--------|----------|---------|
| 10     | -0.50000 | 0.05287 |
| 12     | -0.50000 | 0.08544 |
| 10     | -0.50000 | 0.50000 |
| 16     | -0.48210 | 0.27942 |

**Feedback:** A window titled "feedback" shows a 3D model of the gear with a blue highlight on a specific area.

**Real time drag offending node:** A window titled "Real time drag offending node" shows the 3D model with a red dot on the mesh and a red arrow pointing to it.

# 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  
5<sup>th</sup> World Conference on Computational Mechanics, Vienna, July 2002.

# Sessions at 5<sup>th</sup> World Conference on Computational Mechanics on

**Meshless Methods: 8**

**Mesh Generation: 0**

**BCM—Boundary Cloud Method**

**MPM—Material Point 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 approaches with/out explicit representation of crack geometry:

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