

MAE 4700/5700: ANSYS Section

Fridays 1:25-2:15 pm

Rajesh Bhaskaran
Cornell University



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Co-ordinates

- Dr. Rajesh Bhaskaran
Swanson Director of Engineering Simulation
Mechanical & Aerospace Engineering
- E-mail: bhaskaran@cornell.edu
- Office: 102 Rhodes Hall
- Office hours in the Swanson Lab (163 Rhodes)
 - TBA



Computer Labs with ANSYS

- CIT public labs
 - B7 Upson
 - 318 Phillips
 - ACCEL lab in Carpenter Hall
- 471 Rhodes
- Swanson Lab (163 Rhodes)
 - 16 workstations
 - 2 quad-core processors
 - 30 GB of RAM



ANSYS Software

- Leading commercial FEA software
- Founded by Cornell alum Dr. John Swanson in 1970
- Can solve structural, thermal, flow and electro-magnetic problems
- Student version available for \$25/year
 - Instructions to be provided by e-mail
 - Version 13
 - Labs are using Version 14. V14 files cannot be read into V13.



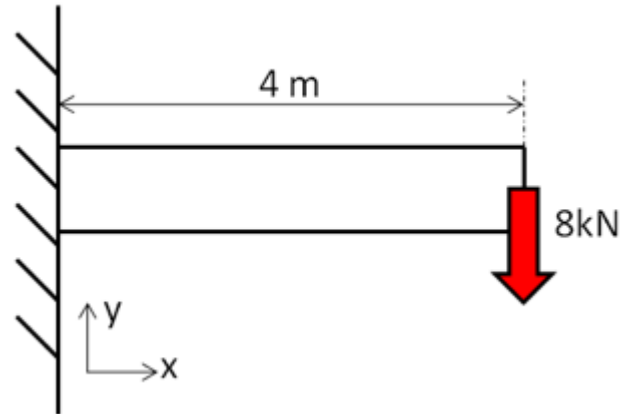
Friday Sections

- Purpose:
 - Learn to *apply* FEA to engineering problems using ANSYS
 - Prepare for project
- Plan:
 - Initially solve some HW problems using ANSYS
 - Compare MATLAB and ANSYS solutions
 - Move on to more complex problems.



ANSYS Exercise 1

Cantilever Beam



- Truss elements are available in ANSYS
 - Need to use scripting (advanced feature)
 - Not used widely in practice



ANSYS Exercise 1

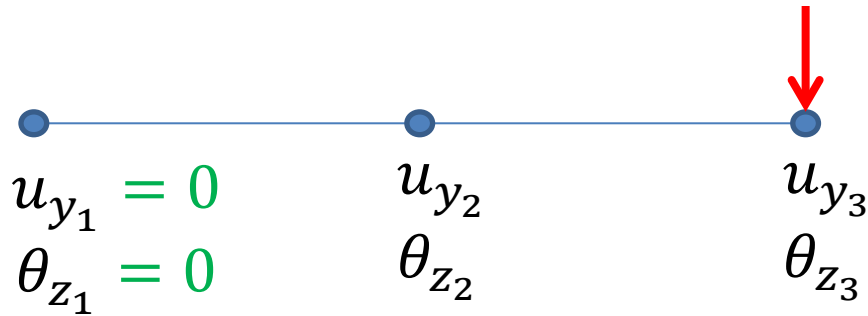
Cantilever Beam

- Beams will appear in HW3
- One problem will be on ANSYS solution of cantilever beam
 - Save work from this section for submission with HW3



Cantilever Beam: Degrees of Freedom

- Consider 2-element mesh



Reaction force at node 1

Reaction moment at node 1



SECTION MEETING #2

9/7/2012

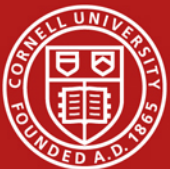
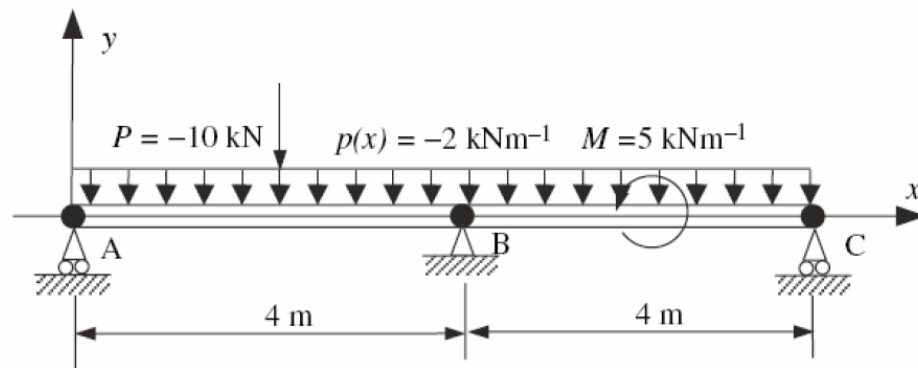


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Cantilever Beam

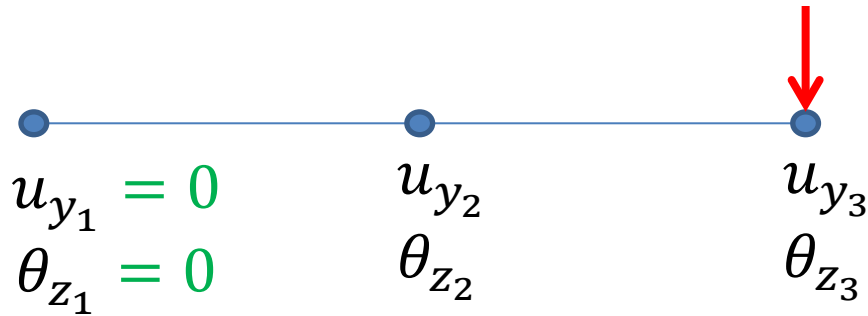
- First ANSYS exercise
 - Can do trusses but need to use scripting (advanced functionality)
 - Pin-jointed trusses rarely occur in practice
- ANSYS beam problem will appear in HW3

Problem 3 – Analysis of a two-span beam (MatLab and Ansys)



Cantilever Beam: Degrees of Freedom

- Consider 2-element mesh



Reaction force at node 1

Reaction moment at node 1



Cantilever Beam

Beam element stiffness matrix

Offset type	Centroid
Model Type	Beam
Material	
Assignment	Go Big Red
Nonlinear Effects	Off
Thermal Strain Effects	Off

K^e : see page 24 of
*Lecture 4: Finite element
 formulation of beam problems*

$$K^e = \frac{E^e I^e}{2L^e} \int_{-1}^1 \begin{bmatrix} 36\xi^2 & 6\xi(3\xi-1)L^e & -36\xi^2 & 6\xi(3\xi+1)L^e \\ 6\xi(3\xi-1)L^e & (3\xi-1)^2 L^{e2} & -6\xi(3\xi-1)L^e & (9\xi^2-1)L^{e2} \\ -36\xi^2 & -6\xi(3\xi-1)L^e & 36\xi^2 & -6\xi(3\xi+1)L^e \\ 6\xi(3\xi+1)L^e & (9\xi^2-1)L^{e2} & -6\xi(3\xi+1)L^e & (3\xi+1)^2 L^{e2} \end{bmatrix} d\xi = \frac{E^e I^e}{L^{e3}} \begin{bmatrix} 12 & 6L^e & -12 & 6L^e \\ 6L^e & 4L^{e2} & -6L^e & 2L^{e2} \\ -12 & -6L^e & 12 & -6L^e \\ 6L^e & 2L^{e2} & -6L^e & 4L^{e2} \end{bmatrix}$$

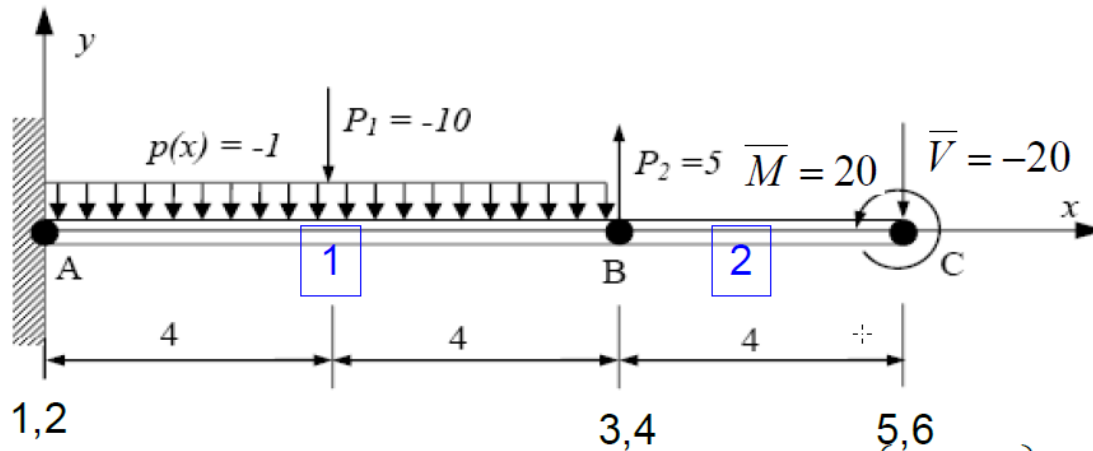
Details of Line Body	
Body	Line Body
Faces	0
Edges	1
Vertices	2
Cross Section	Rect1
Offset Type	Centroid

Poisson ratio doesn't
 appear in K^e

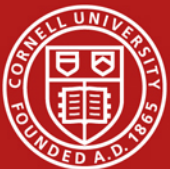


Solve Step

Beam Lecture, Page 43



$$10^3 \begin{bmatrix} 0.23 & 0.94 & -0.23 & 0.94 & 0 & 0 \\ 0.94 & 5.00 & -0.94 & 2.50 & 0 & 0 \\ \hline -0.23 & -0.94 & 2.11 & 2.81 & -1.88 & 3.75 \\ 0.94 & 2.50 & 2.81 & 15.00 & -3.75 & 5.00 \\ 0 & 0 & -1.88 & -3.75 & 1.88 & -3.75 \\ 0 & 0 & 3.75 & 5.00 & -3.75 & 10.00 \end{bmatrix} \begin{Bmatrix} u_{y1} = 0 \\ \theta_{y1} = 0 \\ u_{y2} \\ \theta_{y2} \\ u_{y3} \\ \theta_{y3} \end{Bmatrix} = \begin{Bmatrix} -9 + R_{u1} \\ -15.3 + R_{g1} \\ -4 \\ 15.3 \\ -20 \\ 20 \end{Bmatrix}$$



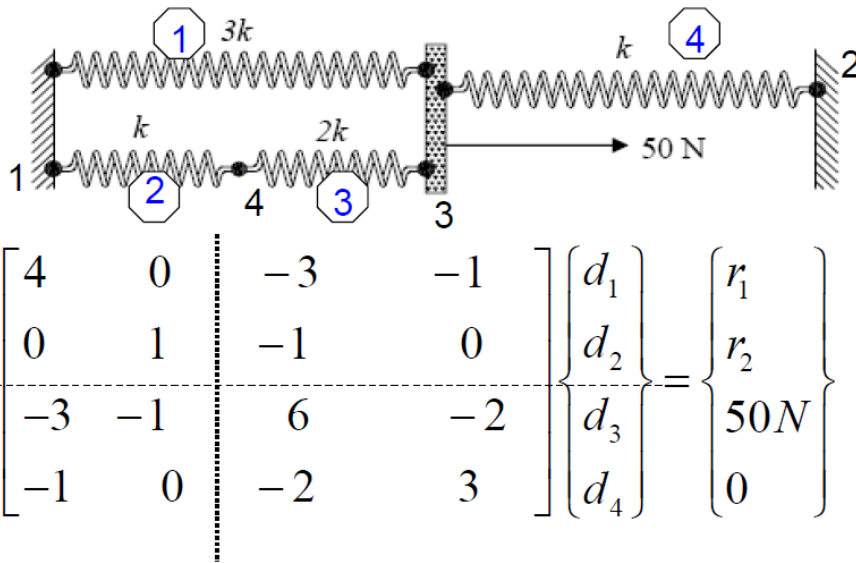
Bending Moment and Shear Force

- General FEM Procedure (see next slide):
 1. Calculate unknown degrees of freedom
 2. Calculate reactions at known degrees of freedom (for instance, at fixed nodes)
- ANSYS then uses reactions to calculate bending moment and shear force:
 - More accurate than differentiating displacement

$$M^1 = EI \frac{d^2 u_y^1}{dx^2}$$



Calculation of Reactions

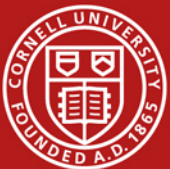


See Lecture 2: Direct approach, page 32

$$k \begin{bmatrix} 4 & 0 & -3 & -1 \\ 0 & 1 & -1 & 0 \\ -3 & -1 & 6 & -2 \\ -1 & 0 & -2 & 3 \end{bmatrix} \begin{Bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{Bmatrix} = \begin{Bmatrix} r_1 \\ r_2 \\ 50N \\ 0 \end{Bmatrix}$$

We partition and apply BCs: $d_1 = d_2 = 0$

$$k \begin{bmatrix} 6 & -2 \\ -2 & 3 \end{bmatrix} \begin{Bmatrix} d_3 \\ d_4 \end{Bmatrix} = \begin{Bmatrix} 50N \\ 0 \end{Bmatrix} \Rightarrow \begin{Bmatrix} d_3 \\ d_4 \end{Bmatrix} = \frac{1}{k} \begin{Bmatrix} 10.7143 \\ 7.1429 \end{Bmatrix} N$$



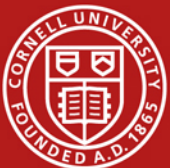
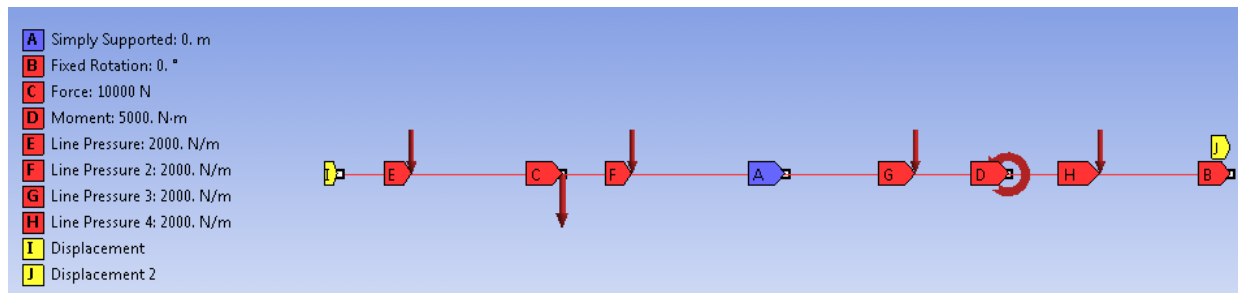
HW3 Tips

- Model the geometry using four lines
- Apply distributed load using *Line Pressure*
- *Simply Supported* boundary condition sets u_x and u_y to zero but leaves θ_z free
- *Frictionless support* in this case will set u_y to zero but leaves u_x and θ_z free



HW3 Tips

- You have to add a BC by fixing the rotations about x and y axes as in the snapshot below. Otherwise you might get a solver pivot error. This is because ANSYS is using a 3D beam element with these additional rotations as dof's.



SECTION MEETING #4

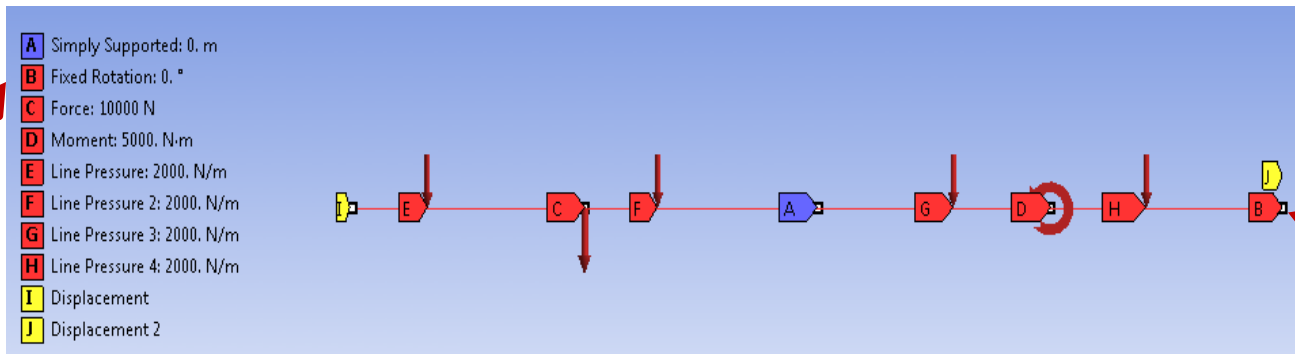
9/21/2012



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HW3 Comments

- Need additional BC for beam problem (#2)
 - Fix the rotations about x and y axes
- Otherwise might get a solver pivot error
 - ANSYS is using a 3D beam element formulation with these additional rotations as dof's.



HW Comments

- Degrees of freedom in ANSYS' beam element

$$\begin{Bmatrix} u_x \\ u_y \\ \cancel{u_z} \\ \cancel{\theta_x} \\ \cancel{\theta_y} \\ \theta_z \end{Bmatrix}$$

Additional constraint ensures that these DOF's are identically zero

Otherwise might get rigid body motion (structure flying off)



HW3 Comments

- You generally apply loads to geometry
 - Transferred to nodes and elements during *Solve*
- Saving files
 - *File > Save*
You need **both** *frame.wbpj* file and *frame_files* folder to restore project
 - *File > Archive*
ANSYS saves entire project in one file *frame.wbpz*



SECTION MEETING #5

9/28/2012



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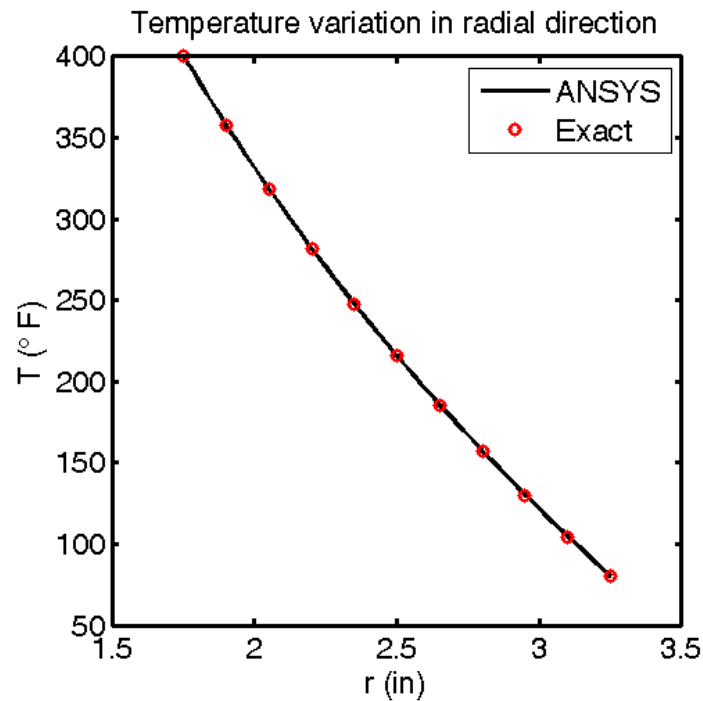
Updated Office Hours

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Axisymmetric Heat Flow (HW4, #3)

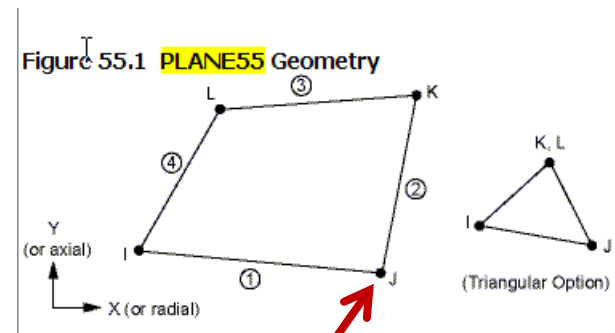
Comparison of ANSYS Result with Exact Solution



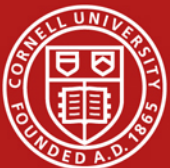
Axisymmetric Heat Flow (HW4, #3)

- Element type used:
 - Look under *Solution* > *Solution Information*
 - *PLANE55*
 - Help page for *PLANE55*
 - 2D Conduction
 - Plane or Axisymmetric
 - Relevant material properties: KXX, KYY (=K in our case)

4 Nodes/Element



Single d.o.f. per
node: Temperature



Axisymmetric Heat Flow (HW4, #3)

- Help page for *PLANE55*
 - Switch to go between plane and axisymmetric: *KEYOPT(3)*
 - *PLANE55 Assumptions and Restrictions*
 - Element must lie in an X-Y plane
 - Y-axis must be the axis of symmetry for axisymmetric analyses

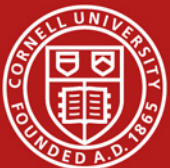
Shape Function
(follow link to
Mechanical APDL
Theory Reference)

$$T = \frac{1}{4}(T_I(1-s) \dots \text{(analogous to } u)$$

$$\text{I} \quad u = \frac{1}{4}(u_I(1-s)(1-t) + u_J(1+s)(1-t) + u_K(1+s)(1+t) + u_L(1-s)(1+t))$$

Lecture 6. page 7

$$u^e(x) = N_1^e d_1^e + N_2^e d_2^e$$



Axisymmetric Heat Flow (HW4, #3)

- Help page for PLANE55
 - A similar element with midside node capability is PLANE77

PLANE55

$$T = \frac{1}{4}(T_I(1-s) \dots \text{(analogous to } u))$$

$$\text{I } u = \frac{1}{4}(u_I(1-s)(1-t) + u_J(1+s)(1-t) \\ + u_K(1+s)(1+t) + u_L(1-s)(1+t))$$

PLANE77

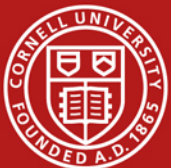
$$T = \frac{1}{4}(T_I(1-s) \dots \text{(analogous to } u))$$

$$u = \frac{1}{4}(u_I(1-s)(1-t)(-s-t-1) + u_J(1+s)(1-t)(s-t-1) \\ + u_K(1+s)(1+t)(s+t-1) + u_L(1-s)(1+t)(-s+t-1)) \\ + \frac{1}{2}(u_M(1-s^2)(1-t) + u_N(1+s)(1-t^2)) \\ + u_O(1-s^2)(1+t) + u_P(1-s)(1-t^2))$$



Important Takeaway

- Need to dig into the element manual to understand key things such as
 - Governing equations
 - Assumptions and restrictions
 - Element formulation
 - Number of nodes/element
 - Degrees of freedom at each node
 - Shape functions etc.
- **INCLUDE SUCH INFORMATION IN YOUR PROJECT PRESENTATION/REPORT**



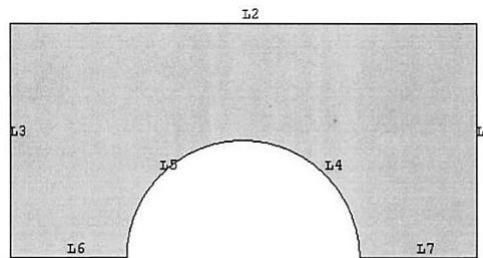
Mapped Meshing

- Valid in 2D and 3D
- Generates regular meshes that generally lead to increased accuracy
- Can be used only in “regular” regions
- For 2D, works on areas with 3 or 4 sides
 - 4 sides: Opposite sides have equal number of divisions
 - 3 sides: All sides must have an equal, even number of divisions

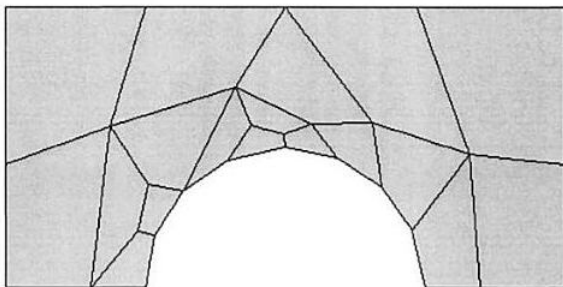


Mapped Meshing

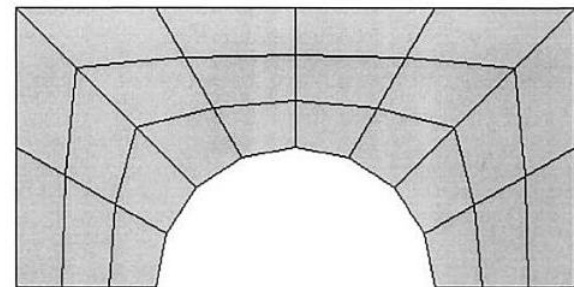
- Example from “The finite element method and applications in engineering using ANSYS” by Madenci & Guven



Free Mesh



Mapped Mesh



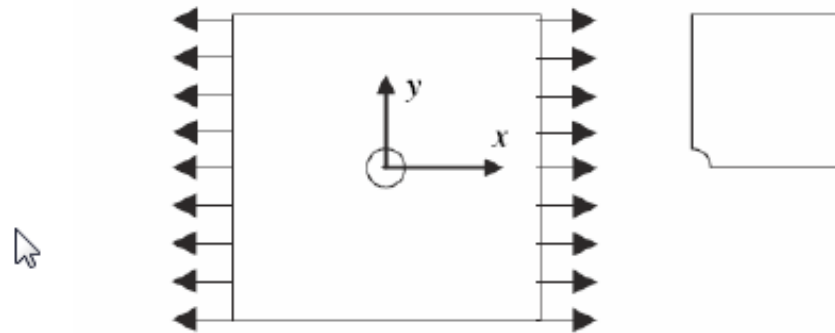
Mapped Meshing

- Why the “mapped” in name?
 - A four-sided area with equal number of divisions on the opposite edges can be mapped to a regular mesh on a square



Upcoming HW

Problem 4 – Thin plate with a hole in tension (MatLab)



Consider a tension problem involving a thin linearly elastic plate with a hole as shown in the figure. Suppose that the plate is a homogeneous isotropic elastic body.

The plate is of unit thickness and subject to tension in the horizontal direction. Because of symmetry in the model and loading, model only one quarter of the plate. Use ANSYS to generate the grid files using 4-node quadrilateral elements.

The plate is $20\text{ cm} \times 20\text{ cm}$ and the radius of the hole is 2.5 cm . Assume Young's modulus is $2.1 \times 10^7\text{ N/cm}^2$ and Poisson's ratio is 0.29 . The uniform load applied is $\sigma_0 = 100\text{ N/cm}$.

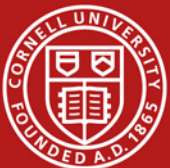


Plate with a Hole

- Degrees of freedom per node: u_x, u_y
- Element formulation:
 - Derived from weak form of elasticity equation
 - Solves the elasticity equation



SECTION MEETING #6

10/5/2012



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Updated Office Hours (Reminder)

- My office hours (held in Swanson Lab, 163 Rhodes):
 - M 3:30-4:30 pm
 - R 3:30-4:30 pm
 - F 2:30-3:30 pm
- Please come during these times for help with ANSYS modeling



Swanson Lab (163 Rhodes)

- 16 Dell T5500 workstations
 - 2 quad-core Intel Xeon 2.26GHz processors
 - 30 GB of RAM
 - Extensive software suite
 - ANSYS including FLUENT
 - MATLAB
 - CAD software: Solidworks, Creo/ProE
- Suitable for large finite-element models (> ~200k elements)
- Contact me if you have access problems



Plan for Today

- Sources for project ideas
 - Verification manual in ANSYS
 - Slides from ANSYS Tech Days
- Project approach
 - Novice vs. expert framework
 - Incremental build-up of FEA model
- Meshes for HW 6
- Plate with a hole in ANSYS (continuation)



Project Ideas: Verification Manual

- Search for “verification manual” in ANSYS help
 - Look through list of verification problems
 - Example:
 - *VM14 Large Deflection Eccentric Compression of a Column*
 - Can also sort by element number
 - Choose *Index by Element Number*



Project Ideas: Slides from ANSYS Tech Days

- ANSYS Tech Days was held on campus in March 2012
 - Several presentations from ANSYS engineers on industrial applications
 - These slides have been sent to you via dropbox
- **Stay away from fluid flow applications**
 - Uses finite-volume solver (FLUENT or CFX), not finite-element solver
 - Not appropriate for MAE 4700/5700





Nonlinear Analysis

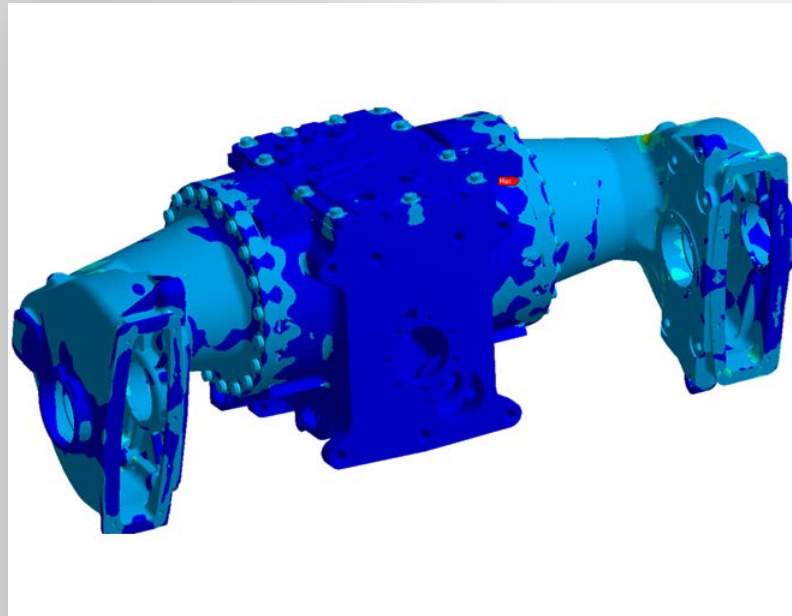
Fracture Mechanics

Linear Static

Instabilities

Acoustics

Contact



Explicit

Dynamics – Modal

Dynamics – Spectral

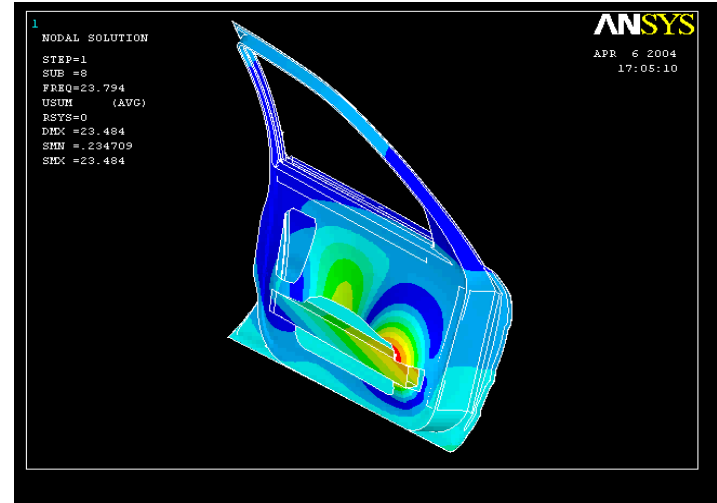
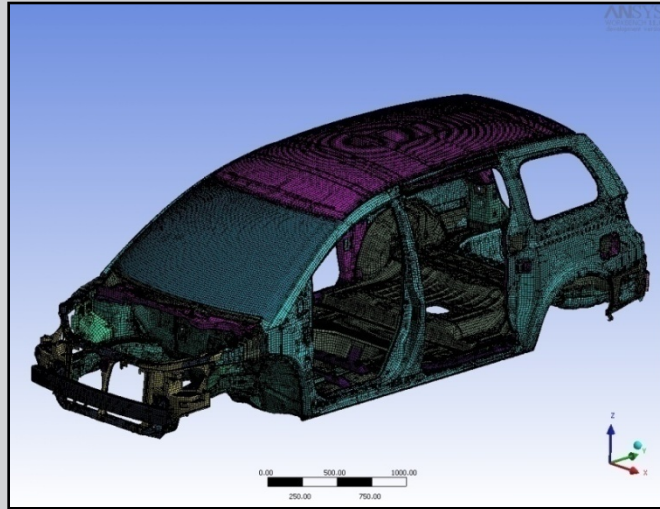
Dynamics – Harmonic

Dynamics – Transient

Rigid/Flexible Mechanisms

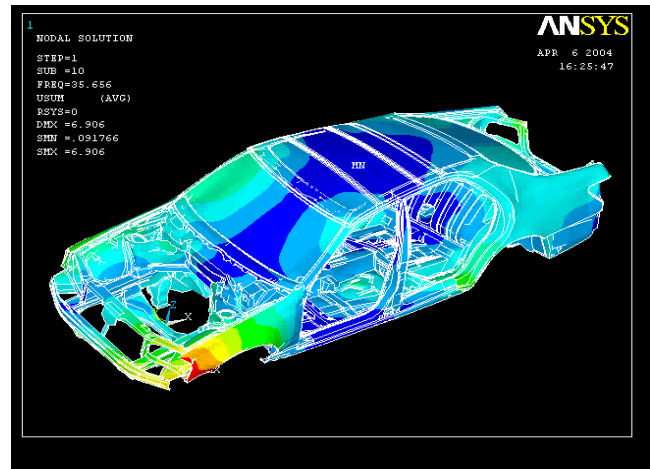
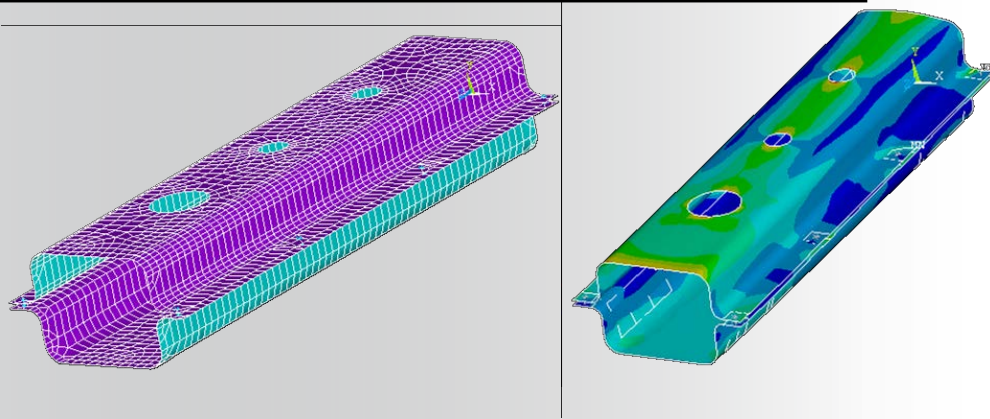
BIW & Component Modeling

Comprehensive Structural capability



Efficient Mid surfacing, Automatic Contact Detection

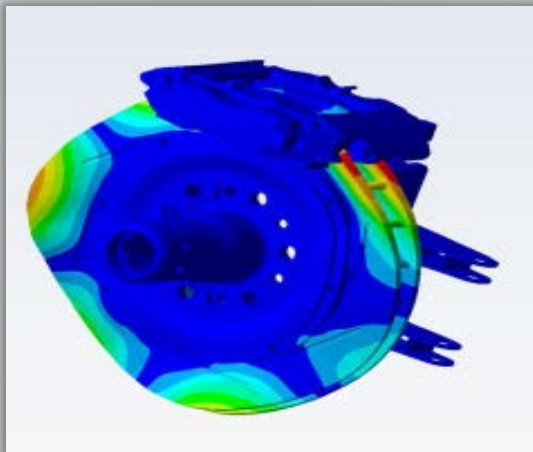
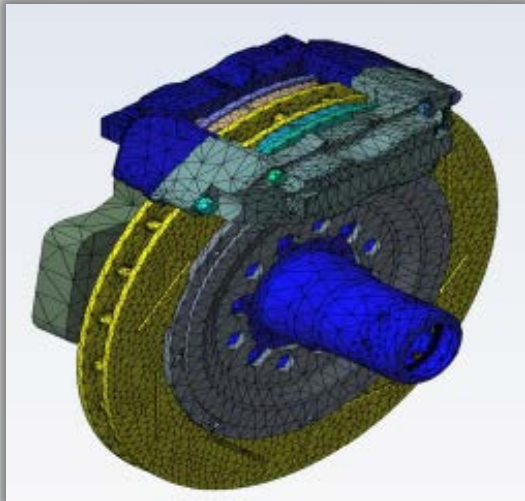
Non linear analysis of Door Assembly



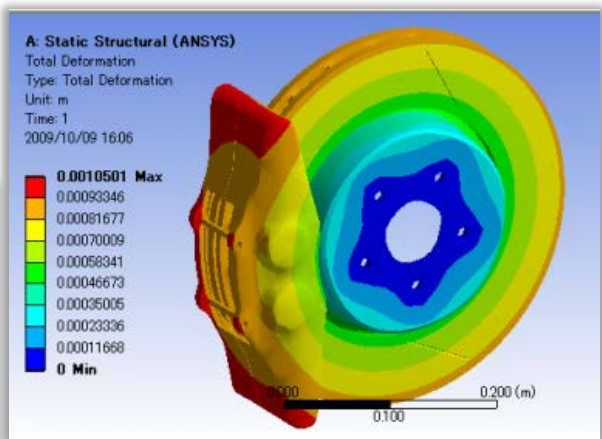
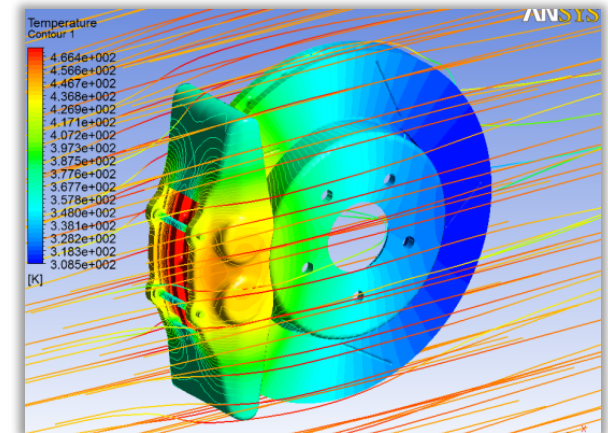
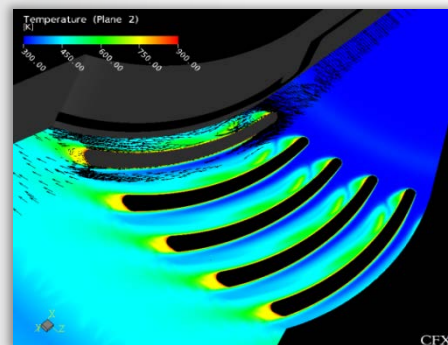
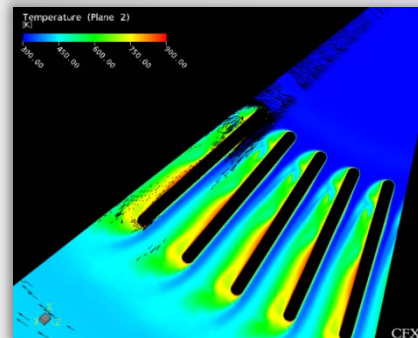
Spot Welds

Dynamic Structural analysis

Estimation of Unstable Modes



Thermal management



Application Area - Orthopaedics

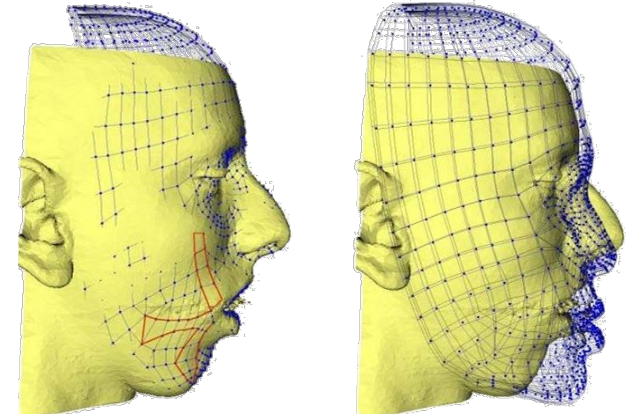
Prosthetics

- Hip, spine, knee, elbow, shoulder, wrist
- Cement injection

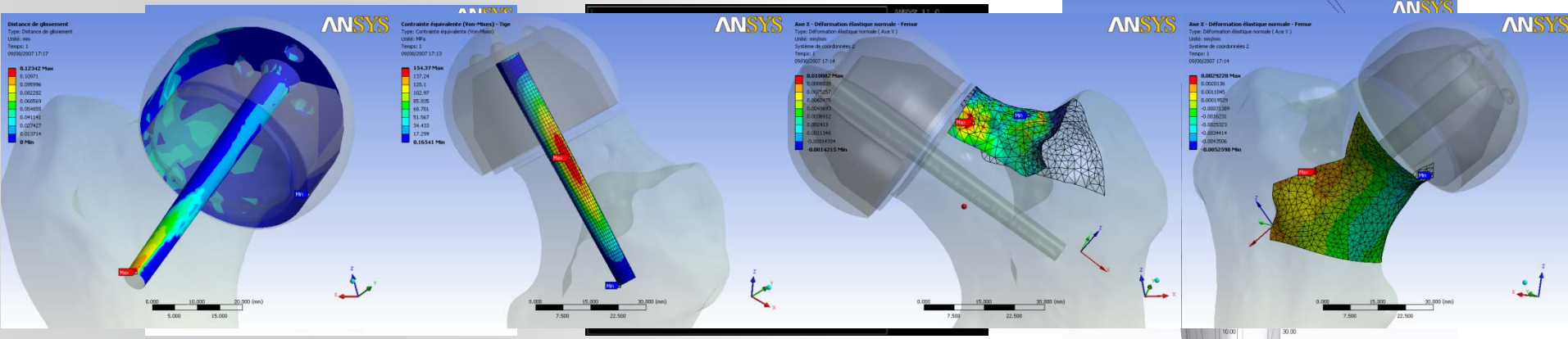
Soft tissues

- Maxillofacial (re)modeling
- Advanced prostheses (arms, legs)
- Tumor withdrawal (electromagnetic)

Surgical planning



Maxillofacial surgery modeling by TIMC-IMAG (courtesy of TIMC-IMAG Laboratory, CNRS/UJF)



Sliding distance of femur mesh

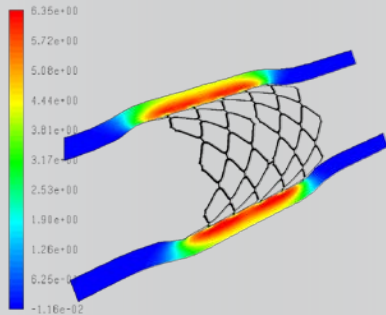
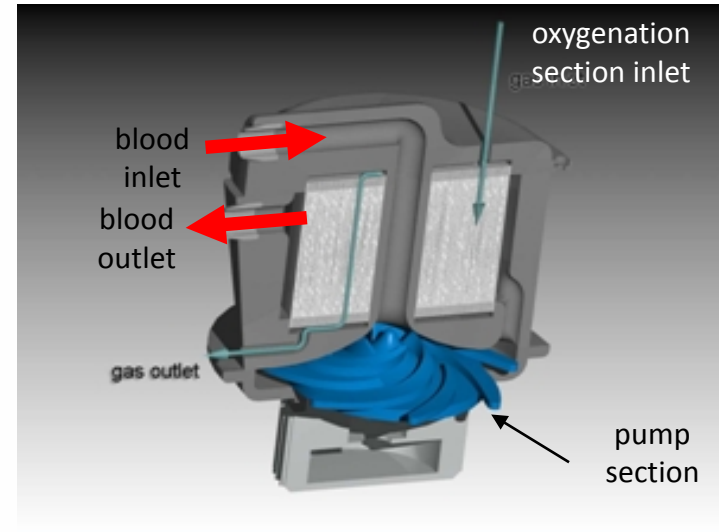
Von Mises stress in the prosthesis

Interpolated Ym
Trabecular tensile and compressive strain parameters of the prosthesis

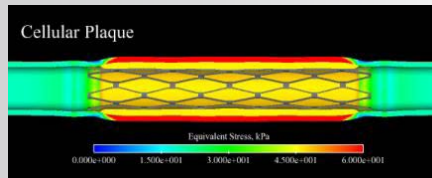
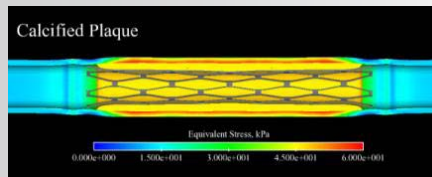
Application Area - Cardiovascular

Stents, heart valves, catheters, transcutaneous treatments, blood pumps, oxygenators, artificial hearts

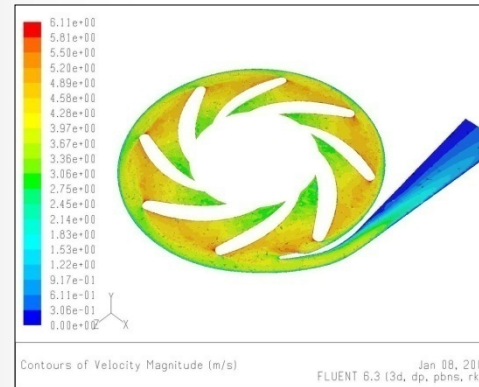
Design, testing (mechanical testing, in-vivo testing)



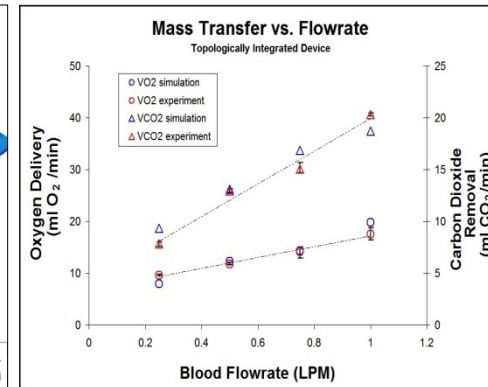
Drug eluting stent, species distribution in the artery wall



Arterial/Plaque Stresses for Calcified (top) and Cellular (lower) Plaque



Contours of Velocity Magnitude (m/s) Jan 08, 2007 FLUENT 6.3 (3d, dp, pbns, rke)



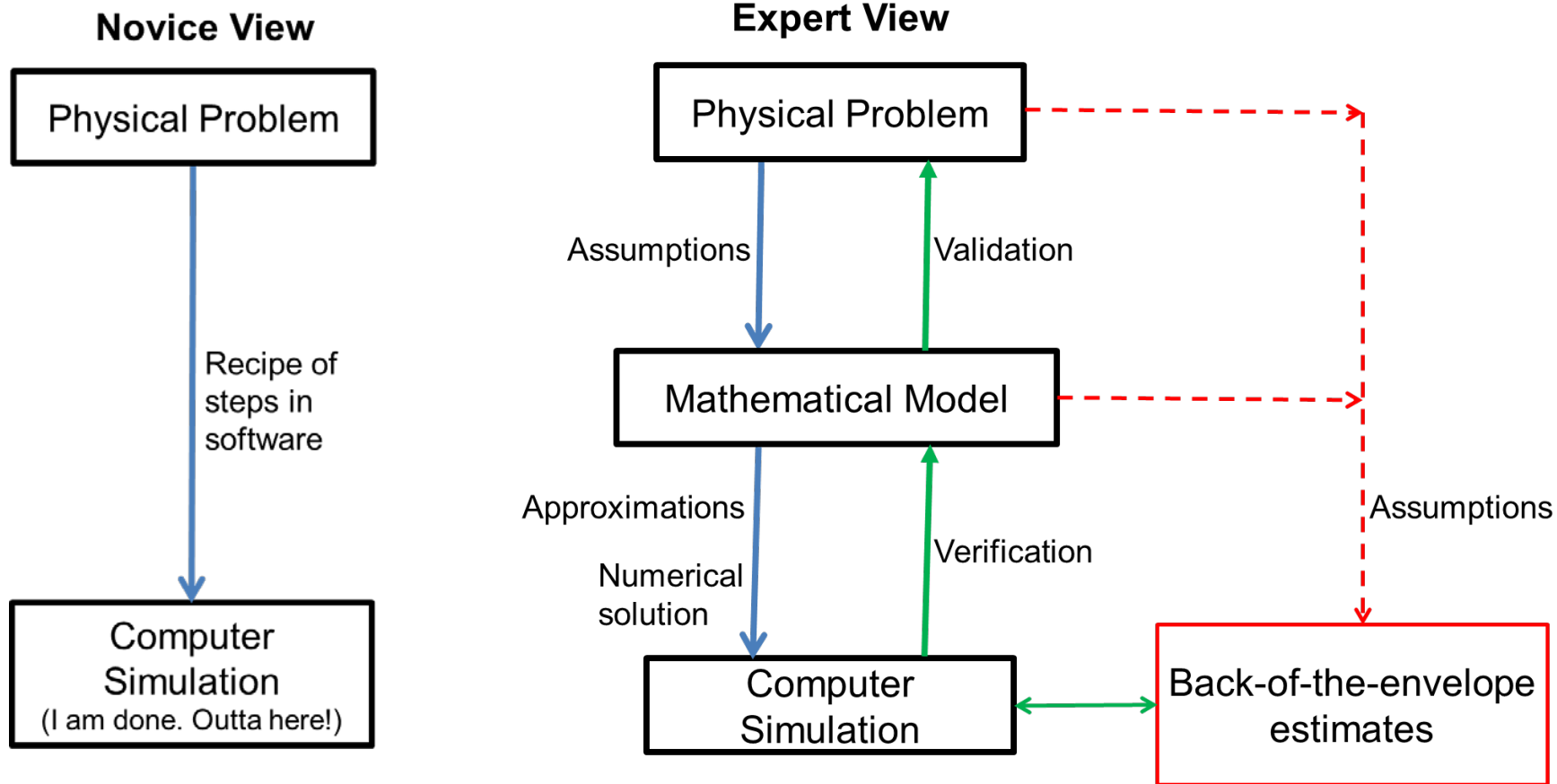
* Fill et al., ASAIO Journal (2008).

Plan for Today

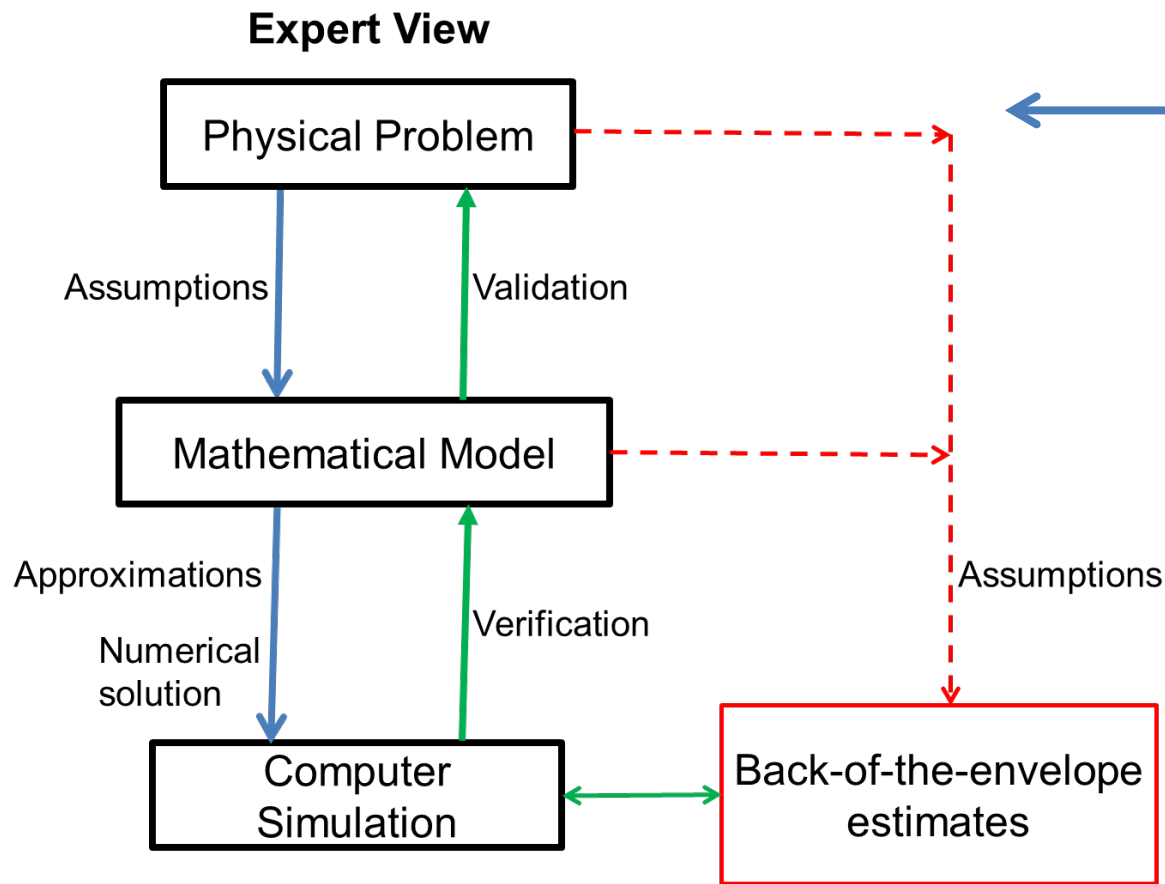
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- Project approach
 - **Novice vs. expert framework** ←
 - Incremental build-up of FEA model
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- Plate with a hole in ANSYS (continuation)



Novice vs. Expert Framework



What to Cover in Project Report and Presentation?



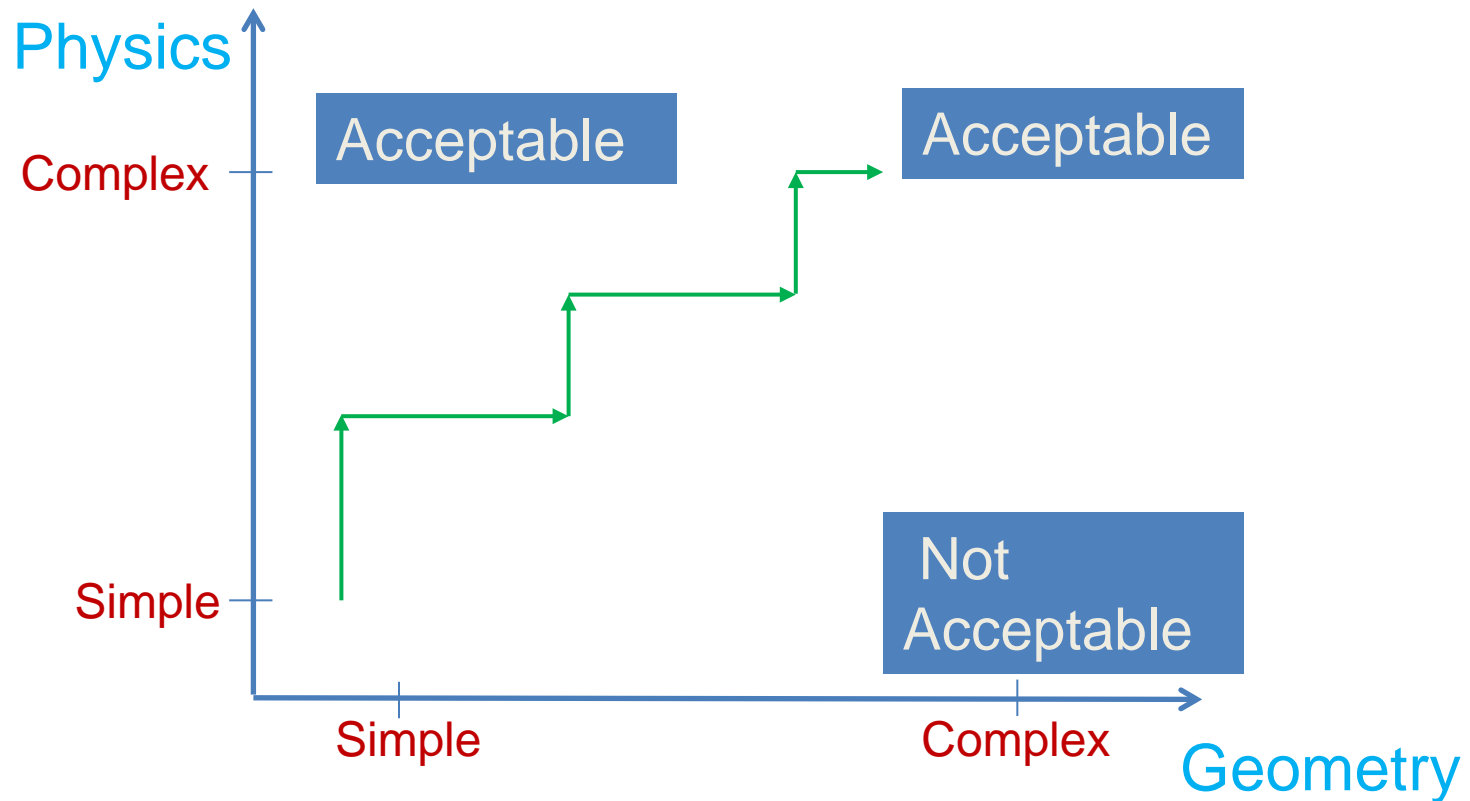
Cover all items in the "expert" framework

In the process, you will come across as an FEA expert!

More discussion in the coming weeks



Incremental Build-Up of FEA Model



Plan for Today

- Sources for project ideas
 - Verification manual in ANSYS
 - Slides from ANSYS Tech Days
- Project approach
 - Novice vs. expert framework
 - Incremental build-up of FEA model
- **Meshes for HW 6** ←
- Plate with a hole in ANSYS (continuation)



Meshes for HW6

- HW6, problem 4, Convection heat transfer:
 - Download from
 - <https://confluence.cornell.edu/display/SIMULATION/Files>
- HW6, problem 6: To be posted



SECTION MEETING #7

10/12/2012



Cornell University



Nonlinear Analysis

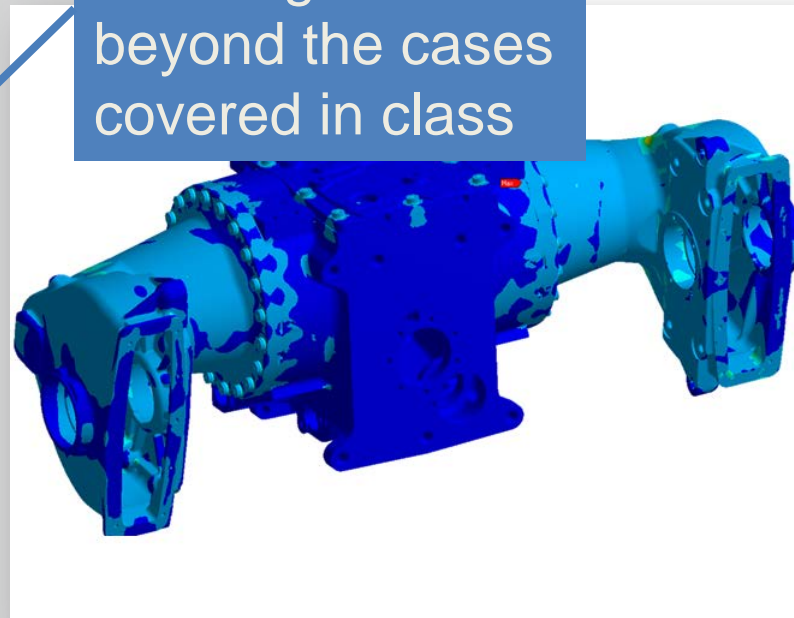
Fracture Mechanics

Linear Static

Instabilities

Acoustics

Contact



Explicit

Dynamics – Modal

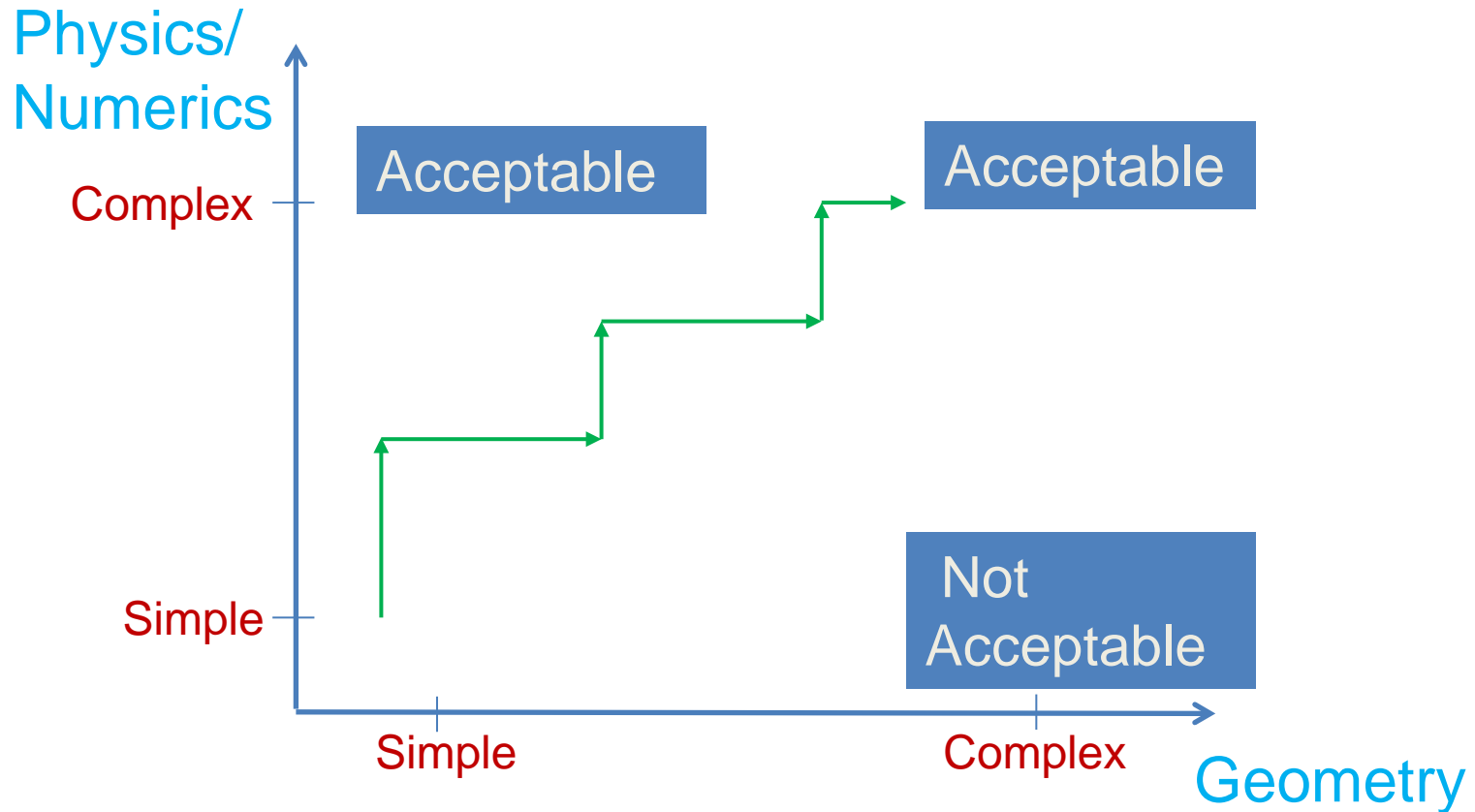
Dynamics – Spectral

Dynamics – Harmonic

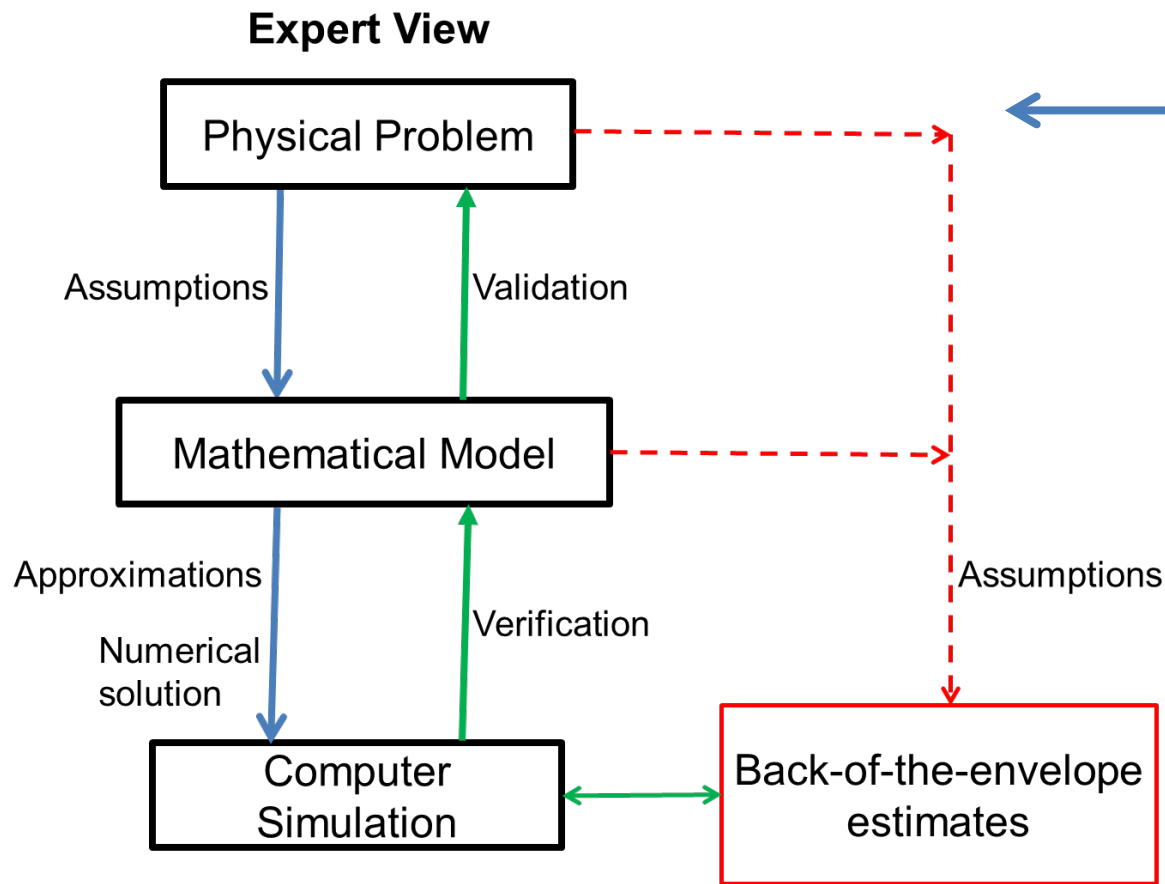
Dynamics – Transient

Rigid/Flexible Mechanisms

Incremental Build-Up of FEA Model



What to Cover in Project Report and Presentation?



Cover all items in the “expert” framework

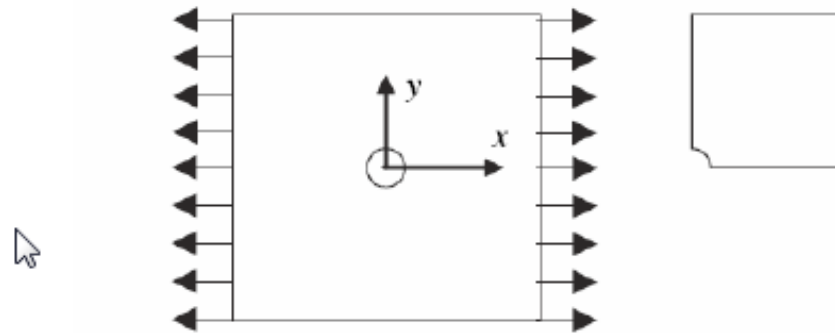
In the process, you will come across as an FEA expert!

More discussion in the coming weeks



Upcoming HW

Problem 4 – Thin plate with a hole in tension (MatLab)



Consider a tension problem involving a thin linearly elastic plate with a hole as shown in the figure. Suppose that the plate is a homogeneous isotropic elastic body.

The plate is of unit thickness and subject to tension in the horizontal direction. Because of symmetry in the model and loading, model only one quarter of the plate. Use ANSYS to generate the grid files using 4-node quadrilateral elements.

The plate is $20\text{ cm} \times 20\text{ cm}$ and the radius of the hole is 2.5 cm . Assume Young's modulus is $2.1 \times 10^7\text{ N/cm}^2$ and Poisson's ratio is 0.29 . The uniform load applied is $\sigma_0 = 100\text{ N/cm}$.



To check the quality of the finite element solution, compare your solution with that of an infinite plate. For a circular hole in an infinite plate subjected to a pure uniaxial tension or compression σ_0 , at ∞ , there exists an exact solution for the stresses (Timoshenko and Goodier, 1970):

$$\sigma_{rr} = \frac{\sigma_0}{2} \left\{ \left[1 - \left(\frac{a}{r} \right)^2 \right] + \left[1 - 4 \left(\frac{a}{r} \right)^2 + 3 \left(\frac{a}{r} \right)^4 \right] \cos 2\theta \right\}$$

$$\sigma_{\theta\theta} = \frac{\sigma_0}{2} \left\{ \left[1 + \left(\frac{a}{r} \right)^2 \right] - \left[1 + 3 \left(\frac{a}{r} \right)^4 \right] \cos 2\theta \right\}$$

$$\sigma_{r\theta} = -\frac{\sigma_0}{2} \left[1 + 2 \left(\frac{a}{r} \right)^2 - 3 \left(\frac{a}{r} \right)^4 \right] \sin 2\theta$$

- Provide a plot showing the FE and exact σ_{xx} stress distribution along the y -axis. What is the stress concentration factor?
- Show the deformed configuration
- Compute and plot the distribution of the finite element principal stress solution (σ_1, σ_2) and the maximum shear stress solution.
- Note that an interesting comparison can be made with the stress pattern obtained by photoelasticity in which fringes correspond to the maximum shear stress $\tau_{\max} = 1/2(\sigma_1 - \sigma_2)$. Verify that the contour lines of τ_{\max} obtained by the finite element approximation are quite similar to the fringe pattern obtained by the photoelasticity shown in the following figure.

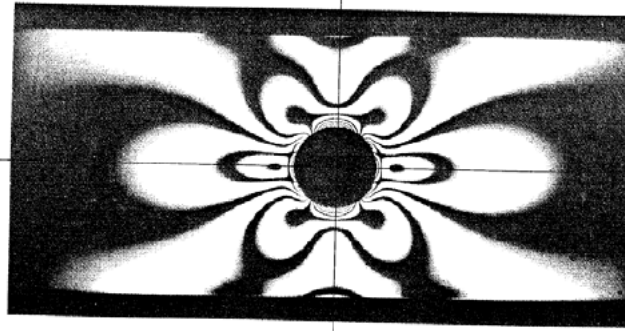
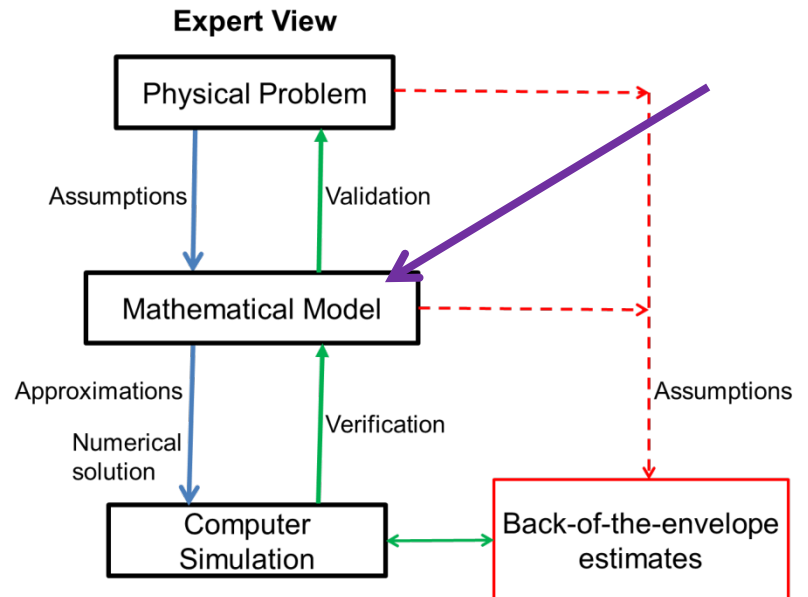
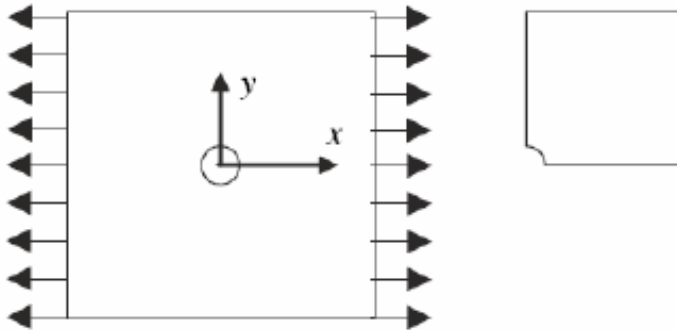


Plate with a Hole in Tension



- Boundary value problem
 - Governing equation
 - Domain
 - Boundary conditions



Modal Analysis

	Spring-mass system	FEA
Static	$k d = f$	$[K]\{d\} = \{f\}$
Forced vibration	$m\ddot{d} + k d = f(t)$	$[M]\{\ddot{d}\} + [K]\{d\} = \{f\}$
Free vibration (Modal analysis)	$m\ddot{d} + k d = 0$	$[M]\{\ddot{d}\} + [K]\{d\} = 0$

Modal Analysis

- No forces are applied, only displacement constraints
- Eigenvalue problem
- Eigenmodes are undetermined to a constant
- Material density is needed to form mass matrix

