

Integration of Simulation Technology into the Engineering Curriculum

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Roadmap

- Motivation
- Case-study approach
- Introduction to numerical concepts
- Web-based instruction
- Experiential learning
- Simulation templates in a lab course
- Conclusions

Current Status

- Computer-based simulations: An integral part of engineering practice
- Enabling factors:
 - Dramatic reduction in hardware cost
 - Maturing of off-the-shelf, commercial software

Current Status

General Motors: CAE software growth

CAE DISCIPLINE	CAE SOFTWARE				
Knowledge Management				CDA, CPIMDET, IVDA, IVED, CTB, FBDA...	CDA, CPIMDET, IVDA, IVED, CTB, FBDA...
Fatigue & QRD			CFS	CFS	CFS
Manufacturing			PANELFORM, LINEFORM, PAMSTAMP, RAPIDFORM, MRPS, deCAS...	PANELFORM, LINEFORM, PAMSTAMP, RAPIDFORM, WRAPFORM, MRPS, deCAS, DYNA3D	PANELFORM, LINEFORM, PAMSTAMP, RAPIDFORM, WRAPFORM, MRPS, deCAS, DYNA3D
Acoustics			RUMORSE	AutoSEA, Arbie, SYSNOISE, NASTRAN	AutoSEA, Arbie, SYSNOISE, NASTRAN
Powertrain Analysis			FLARE, ENIGMA	FLARE, ENIGMA, MCE	FLARE, ENIGMA
Optimization			ODYSSEY	ODYSSEY, MARS, RASNA, NASTRAN	ODYSSEY, MARS, RASNA, NASTRAN
Fluids & Heat Transfer			KIVA, GMFIRE, VINE3D	GMTEC, FLUENT, STARCD, ICEMHVAC, CACTUS	GMTEC, FLUENT, STARCD, ICEMHVAC
Mechanisms	GRAM		ADAMS, DADS	ADAMS, DADS	ADAMS, DADS
Vehicle Safety	MVMA2D, FEBIS		LSD, CAL3D, GENPAK, NONDRIS	DYNA3D, PAMCRASH, MADYMO, SYMDYN, CAL3D	DYNA3D, PAMCRASH, MADYMO, SYMDYN
Dimensional Management	VSM		VSM	VSM, TRIKON, MAPS, SVSM	VSM, EAVS, PDATK
Energy Management	GPSIM		GPSIM	GPSIM, OVERDRIVE	GPSIM, OVERDRIVE
Electrical & Control		GEBAMO	MATRIXx, GEBAMO	MATRIXx, SABRE, MATLAB, SNEAK, EMAS, GEBAMO, ACSL, EASY5, ADSIM	MATRIXx, SABRE, MATLAB, SNEAK, EMAS, GEBAMO,
Structural Analysis		NASTRAN, SMUG	NASTRAN, ABACUS, MARC, ANSYS, FASTAR, PATRAN, SMUG, INSTANT	NASTRAN, ABACUS, RASNA, MARC, ANSYS, HYPERMESH, PATRAN, SMUG, INSTANT, TEKOD, FEMB, NASPLT, Aries, MSC/XL, Prep7, IDEAS, Pro/Engineer, UG/GFEM	NASTRAN, ABACUS, RASNA, MARC, ANSYS, HYPERMESH, PATRAN, SMUG, INSTANT
Vehicle Dynamics	CF4, CT9	CF4, CT9, SNAC	ADAMS, DADS, SNAC	ADAMS, DADS, SNAC, CDA	ADAMS, DADS, SNAC, CDA
Noise & Vibration	DYANA	DYANA	ACSL, NASTRAN	NASTRAN, FASTAR	NASTRAN, Overdrive, FASTAR
	1965	1975	1985	1995	TODAY


Growth & Proliferation

Chart courtesy of Dr. Keith Meintjes, GM

Current Status

- Simulation in academia:
 - Extensive use in research
 - Not integrated systematically into the undergraduate ME curriculum at Cornell and peer universities

Consequences

- Students are not provided with a solid foundation in CAE simulation technology
- Training in an industrial setting:
 - Emphasizes developing software skills
 - Pays less attention to underlying theoretical and numerical concepts
-  This gap in training means that students are not being prepared to make the best or appropriate use of this powerful technology

Consequences

- The potential to enhance the learning experience is not realized
- Simulation tools can be used:
 - As virtual lab environments amenable to hands-on exploration
 - To make strong connections between theory and practice
 - To provide a rich visual environment
 - To make abstract concepts more concrete
 - To analyze more realistic problems

Approach

- Albert Einstein in essay *On Education*:
 - “I oppose the idea that the school has to teach directly that special knowledge and those accomplishments which one has to use later directly in life”
 - “If a young man has trained his muscles and physical endurance by gymnastics and walking, he will later be fit for every physical work”
- **Emphasis: Imparting concepts rather than skills**

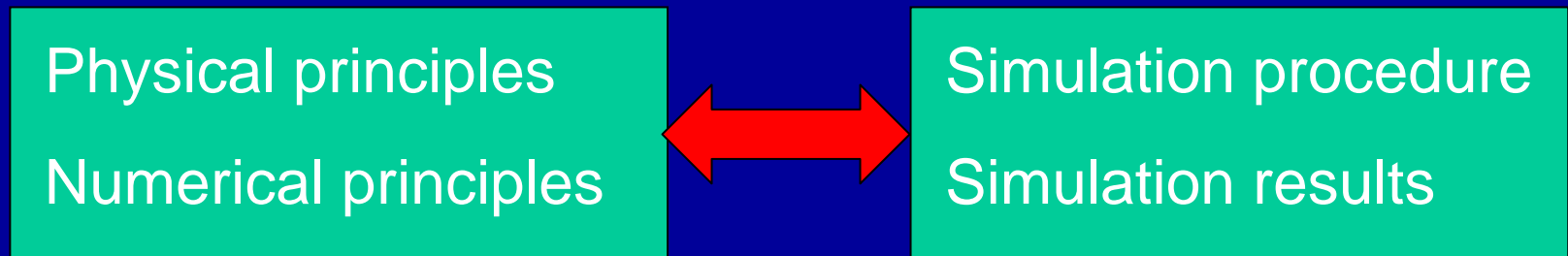
Approach

- Our approach primarily uses industry-standard commercial codes such as ANSYS & FLUENT
- Reasons for using commercial codes:
 - Very sophisticated with a large investment of manpower
 - Students already are using them for projects and co-op assignments
 - Used extensively in engineering practice

Case Study Approach

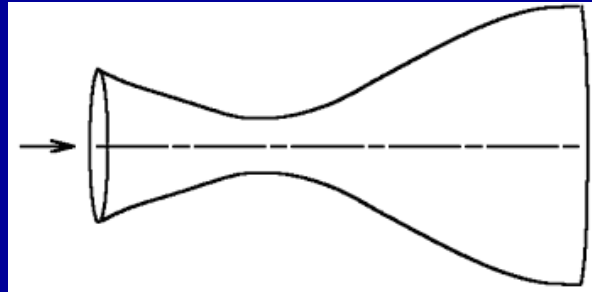
- Apply simulation tools to solve canonical problems with analytical solutions or approximations
- Analogous to validation during code development
- Start with a simple example: eg. 2D static truss, laminar pipe flow etc.
- Gradually build up the complexity of the exercises

Case Study Approach



- Make strong connections between theory and simulation
- Emphasize independent learning through online help etc.
- Enables a modular approach: Individual case studies can be adopted separately

Example: Compressible Nozzle Flow

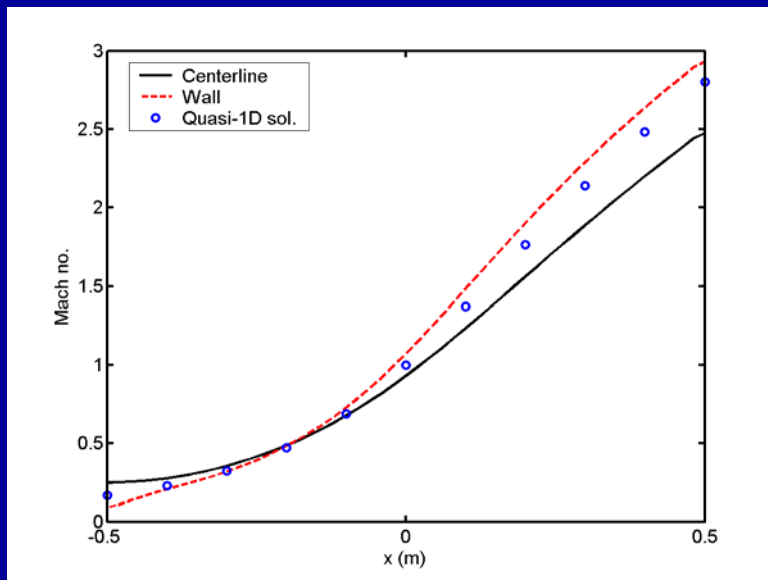


- High-speed flow through an axisymmetric converging-diverging nozzle
- Theory: Inviscid, quasi-1D analysis
 - Predicts operating regime based on $P_{o,in}/P_{exit}$
 - Isentropic solution: Gives Mach number, pressure, temperature variations

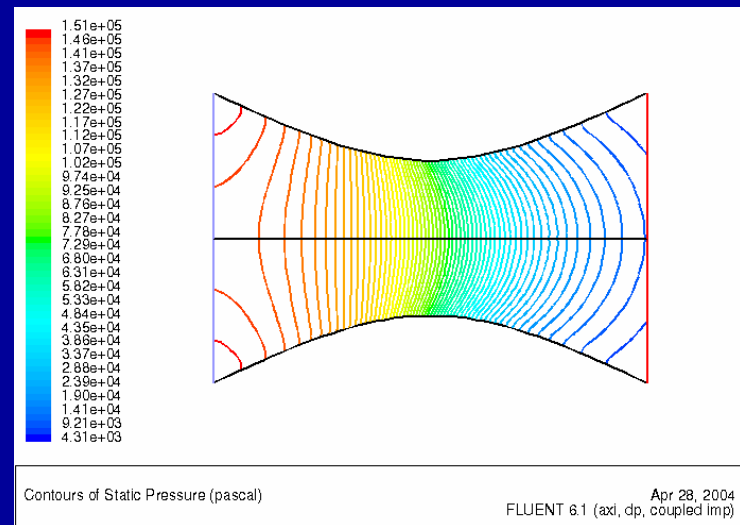
Example: Compressible Nozzle Flow

- Simulations: Axisymmetric, inviscid solution using FLUENT
- Isentropic, supersonic case: $P_{o,in}/P_{exit} = 27.1$

Mach No. Variation



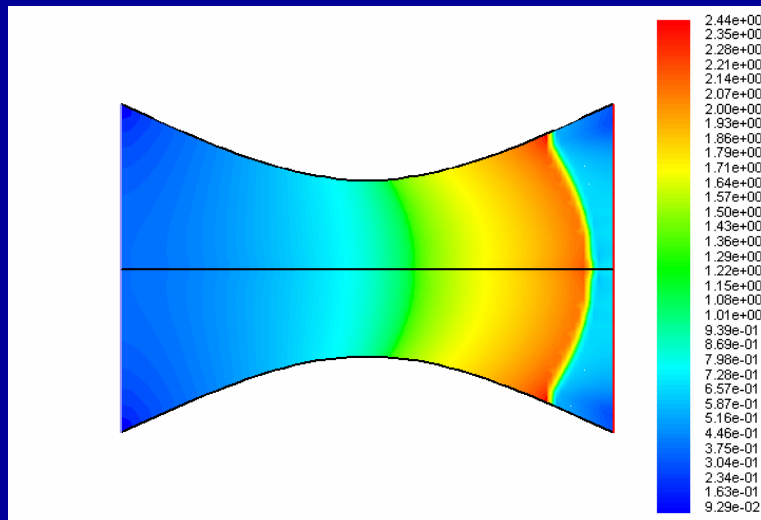
Pressure Contours



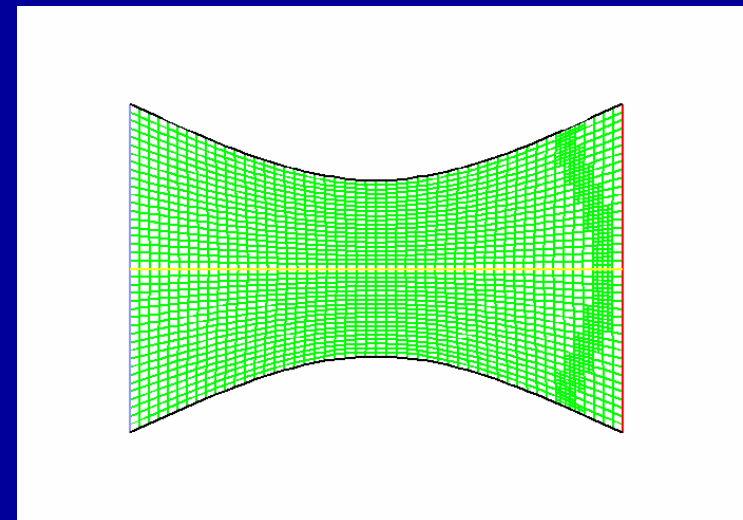
Example: Compressible Nozzle Flow

- Non-isentropic case: $P_{o,in}/P_{exit}=1.56$
- Quasi-1D analysis: Shock in the diverging section

Mach no. contours

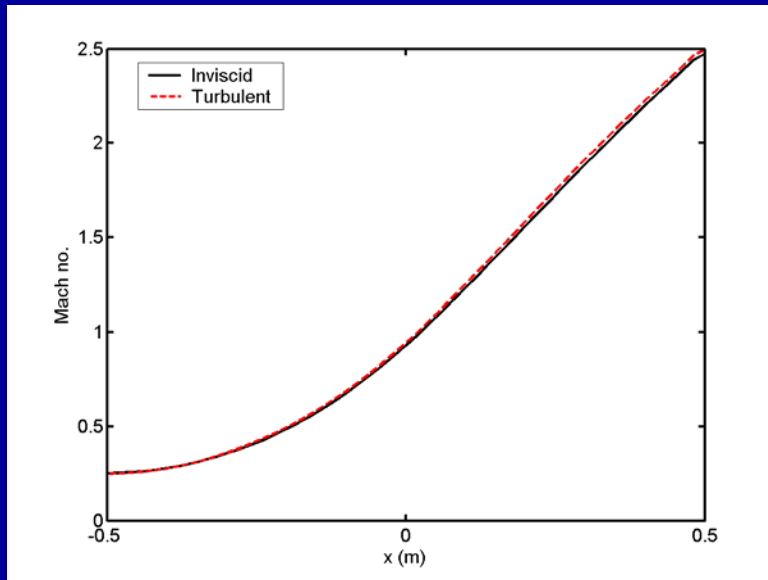


Adapted grid

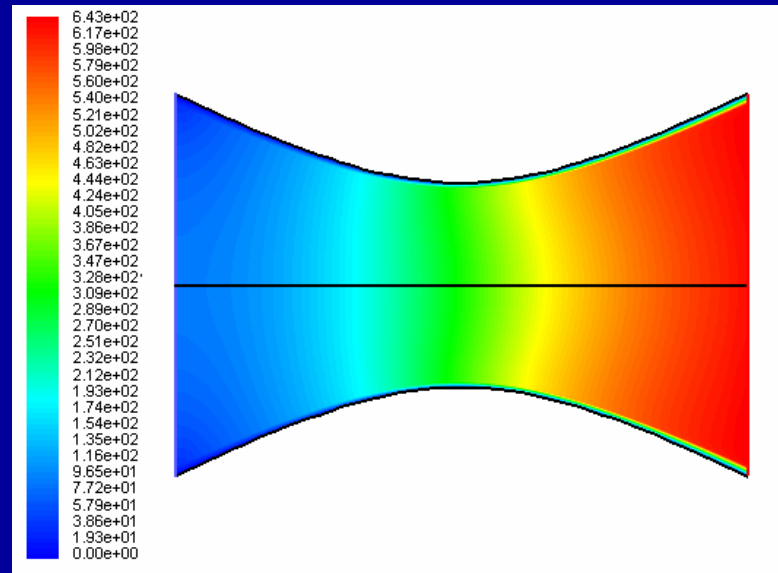


Example: Compressible Nozzle Flow

Mach no. variation
for turbulent case



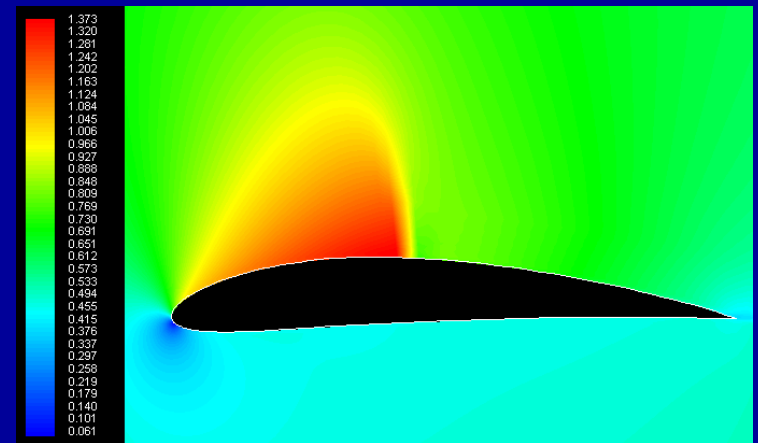
Velocity magnitude
for turbulent case



Inviscid assumption is valid for high Re, favorable dP/dx

Case Study Approach

- Case studies used in *Intermediate Fluid Dynamics*:
 - Laminar and turbulent developing flow in a pipe
 - Laminar and turbulent flat plate boundary layer
 - Flow over a backstep
 - Compressible nozzle flow
 - Flow over an airfoil
- Student survey in 2003:
24/38 students indicated
the case studies were their
favorite part of the course

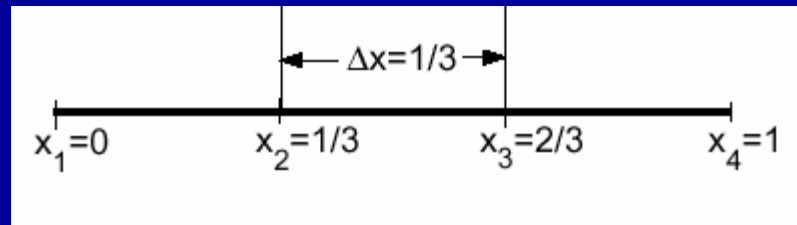


Introduction to Numerical Concepts

- To perform the case studies, students need to understand basic numerical concepts such as:
 - Why grid refinement is necessary?
 - What are first and second-order schemes?
 - Why iterations are required?
- The necessary background is provided through a brief introduction to the numerical solution procedure prior to the case studies

Introduction to Numerical Concepts

- Pedagogical philosophy used to introduce CFD basics:
 - Illustrate each step in CFD solution process on simple 1D model equation on a small grid
 - Relate model problem concepts to general CFD solution process for each step



- Makes fundamental concepts more concrete than a verbal and graphical description

Introduction to Numerical Concepts

- Topics chosen were the minimum necessary to perform and understand the case studies
- Topics can be revisited later in greater detail
- Similar to “just-in-time” teaching in a project-centered approach (Schmidt et al, 2003)
 - Teach a particular concept as students encounter it while performing a project

Web-Based Instruction

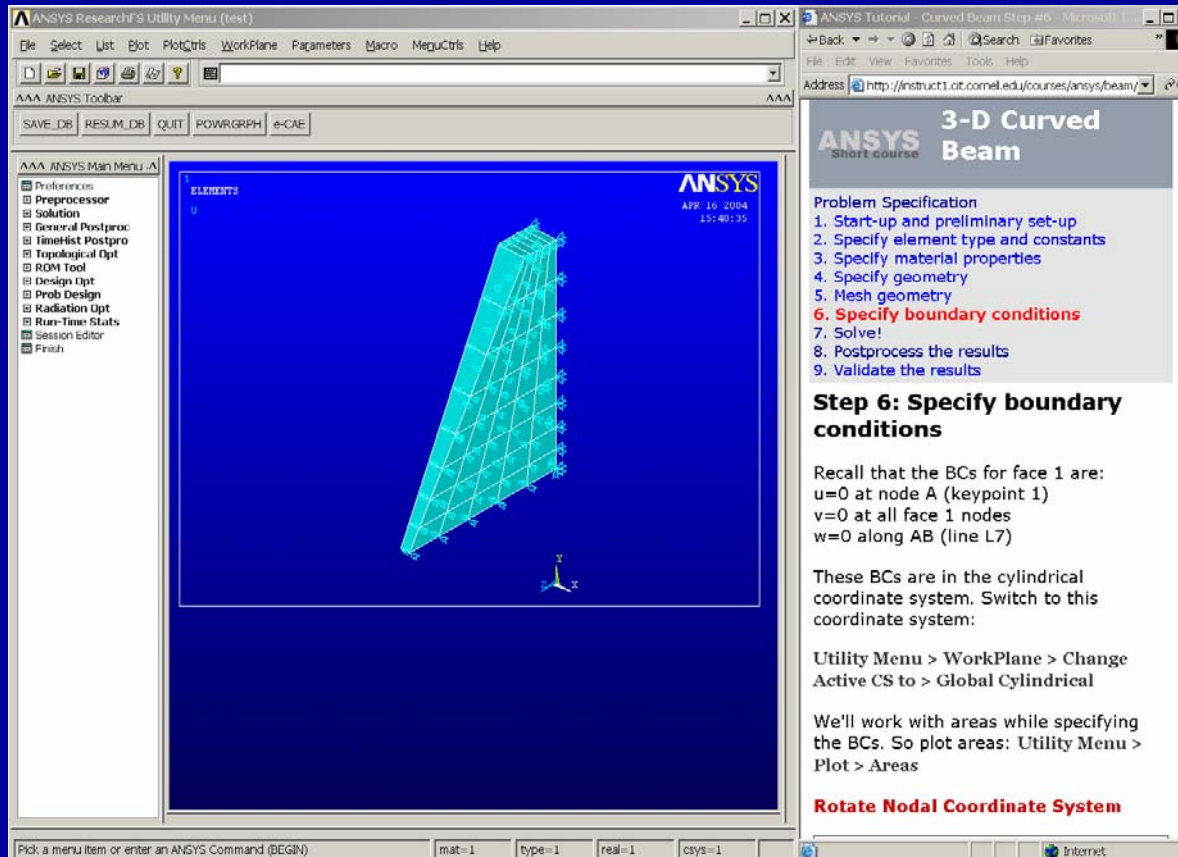
- Advantages of the web:
 - Reduces face-to-face time required for teaching the mechanics of using the GUI
 - Enables learning through self-paced, hands-on use
 - Can give real-time feedback to the user
 - Material easier to update for newer versions of the software

Web-Based Instruction

- Have developed web-based tutorials to teach the use of:
 - FEA simulations using ANSYS
 - CFD simulations using FLUENT
- Mode of use:
 - Run web browser and ANSYS/FLUENT interface side-by-side
 - Read instructions from browser and implement in ANSYS/FLUENT

Web-Based Instruction

Arrangement of ANSYS and browser windows



Web-Based Instruction

- As the user follows a tutorial and clicks away with the mouse, she is apt to lose track of the big picture
- Providing a structure to the learning experience is important
 - Each tutorial is broken down into the same steps
 - The list of steps appears at the top of each page of the tutorial
 - Current step is highlighted to track progress

Validation of Results





- Challenge: To teach students to regard the results skeptically
 - Discourage blind acceptance of results that the computer spits out
 - Analogous to the pitfalls of the “formula mentality”
- Added a separate validation step to each tutorial

Validation of Results

- Validation step in the ANSYS tutorials:
 - Do the deformed shape, stresses etc. look reasonable?
 - Are boundary conditions being applied correctly?
Check using animations
 - Do the reactions balance the applied forces?
 - Is the mesh resolution adequate?
 - How do the results compare with theory or handbook values?
- Demonstrate how easy it is to get wrong results

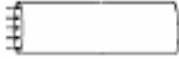

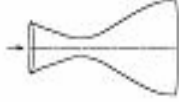

Web-Based Instruction

Basic ANSYS tutorials

	Two-Dimensional Static Truss
	Plate with a hole
	Vibration analysis of a frame
	Three-dimensional curved beam

Web-Based Instruction

Basic FLUENT tutorials

	Laminar Pipe Flow
	Turbulent Pipe Flow
	Compressible Flow in a Nozzle
	Flow over an airfoil

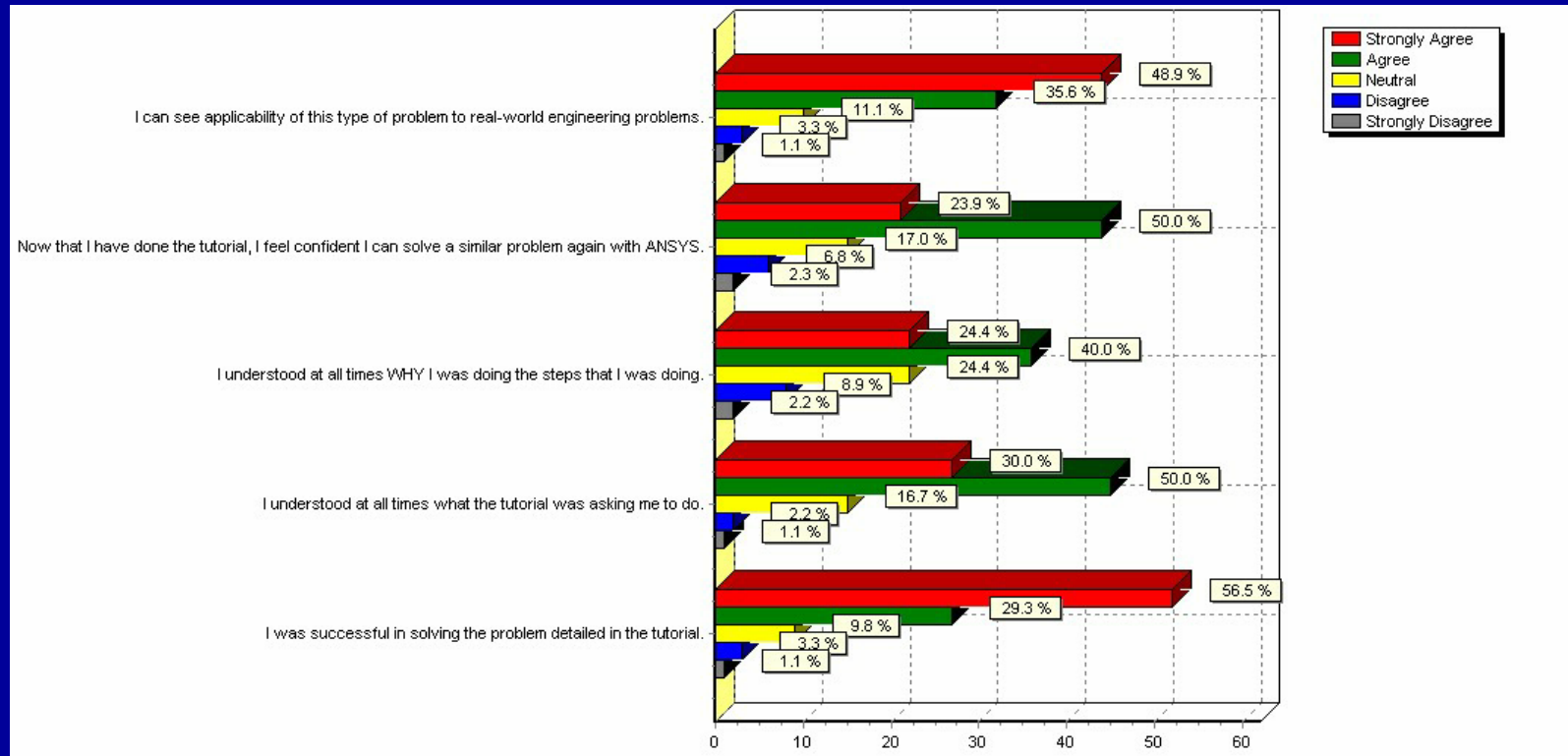
Tutorial repository is being built-up through student M.Eng projects

Student Response

- Student survey in *MAE470/570 Finite Element Analysis* in spring 2003 to evaluate the effectiveness of the ANSYS tutorials
- 48 survey responses
- Survey covered:
 - Navigational features and formatting
 - Pedagogical effectiveness

Student Response

Survey results on pedagogical effectiveness

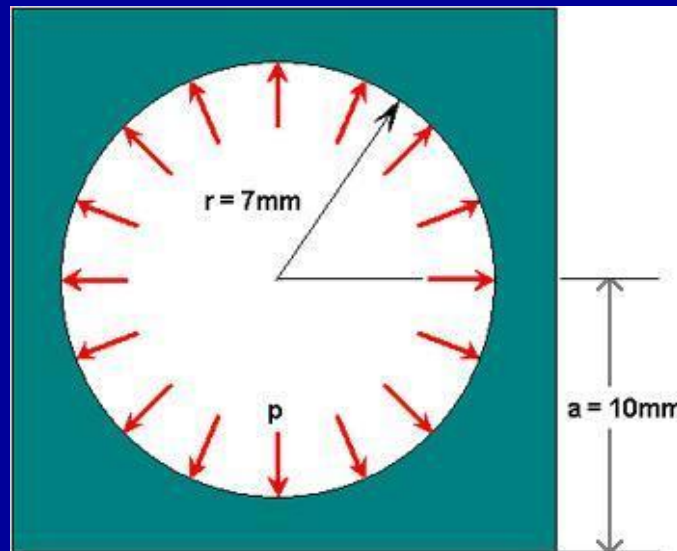


Experiential Learning

- Modus operandi:
 1. Students go through the tutorial outside of class
 2. Follow-on hands-on sessions in the classroom/computer lab
- Hands-on sessions:
 - Tweak original problem and study how the solution procedure and results change
 - A very effective way to clarify and reinforce concepts

Experiential Learning

- Example :
 - Plate tutorial: Solve using 4-node quadrilateral elements

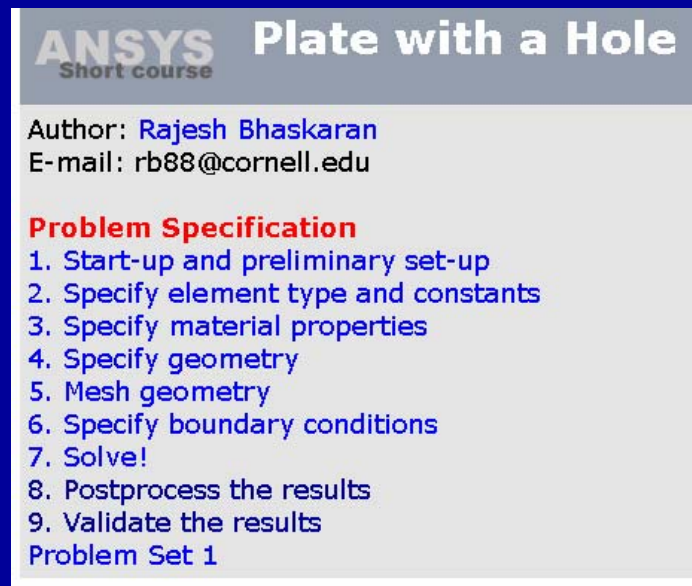


Experiential Learning

- Example (continued):
 - Hands-on session:
 1. Start from tutorial solution using 4-node quad
 2. Which of the nine tutorial steps need to be modified for the 8-node quad solution?

For instance, does the boundary condition specification step (step 6) have to be redone?

Opportune moment to discuss the difference between applying loads to the geometry or to the mesh



ANSYS Plate with a Hole
Short course

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Problem Specification

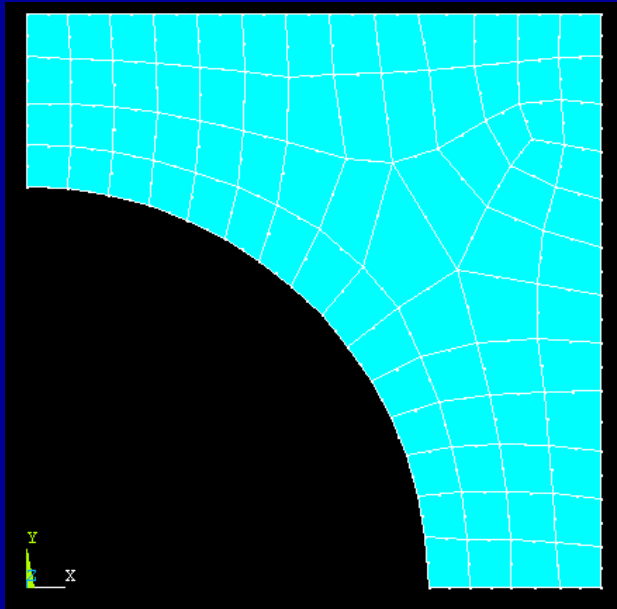
1. Start-up and preliminary set-up
2. Specify element type and constants
3. Specify material properties
4. Specify geometry
5. Mesh geometry
6. Specify boundary conditions
7. Solve!
8. Postprocess the results
9. Validate the results

Problem Set 1

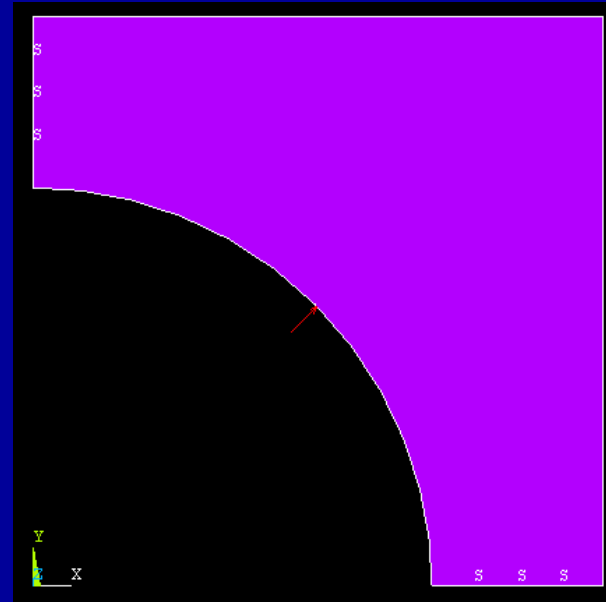
Experiential Learning

Remeshed Model

Element Model



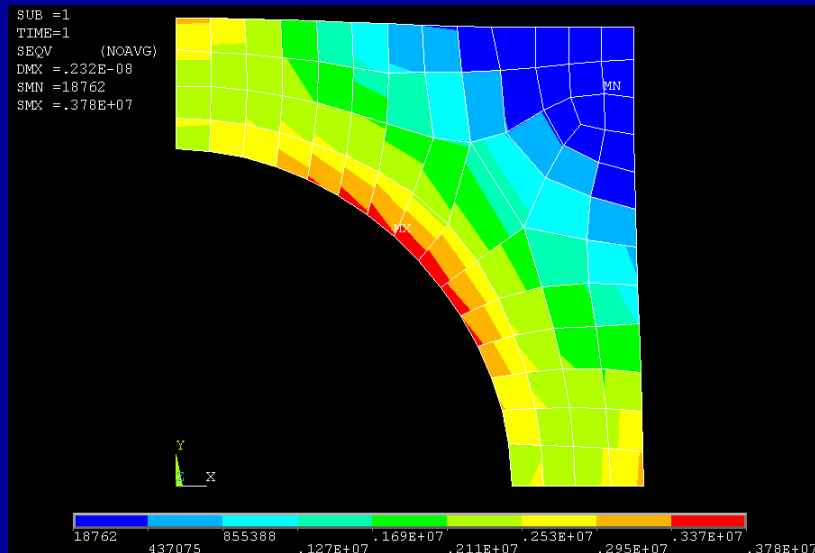
Geometry Model



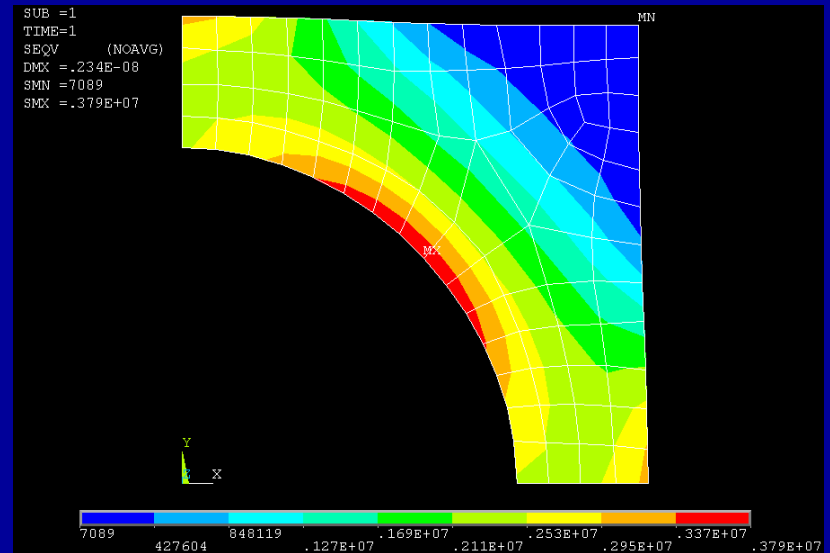
Experiential Learning

- Example :
 - Hands-on session (continued):
 3. Compare the element solutions for the two cases

Four-node quad



Eight-node quad



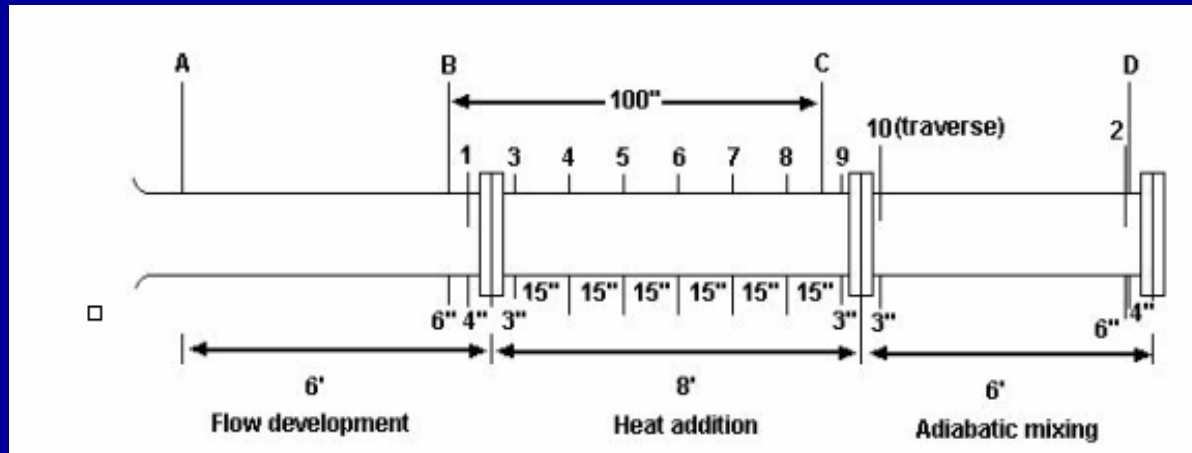
Experiential Learning

- Wallace & Weiner (1998):
 - Computer-based experiential learning more effective than traditional lecture-based learning
 - Hands-on exercises provide extra motivation for students to participate in learning in the classroom
- Combination of simulation and web technologies enables a new and more effective way of teaching

Simulations in a Lab Course

- Approach:
 - Perform simulation corresponding to experiment
 - Compare experimental and simulation results
- Experiment considered: Heated pipe flow
- *FlowLab*: Problem-specific front end to *FLUENT*
- Template development supported by NSF with Univ. of Iowa, Iowa State Univ., Howard Univ. and Fluent Inc. as partners.
- Software development done by Fluent with input from university partners

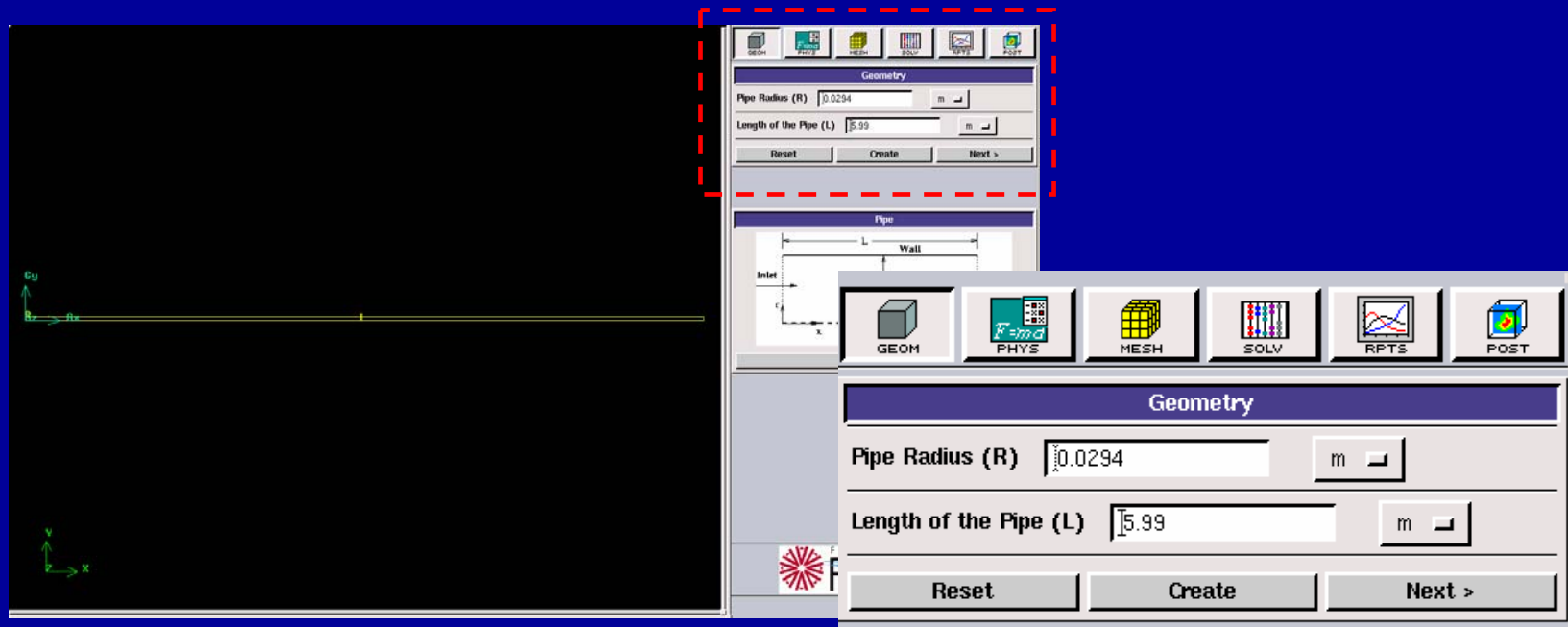
Heated Pipe Flow Experiment



- Raw measurements: Wall and gas temperatures; pressure drops; power to heater
- After number crunching, obtain Reynolds number, friction factor and Nusselt number

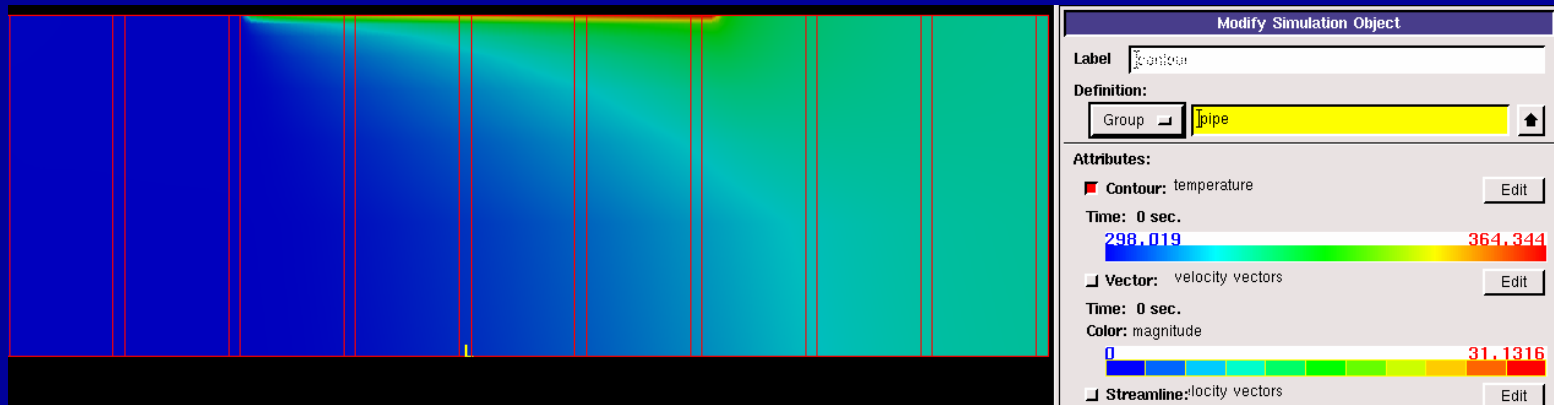
Heated Pipe Flow Experiment

FlowLab Interface



Heated Pipe Flow Experiment

FlowLab output: Temperature contours



Heated Pipe Flow Experiment

	Experiment	Correlation	Numerical Simulation
Reynolds number	100820	input	input
Friction factor	$.0180 \pm .003$	$.0177$	$.0168$
Nusselt number	185	183	192

Heated Pipe Flow Experiment

- Students gain:
 - Physical understanding of the experimental system that is hard to get from a few point measurements.
 - Confirmation of some aspects of the data processing for the experiment (e.g. that mixing region is long enough).
 - Confirmation of experiment and correlation.

Conclusion

- Case studies:
 - Canonical problems
 - Strong connection between simulation and theory
 - Enables a modular approach
 - Numerical concepts are introduced “just-in-time”
- Web-based instruction:
 - Self-paced, hands-on learning
 - Reduces face-to-face time required for teaching software use

Conclusion

- Experiential learning:
 - More hands-on, visual learning in the classroom
 - Combination of simulation and web technologies enables more effective pedagogy
- Simulation templates:
 - Enable simulation use in a lab setting
 - Contribute to improved understanding of the experiment

Conclusion

- Emphasis is on:
 - Understanding of the solution procedure
 - Analysis and validation of results
 - Concepts rather than skills
 - Making connections between fundamental concepts and simulation
 - Explaining abstract concepts through visual aids

External Feedback

Advisory Committee for Swanson Engineering Simulation Program

Chair: Dr. John Swanson, founder of ANSYS Inc.

Software Companies

ANSYS Inc.

Fluent Inc.

The Mathworks

PTC

University of Michigan

Engineering Companies

Boeing

Ford Motor Company

GE Aircraft Engines

General Motors

Pratt & Whitney

Acknowledgements

- Dr. John Swanson for supporting the *Swanson Engineering Simulation Program*
- Professors Lance Collins, Betta Fisher, Subrata Mukherjee
- NSF Department of Undergraduate Education
- Cornell University *Faculty Innovation in Teaching Grants* Program
- Website development: Marilyn Dispensa, Warren Wong
- *Swanson Engineering Simulation Program* Advisory Committee