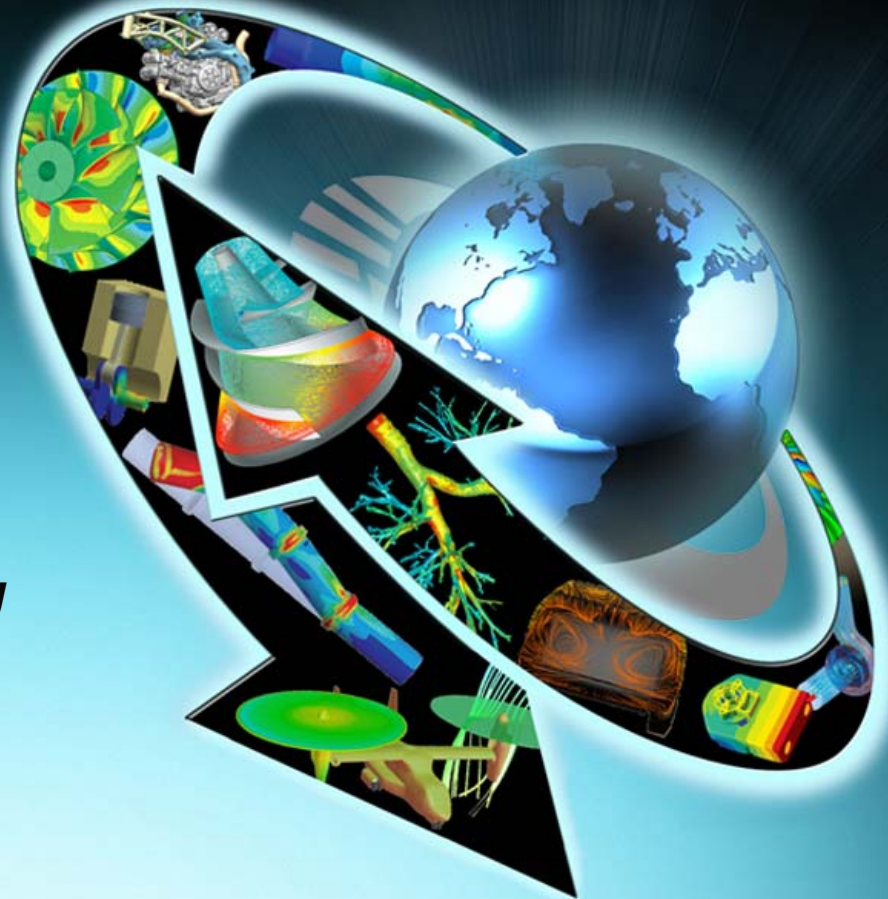




# Verification and Validation of FEA Simulations

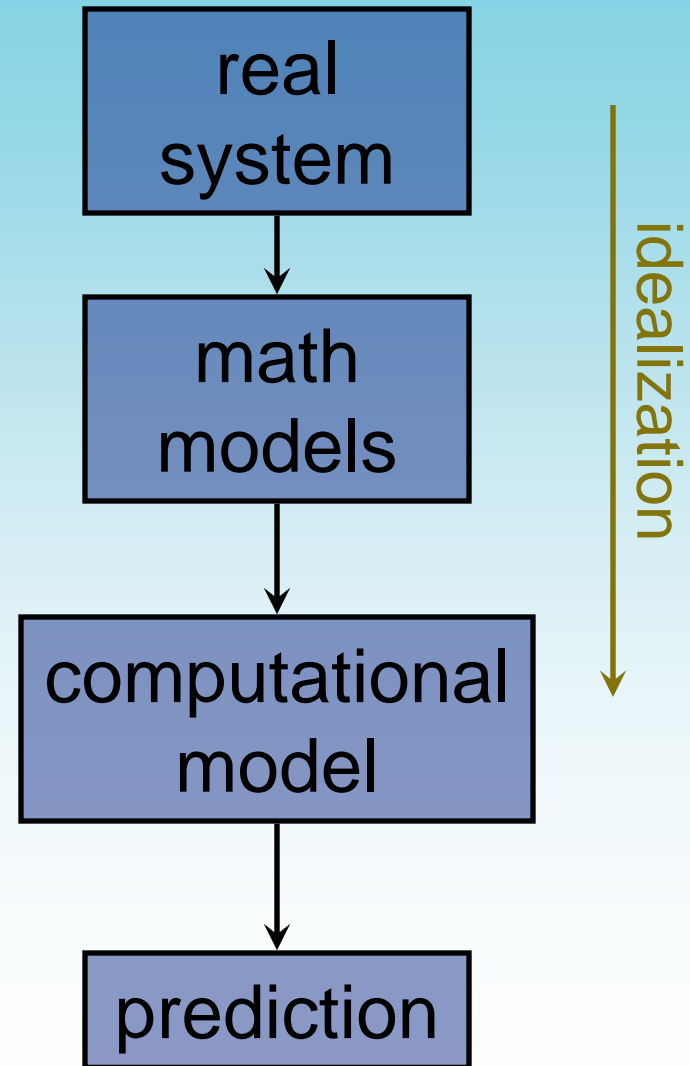
**Dave Conover**  
**Chief Technologist**  
**Mechanical Business Unit**  
**ANSYS, Inc.**

***Integration of Simulation  
Technology into the Engineering  
Curriculum***  
**Cornell University**  
**July 25-26, 2008**



- **You only learn 1/3 of what you need to know in school**
- **It's not what you know, it's what you can know**
- **Critical thinking and problem solving are crucial**
- **A good grounding in the basics and fundamentals will take you far**

**Simulation** is the prediction of the behavior of engineered systems via *mathematical* and *computational* models



- 1. What question am I trying to get an answer to?**
  - Correct an observed failure?
  - Validate a product design? (What criteria?)
  - Make a design more robust?
  - Lower the cost?
  - Gain product insight?
- 2. How accurate do I need to know it?**
  - Absolute answer or a trend?
  - What are the uncertainties?
- 3. What do I think the answer is?**
- 4. How will I validate it?**

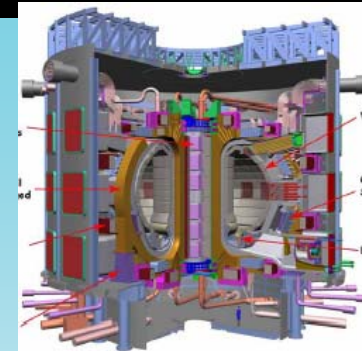
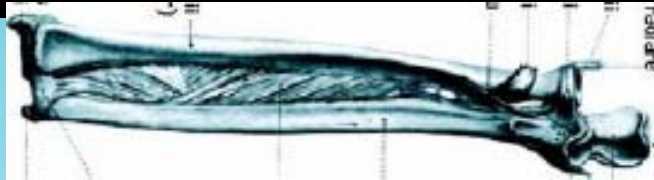
- **Verification is answering “Did I construct the **models right?**”**
  - Can I show the source of each assumption, each numerical model, and its required data?
  - Do they accurately represent the conceptual description of the real world?
- **Validation is answering “Did I construct the **right models?**”**
  - Is it an accurate representation of the real world?
  - Where the approximations and assumptions justified?

**“You cannot really  
validate a simulation,  
only invalidate it”**

# Simulation Process



real system



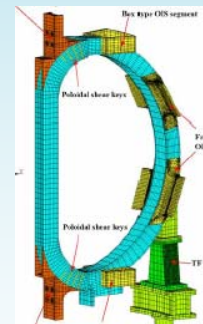
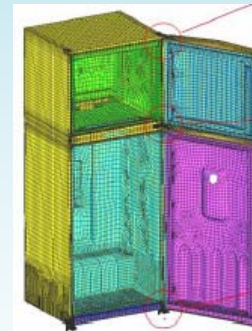
math models

$$\sigma_{ij}(x_i, t) = G_{ijkl}(x_i, t) \varepsilon_{kl}(x_i, 0+) + \int_0^t G_{ijkl}(x_i, t - \tau) \frac{\partial \varepsilon_{kl}(x_i, \tau)}{\partial \tau} d\tau$$

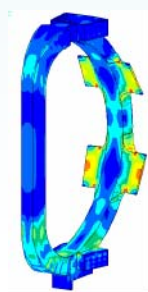
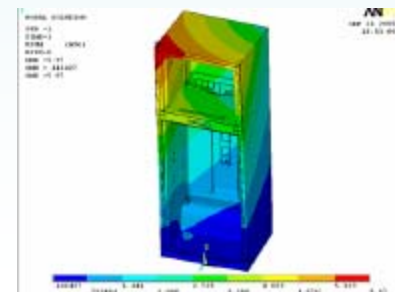
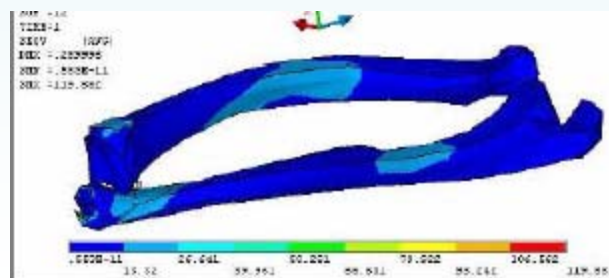
$$\delta \Pi_{int} = \int_{\bar{\Omega}} \int_{-h/2}^{h/2} \mathbf{P} : (\delta \mathbf{a}_\alpha \otimes \bar{\mathbf{g}}^\alpha + \delta \mathbf{a}_3 \otimes \bar{\mathbf{g}}^3 + \theta^3 \lambda \delta \mathbf{a}_{3,\alpha} \otimes \bar{\mathbf{g}}^\alpha) \mu d\theta^3 d\bar{\Omega} + \int_{\bar{\Gamma}_c} \int_{-h/2}^{h/2} \mathbf{T} \cdot (\delta [\mathbf{x}] + \theta^3 \lambda \delta [\mathbf{a}_3]) \mu d\theta^3 d\bar{\Gamma}_c.$$

$$\{\mathbf{F}^{\text{fb}}\} = \int_{\text{vol}} \{\mathbf{N}\}^T (\{\mathbf{J}\} \times \{\mathbf{B}\}) d(\text{vol})$$

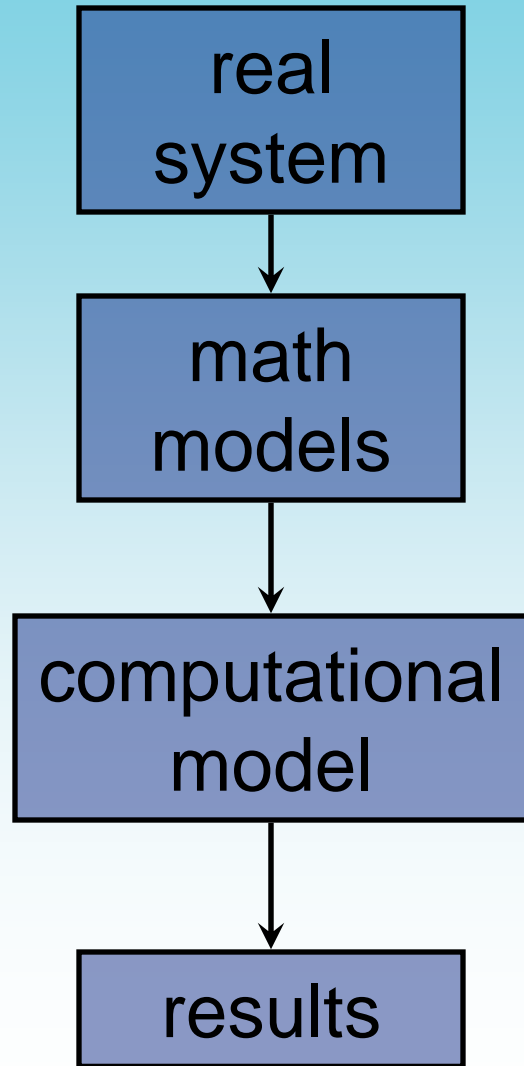
computational model



results

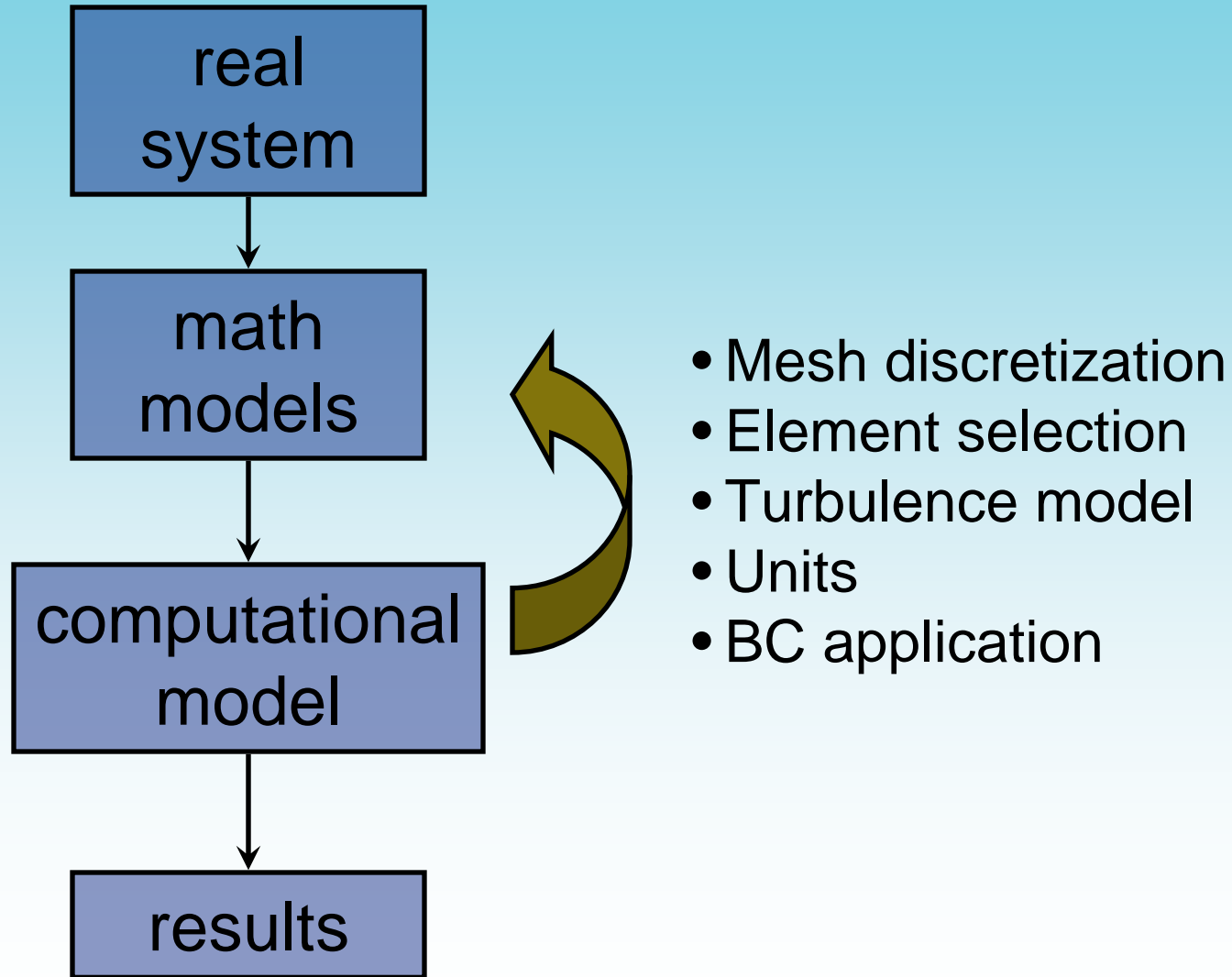


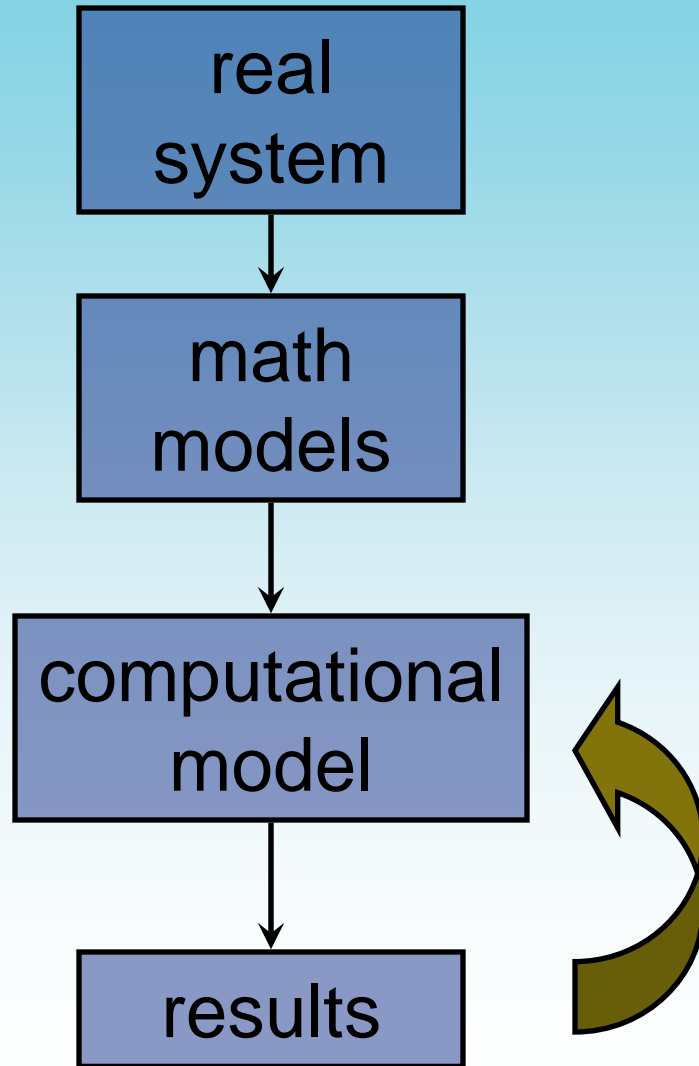
# Verification Questions



- Geometry
- Engineering assumptions
- Material model(s)
- BCs/environment
- Joints, welds, connections
- Uncertainties in data

# Verification

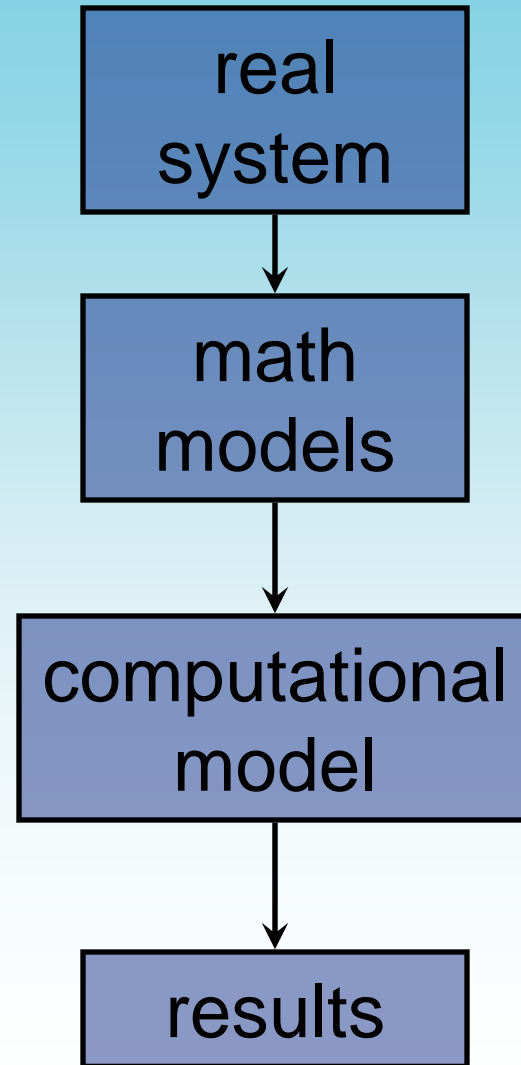




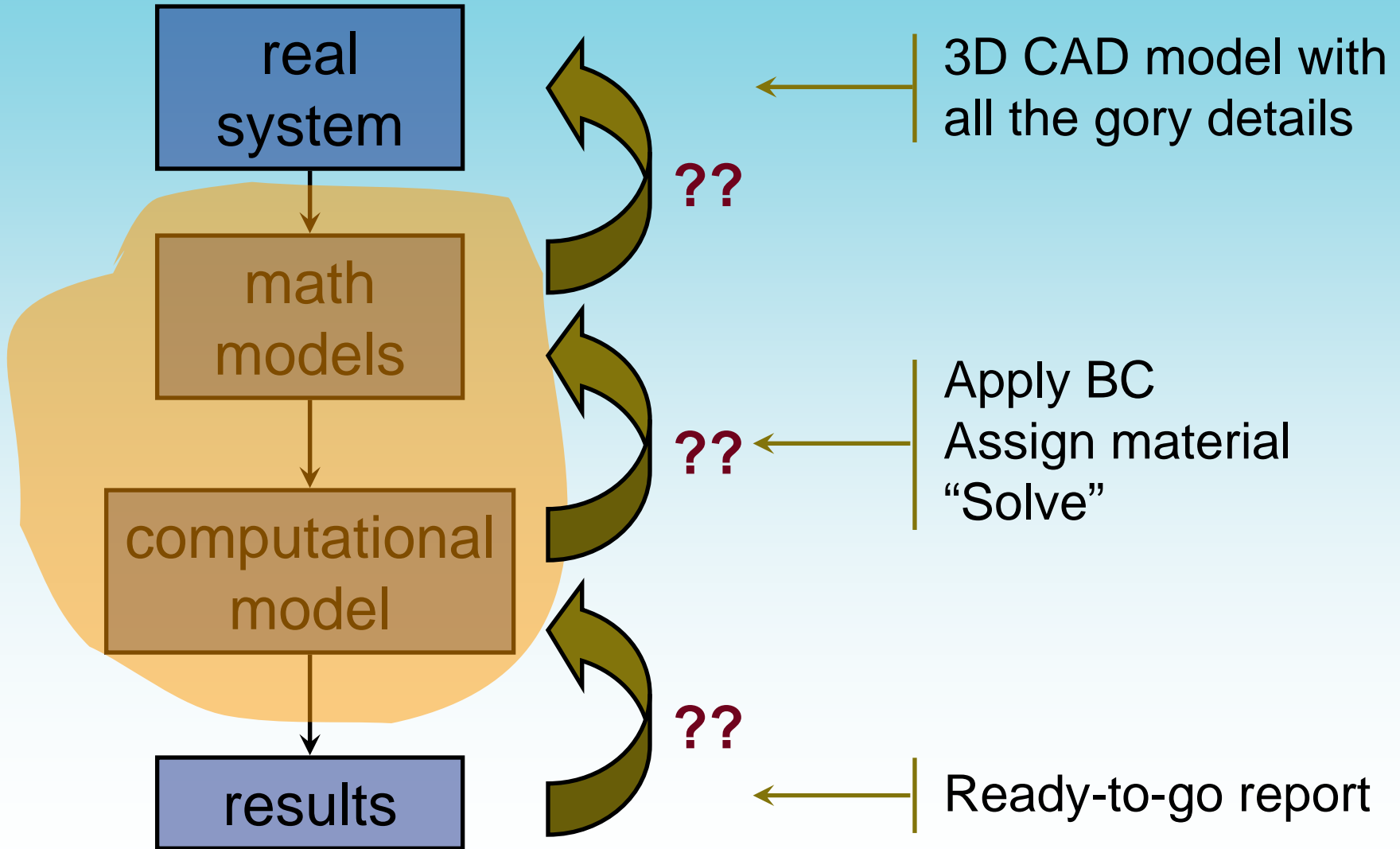
- Assumptions maintained
- Equilibrium attained
- Read notes and warnings
- Mesh and solver accuracy

# Validation Questions

- Comparisons:
  - Test results
  - Closed form solutions
  - Simplified analyses
  - Similar validated models
  - Historical data
- Reasonableness
- Anomalies justified



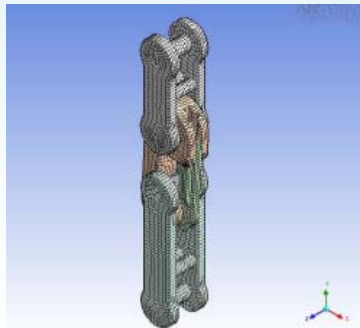
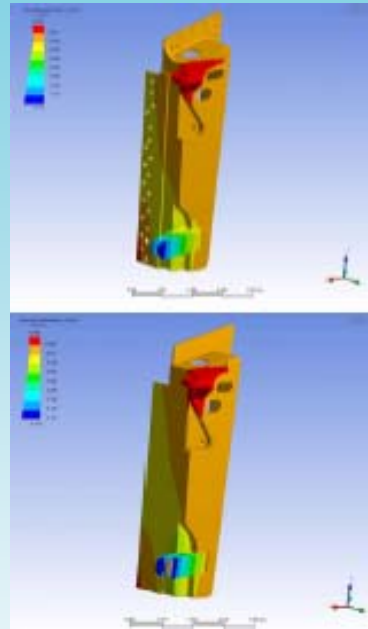
# "Push Button" GUI Debate



- **Thorough understanding of engineering principles**
- **Ability to think critically**
  - Analysis, synthesis and evaluation
- **Validation process as part of class work**
  - Formal part of reports and projects
  - Peer project reviews
  - Test and simulation done together

# Industry Examples<sup>†</sup>

...To verify that the simplified shell models were properly representing their solid counterparts, a test case was performed. The results of the test case showed that the calculated deflections and stresses of the solid component and simplified shell component were very similar.



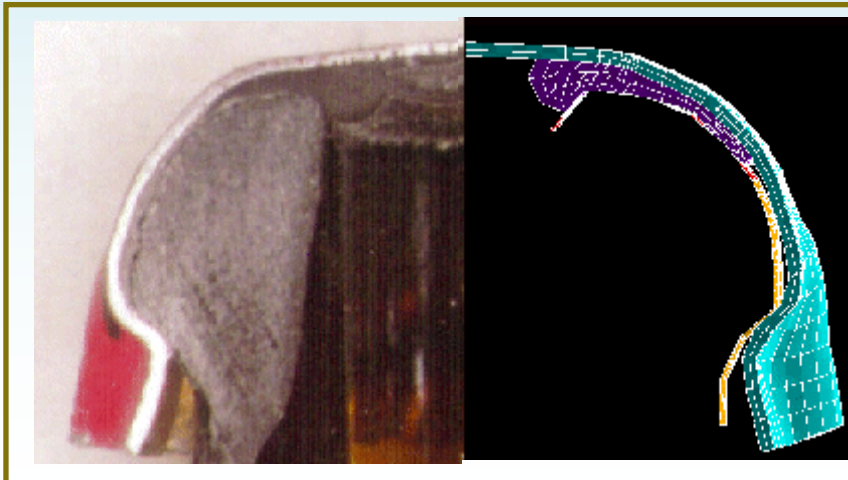
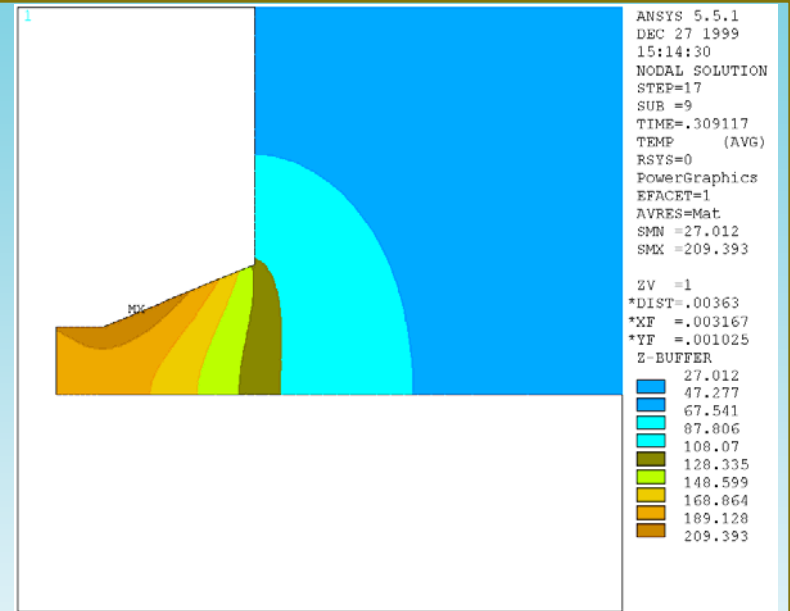
...Different meshes, contact parameters, solvers and load increments were tested in several analyses to improve the convergence and to verify the precision of the results.

<sup>†</sup> Taken from past ANSYS International Conference proceedings

# Industry Examples



...Since the purpose of this model is to describe a phenomena that is difficult or impossible of measure, verification of the model is also difficult. The verification presented here comes from two sources. First, some results found in the literature can help to determine if the simulation results are reasonable. Second, a closed form solution for the heat flux applied to semi-infinite plate can be used for comparison.



...We can now compare the geometry obtain by the simulation with true geometry. Figure 15 and 16 show good agreement between geometries.

# Industry Examples

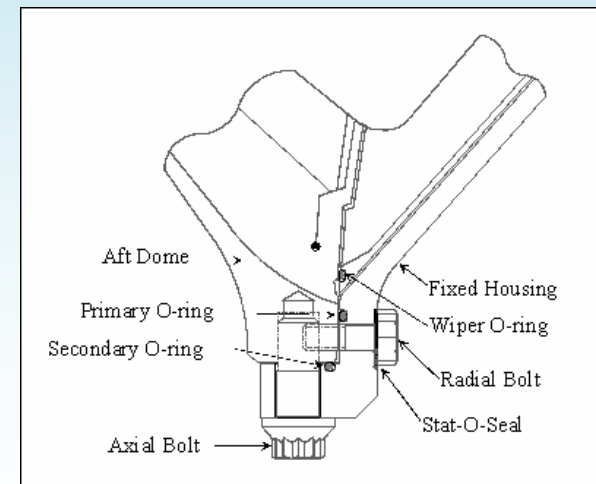
...In order to verify the accuracy of the nozzle-to-case joint finite element model, two comparisons were made. First, a comparison was made to the older finite element model from the late 1980's. Any difference in gap opening was investigated to determine the cause, and gain a better understanding of what was affecting the model. This older model had been previously correlated back to several experimental tests for verification. For a second comparison, the results from the new model were also compared to one of the experimental tests.

...

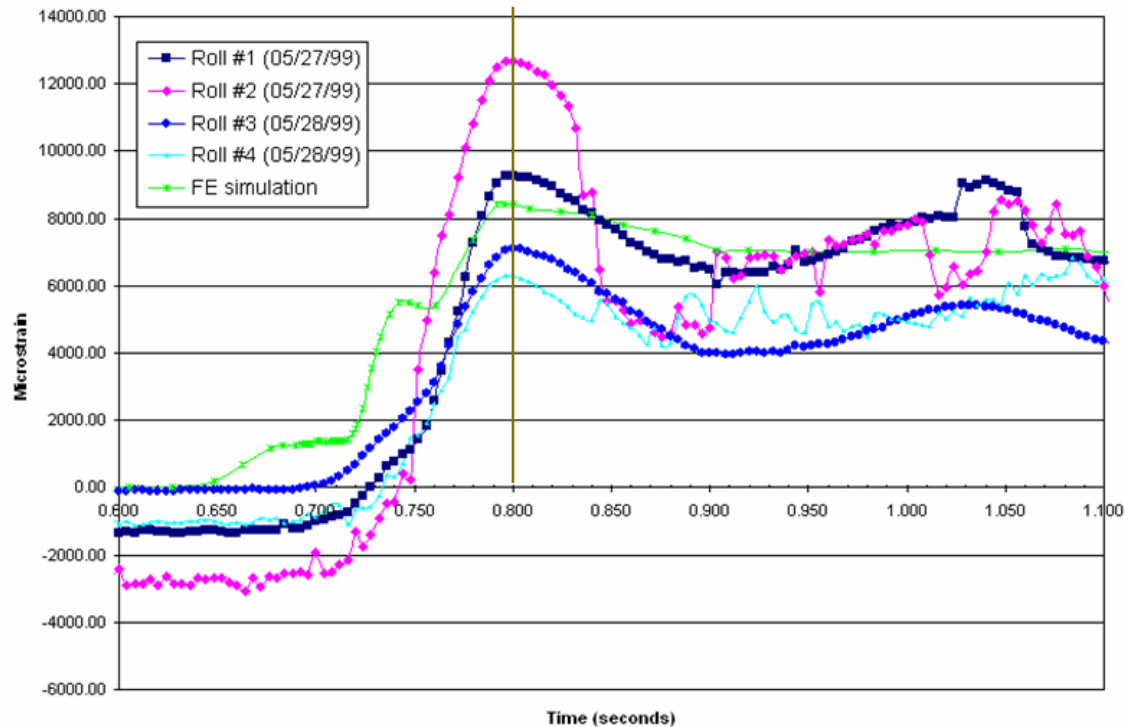
Several modifications were made to both models to determine why they behave differently. The main differences listed from most to least significance were:

- Use of the nonlinear geometry option
- Addition of the nozzle axisymmetric model
- Different contact elements

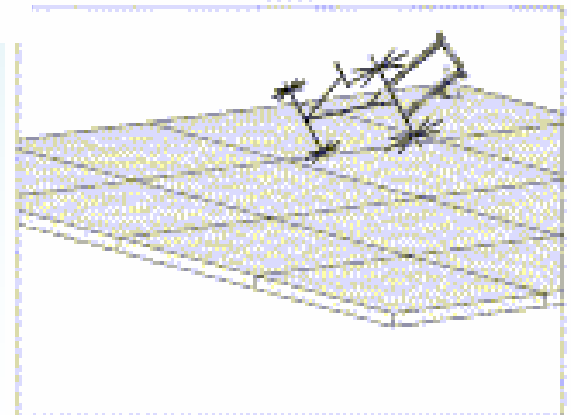
...



# Industry Examples



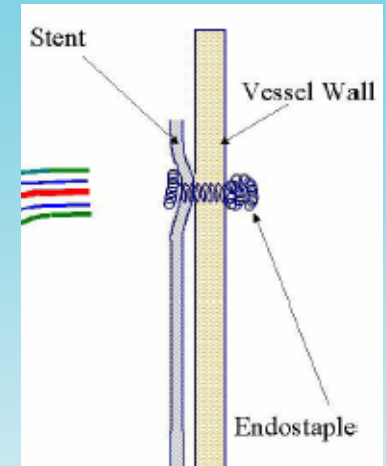
...a graph of strain readings for all four rolls. Strain gage readings for the unloaded roll bar, before 0.7 seconds, are not necessarily 0 strain, due to difficulties experienced in initially zeroing the amplification circuitry. Difficulties in initially zeroing the gage, however, should only affect the magnitude of the recorded signal, not the trend or pattern of strain.



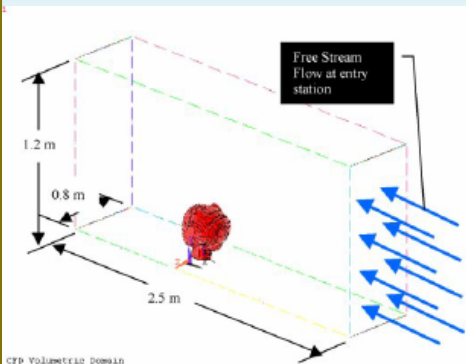
# Industry Examples



...The mesh refinement implemented in this study was verified via an independent analysis of the out-of-plane bending of a curved bar. The curved bar in this case was a prismatic semi-circular beam, of solid circular cross-section, which was fully restrained against motion at the fixed end, and loaded perpendicular to the plane of the beam at the free end. This configuration was utilized because exact solutions for this problem are widely available in the open literature.



...mathematical modeling of airflows is very complex especially where a significant part of the flow is turbulent. This is compounded further if compressibility effects have to be taken into consideration. In this application, it was anticipated that turbulence and compressibility effects would be significant. It was therefore crucial that the computer model was 'calibrated' by carrying out a series of low speed wind tunnel test correlations to ensure that any avoidable inaccuracies such as poor meshing are minimized before proceeding to carrying out the simulation at 450 knots.



- NAFEMS <http://www.nafems.org/>
- *VV&A Recommended Practices Guide* (DoD) <http://vva.dmsso.mil/>
- *Simulation-Based Engineering Science - Revolutionizing Engineering Science through Simulation*, A Report of the National Science Foundation Blue Ribbon Panel [http://www.ticam.utexas.edu/events/SBES\\_Final\\_Report.pdf](http://www.ticam.utexas.edu/events/SBES_Final_Report.pdf)
- *Building Better Products With Finite Element Analysis*, Adams, V., Askenazi, A., (1998)
- [www.xansys.org](http://www.xansys.org), an ANSYS email list server