Technical Requirements for the Deployment of Engineering Simulation Apps

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Executive Summary

• Democratization of numerical simulation through the development and deployment of expert-designed Engineering Simulation Apps is gaining momentum.

• However, such apps must satisfy certain technical requirements to ensure the level of reliability expected in professional use.
Benefits & Value to Industry

• Making difficult classes of problems easier to analyze, more accurate, and faster to solve by the specialist analyst

• Making routine classes of design analysis problems solvable by designers and engineers as they did for years when using handbooks produced by methods groups

• Empowering new engineers to be productive sooner with access to reliable technology capturing the institutional knowledge and best practices in the form of simulation apps
Outline

• Smart Simulation Apps
  – What are they?
  – Why are they important?
  – What are the challenges?

• Technical Requirements
  – Simple: Easily understood
  – Accurate: Correct in all details
  – Efficient: Achieve goals with minimum effort
  – Reliable: Trusted quality of approximation
Smart Simulation Apps

What do we mean by Sim Apps?
Why are they important?
What are the challenges?
Smart Simulation Apps
What are Sim Apps?

• FEA-based software tools for standardization and automation of recurring analysis tasks and process workflows
  — Developed by expert analysts for users who are non-specialists
  — Designed to fit into existing analysis processes that capture institutional knowledge and best practices
  — Consistent results are produced by tested and approved analysis procedures
Smart Simulation Apps
Why are Sim Apps Important?

• Proper application of numerical simulation procedures requires expertise in computational engineering that is not widely or readily available
  – Smart Simulation Apps leverage this expertise for recurring analysis tasks and process workflows
    • Similar to the expertise of specialists in applied mechanics made available through engineering handbooks
Smart Simulation Apps

Why are Sim Apps Important?

• Deploy models of much greater complexity than those available in engineering handbooks
  – Fewer simplifying assumptions than classical methods
  – Adaptable to industry, company and products
Smart Simulation Apps
What are the Challenges?

• Definition and enforcement of modeling rules
  – Ensure that modeling assumptions, meshing rules, element selection, extraction of results are consistent with the principles and methods of numerical simulation

• Expertise and time required to anticipate all variations and use cases
  – Dependent on experts to create and manage, including the performance of Q/A

• ROI from process automation problematic
  – Overall complexity and time to create by experts before allowing non-experts to use
Smart Simulation Apps
What are the Challenges?

• Geometry approximation: Low-order mapping problematic and too much de-featuring needed
  – Meshes and elements requiring restriction that only an expert can understand and are dangerous to use without the expert

• Solutions of high-fidelity, multi-scale problems are difficult
  – Solutions are not continuous but discrete and nodal based, making it difficult to get accurate stress in regions of high stress concentration
Smart Simulation Apps
What are the Challenges?

• A-posteriori quantification of solution accuracy for every set of inputs and result of interest
  – Need to ask the expert author of the Sim App
  – If an expert is needed to tell when the solution is right, the expert is also needed to tell when it is not

  3D solid modeling of large scale geometries challenging when thin domains are involved
  – Large element libraries and mixture of incompatible models (shell-solids, shell-beams, etc.) compound the problem
What are the Challenges?  
Example Element Library

1. C3D4 4-node linear tetrahedron
2. C3D4H(S) 4-node linear tetrahedron, hybrid with linear pressure
3. C3D6(S) 6-node linear triangular prism
4. C3D6(E) 6-node linear triangular prism, reduced integration with hourglass control
5. C3D6H(S) 6-node linear triangular prism, hybrid
6. C3D20R(S) 20-node quadratic brick, reduced integration
7. C3D8H(S) 8-node linear brick, hybrid with constant pressure
8. C3D8I 8-node linear brick, incompatible modes
9. C3D8IH(S) 8-node linear brick, incompatible modes, hybrid with linear pressure
10. C3D8R 8-node linear brick, reduced integration with hourglass control
11. C3D8RH(S) 8-node linear brick, reduced integration with hourglass control, hybrid with constant pressure
12. C3D10(S) 10-node quadratic tetrahedron
13. C3D10H(S) 10-node quadratic tetrahedron, hybrid with constant pressure
14. C3D10I(S) 10-node general-purpose quadratic tetrahedron, improved surface stress visualization
15. C3D10M 10-node modified tetrahedron, with hourglass control
16. C3D10MH(S) 10-node modified tetrahedron, with hourglass control, hybrid with linear pressure
17. C3D15(S) 15-node quadratic triangular prism
18. C3D20(S) 20-node quadratic brick
19. C3D20H(S) 20-node quadratic brick, hybrid with linear pressure
20. C3D20R(S) 20-node quadratic brick, reduced integration
21. C3D20RH(S) 20-node quadratic brick, reduced integration, hybrid with linear pressure
22. C3D15V(S) 15 to 18-node triangular prism
23. C3D15VH(S) 15 to 18-node triangular prism, hybrid with linear pressure
24. C3D27(S) 21 to 27-node brick
25. C3D27H(S) 21 to 27-node brick, hybrid with linear pressure
Example Element Library
Reduced Integration

• What is the problem?
  – Reduced integration was introduced because low-order elements were found to be “too stiff”
  – It was found that reducing the number of quadrature points the elements become more “compliant”
    • Unrealistic expectation: The error of approximation caused by low-order elements is always canceled by the error in integration
    • Instability: Reduced integration elements are prone “hour-glassing” (zero energy modes of deformation)
  – This type of elements makes solution verification impossible
Smart Simulation Apps

Technical Requirements
Simple – Accurate – Efficient – Robust – Reliable
Smart Simulation Apps

Technical Requirements

• Across the simulation functions of knowledge capture, conceptualization, modeling, numerical approximation and prediction, the technology foundation used by Sim Apps should be:
  – Simple & Standard
  – Accurate & Complete
  – Fast & Efficient
  – Robust & Reliable

• If they meet these technical requirements then they are what we consider Smart Sim Apps!
Smart Simulation Apps

Technical Requirements

**Simulation Functions**
Knowledge capture – conceptualization – modeling – numerical approximation – prediction

**Physical Reality** → **Mathematical Model** → **Numerical Solution** → **Prediction**
- Conceptualization
- FEA
- Extraction

**Technical Requirements**
Simple & Standard – Accurate & Complete
Fast & Efficient – Robust & Reliable
Technical Requirements
Simple & Standard

• **Simple**: Minimal element library to capture topology
  – Feasible to use 3D solid elements throughout

• **Standard**: Numerical simulation
  – Idealization separate from the approximation
  – Support high-fidelity, multi-scale analysis on the same mesh – same elements for all analysis types
Simple & Standard Numerical Simulation

- Development of the knowledge base of FEA and technical requirements for Verification and Validation

Parallel development since the 1970s

1. The first paper on FEM (1956)
2. NASA RFP for structural analysis software (1965)
3. The first mathematical papers on FEM (1972)

Predictions with Solution Verification
Predictions w/o Solution Verification
Numerical Simulation
Hierarchic Spaces & Models
Legacy FEA
Finite Element Modeling
Tuning
Technical Requirements
Accurate & Complete

• **Accurate:** Numerical simulation is more than the mesh!
  – Objective measure of solution quality every time
  – Feedback when the answer exceeds rules or is wrong
  – High-resolution results from low-density meshes

• **Complete:** One model for structural response and detailed stresses
  – Continuous solution available for post-processing
  – Convergence assessment of any function, anywhere, anytime
Accurate & Complete Example Contact Problem

Effect of rework on max stress in lip area of housing
Accurate & Complete Example Contact Problem

High resolution results from low density meshes
Technical Requirements

Fast & Efficient

• **Fast**: Simplified modeling and live post-processing
  – Fewer reruns tweaking the mesh speeds up process
  – Fast automatic sequence of solutions for error control
  – A-posteriori error estimation of any result anywhere in the model

• **Efficient**: Large 3D solid models for detail stress analysis are feasible
  – No need to mix shells and solids
  – Same elements for all analysis types
Fast & Efficient
Example Thin-Wall Structure
Fast & Efficient
Example Thin-Wall Structure

Efficient meshes for 3D solids
Technical Requirements
Robust & Reliable

• **Robust**: Must fit existing workflows and use terminology familiar to end user
  – Meshes and processes are not brittle
  – Must be safe to use and fault tolerant

• **Reliable**: Usable by specialists and non-experts alike with confidence
  – Users receive an objective measure of solution quality without an expert on call
Robust & Reliable Example e-Handbook
Robust & Reliable Example e-Handbook
Robust & Reliable Example e-Handbook

Safe to use with objective measure of quality
Smart Simulation Apps
Summary

• Engineering Simulation Apps provide a framework for the preservation and accumulation of institutional knowledge
  – Fit into existing analysis processes
  – Capture best practices
  – Produce consistent results
  – Remove operator-dependence
  – Increase productivity
Smart Simulation Apps Summary

• Engineering Simulation Apps are “Smart” when enabling simple, accurate, efficient, robust, and reliable simulations with built-in quality assurance
  – Simulation apps must incorporate solution verification procedures for all reported results
• Essential technical requirement of Simulation Governance
Thank You!

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TECHNICAL REQUIREMENTS FOR THE DEPLOYMENT OF SMART ENGINEERING SIMULATION APPS

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Democratization of numerical simulation through the development and deployment of Smart Engineering Simulation Apps is gaining momentum; however such apps must satisfy several important technical requirements to ensure the level of reliability needed for professional use by experts and no-experts alike.

What are Smart Engineering Simulation Apps?

By Smart Engineering Simulation Apps we mean FEA-based software tools for standardization and automation of recurring analysis tasks and process workflows for use by non-specialists. Designed to fit into existing analysis processes of an engineering organization or industry, simulation apps ("sim apps") capture institutional knowledge, best practices and design rules, can be shared by engineering groups at different geographic locations and produce consistent results by tested and approved analysis procedures. When designed to meet the requirements of Simulation Governance, sim apps for engineering use are "smart" because their embedded intelligence enables accurate, efficient, robust, and reliable simulations with built-in quality assurance, so critical for the non-expert user.
References

• First paper on FEA

• Hierarchic models and simulation

• More references available at [www.esrd.com](http://www.esrd.com)