The Role of Simulation Governance in the Democratization of Simulation Through Sim Apps in the A&D Industry

Ricardo L. Actis & Barna A. Szabo
Engineering Software Research & Development, Inc.
Saint Louis, Missouri

8 November 2017
NAFEMS Benchmark July 2017

The Big Issues

Hosting the Debate - Finding the Answers
Ian Symington, Technical Officer, NAFEMS

SHORT TERMS WITH BIG MEANINGS

We operate in an industry littered with jargon and terminology, and so I think it was appreciated, by everyone when Barna Szabo started his presentation with clear, precise, definitions on some of the terms featured in the congress “Big Issues”

Simulation Governance -
What it takes for organizations to develop confidence in the results of their numerical simulation projects.

Democratization -
How to extend the benefits of numerical simulation to persons whose expertise is in other fields

Certification -
How to convince others that the results of numerical simulation can be trusted.
Outline

• Value of numerical simulation
  – Simulation challenge

• Simulation function
  – Role of Simulation Governance

• Democratization of simulation
  – Enabling technology for democratization

• Examples

• Concluding remarks
Value of Numerical Simulation

• The technical and business value of numerical simulation performed by engineers in the aviation, aerospace, and defense industry is well established.

• However, the performance requirements and system complexity of the products that must be designed and sustained over many years of operation have increased exponentially.

• Creating additional demands on engineering to improve the speed and reliability of simulation and analysis functions.
The Simulation Challenge

• **Industry trends**
  - More simulations being performed than ever
  - Increased performance expectations
  - Systems engineering integration
  - Engineering shortage from industry retirement

• **Engineering challenges**
  - Moving high fidelity simulation earlier in the design cycle
  - Increased complexity, higher fidelity and more configurations and variance of design
  - Compressed engineering design cycles
  - Concurrency of engineering and build

• **Simulation drivers**
  - Higher-fidelity analyses with increased reliability
  - Avoid the analyst team to be ‘silied’ further due to complexity of tools
  - Higher-performing structures that are more efficient and reliable
The Numerical Simulation Challenge

- Incremental improvements made to the status quo of simulation without greater innovation are reaching a point of diminishing returns to address these new challenges.

- At the same time, the capabilities and complexity of the analysis tools require ever greater levels of expertise and specialization from the engineering staff.

- Simulation governance, a concept that originated from the appreciation that numerical simulation is a highly complex activity, is essential to address these challenges.
Simulation Function
What are the Challenges?

\[(D, I) \rightarrow F \rightarrow F_{\text{num}}\]

Transformation of one set of data $D$ based on an idealization of physical reality $I$ to the quantities of interest $F$ approximated by $F_{\text{num}}$
Simulation Function

What are the Challenges?

(D, I) $\rightarrow$ F $\rightarrow$ $F_{num}$

- Aleatory uncertainties
- Epistemic uncertainties
- Approximation Errors

Physical reality

Mathematical model

Numerical solution

Prediction

Conceptualization

Finite Element Analysis

Extraction Procedures

What is the role of Simulation Governance?

idealization

approximation
Role of Simulation Governance
What it takes for organizations to develop confidence in the results of their numerical simulation projects?

- Management is responsible for the exercise of command and control over all aspects of numerical simulation. Therefore management is responsible for simulation governance
  - The procedures that must be established for enhancing and ensuring the reliability of predictions based on numerical simulation
    - Proper formulation of idealizations → mathematical models
    - Adoption of the best available simulation technologies and practices
    - Solution and data verification procedures
  - Key elements of Simulation Governance
    - Verification, validation,
    - uncertainty quantification and standardization
Value of Simulation Governance

Why is SimGov important?

• As the value of the simulation function increases, the practice of simulation governance becomes critical to ensuring the reliability and robustness of analysis methods and tools used in support of engineering decision-making processes.

• To remain competitive, companies need to manage their simulation resources and projects effectively:
  – Properly managed simulation is a valuable corporate asset.
  – Poorly managed simulation can be a great corporate liability.
Democratization of Simulation

• For many valid reasons, FEA software is regarded as so specialized that only expertly trained analysts can employ it with any degree of reliability and confidence in the results.

• Attempts to promote the use of FEA by general design engineers without expert training have been disappointing for equally valid reasons.

• There has been much discussion about the democratization of simulation, but is it feasible in an industry like A&D?
Democratization of Simulation

• The admirable vision for expanding the use of simulation by non-experts cannot be safely realized unless a new approach to analysis based on predictive computational science and numerical simulation emerges to replace the art of finite element modeling as it has been practiced up to now.

• The solution lies in the practice of Simulation Governance which provides safeguards to ensure that the most difficult computational problems can be solved by experts with confidence, while more routine analysis in support of design decisions can be performed by engineers without expert training.
Enabling Technology for Democratization

Brief history of FEA

• Development of the knowledge base of FEA and Simulation Governance

1. First paper on FEA – 1956
2. NASA RFP for structural analysis software – 1965
3. First mathematical paper on FEA – 1972
5. Demonstration of exponential convergence – 1984
8. Introduction of Simulation Governance – 2011
Enabling Technology for Democratization

What is needed?

• Simulation technologies based on legacy FEA struggle when used by engineers without specialized training due to their inability to measure solution quality, an essential requirement of SimGov. So what is needed?
  – Idealization separate from the approximation
    • Simple and minimal element library to capture geometry
  – Solution verification with automatic Q/A as an inherent capability
    • Objective measures of quality without an expert on call
  – Feasible to use solid elements throughout for A&D applications
    • High-fidelity, multi-scale analysis on the same mesh
  – Continuum solutions throughout model, not just nodal
    • Ability to perform live dynamic processing of results
Enabling Technology for Democratization

Simulation Apps

• With these technical requirements it is feasible to develop and deploy simulation apps that are S.A.F.E.R.
  – Simple – Accurate – Fast – Efficient – Reliable

• What are Simulation Apps?
  – FEA-based software tools for standardization and automation of recurring analysis tasks and process workflows
  – Developed by expert analysts, Sim Apps are designed to fit into existing analysis processes, capturing institutional knowledge and best practices and producing consistent results regardless of the user expertise with FEA
Simulation Apps

S.A.F.E.R. technical requirements

• **Simple & Accurate** – Predictive computational science instead of the art of finite element modeling
  – Minimal element library to capture topology
  – Feasible to use 3D solid elements throughout

• **Fast & Efficient** – Automatic sequence of solutions for error control
  – Proven extraction procedures for the data of interest
  – Solution verification for all reported results

• **Reliable & Robust** – Usable by specialists and non-experts alike with confidence
  – Must fit existing workflows and use terminology familiar to users
  – Objective measure of solution quality without an expert on call
Simulation Apps Example 1

Composite joint analysis – Enabling technology

- Single layer mesh (‘parent mesh’)
- Ply-by-ply mesh (‘auto-lamination’)

- Ply lay-up
Simulation Apps Example 1
Composite joint analysis – Enabling technology

‘Parent mesh’ update

‘Auto-lamination’ update

'Change Parameters'

Model Info | Parameters | Rules
--- | --- | ---
Name | Description | Expression | Value
l1 | skin thickness | 3.0000e-001
NL1 | Number of plys for t1 | 7.0000e+000
t2 | T-thickness | 2.0000e-001
NL2 | Number of plys for t2 | 5.0000e+000
L1 | Base length | 1.1000e+001
L2 | Extension | 8.0000e+001
L3 | Upright length | 3.2000e+000
W | width | 1.0000e+000
R | Radius | 9.0000e+001

Change Parameters

‘Parent mesh’ update

‘Auto-lamination’ update
Simulation Apps Example 1
Composite joint analysis – Deployment
Simulation Apps Example 1
Composite joint analysis – Deployment
Simulation Apps Example 1
Composite joint analysis – Energy release rate

Energy release rate $G_i$ along delamination front

Convergence of ERR at location of maximum value $G_i$ v. DOF
Simulation Apps Example 2

Crack propagation life – Enabling technology

- R&D tool in support of an experimental program to account for engineered residual stresses in lifing
  - Incorporation of the beneficial effects of residual stresses due to cold-expansion in the computation of crack propagation life of components with cold-worked holes
  - Life estimate procedures require accurate computation of SIFs along the crack front
  - The shape of the propagating crack is solution-dependent
Simulation Apps Example 2

Crack propagation life – Deployment

- **Given**: Initial crack in a cold-expanded hole, the spectrum loading, the material properties (E, ν, da/dN – ΔK curves), and the residual stress distribution
- **Compute**: the crack trajectory from the initial pre-crack to the critical crack size, the crack length as a function of the number of cycles, and the expected crack propagation life
Simulation Apps Example 2
Crack propagation life – Deployment

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Simulation Apps Example 2

Results – Crack propagation life estimates

- Crack front shape and step-by-step crack increment information
- Crack length as a function of the number of cycles
- SIF values along the crack front with objective measure of quality
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Concluding Remarks

How to extend the benefits of numerical simulation to persons whose expertise is in other fields?

• The technical requirements and challenges for the creation, deployment, and use of Sim Apps within the aerospace industry was examined

• The standardization, automation, and democratization of new technologies such as Sim Apps through the adherence to Simulation Governance offers the aerospace industry many benefits at the engineering, project, and business levels
Concluding Remarks

Benefits to A&D engineering

- Making difficult problem classes in simulation S.A.F.E.R. to respond to the increasing complexity of products and compressed engineering design cycles
- Simplifying, standardizing, and automating engineering analysis functions to become more reliable, and robust regardless of the expertise of the user
- Empowering new engineers to be productive sooner with access to tools that have captured institutional knowledge
- Elevating the role of analysts to a higher level by creating IP such as Sim Apps that captures organizational knowledge and best practices
- Bringing governance to the engineering simulation function, especially as it replaces more prototyping and physical testing, all to facilitate concurrency of engineering and build without adding more risk
Concluding Remarks

Business value to A&D

• Encapsulate the growing complexity of engineering analysis
  – Deploying best available simulation technology and suppressing the increasing time required for engineering analysis

• Contain the escalating cost of engineering analysis
  – and mitigating technical risks of engineering analysis

• Improve reliability of engineering analysis processes
  – by enhancing robustness of engineering analysis methods & tools
  – ensuring reliability for the expert and non-expert simulation analysts
  – and enlarging capacity and competency of engineering analysis groups
TECHNICAL REQUIREMENTS FOR THE DEPLOYMENT OF SMART ENGINEERING SIMULATION APPS

Ricardo Actis, D.Sc.

May 2016

Democratization of numerical simulation through the development and deployment of expert-designed Smart Engineering Simulation Apps is gaining momentum; however such apps must satisfy the technical requirements of Simulation Governance to ensure the level of reliability needed in professional use.

Thank You!

Ricardo Actis, President & CEO
ricardo.actis@esrd.com
+1-314-744-8083
www.esrd.com