Model Verification and Validation Process

Presented to: CBA Meeting

By: David Moorcroft

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Finite Element Models

- **Finite Element Model Software Programs**
  - ARE NOT FAA APPROVED
  - Are acceptable for use much like other engineering software
  - Must be credible programs

Dave's note: also applies to multibody software

LAACO DER Recurrent Workshop 1998

Numerical Methods Overview

- **The results of a numerical simulation are completely dependent on the quality & accuracy of the model**
  - The software should be credible
  - The solution should be accurate
  - The simulation results should be compared to high quality test data
  - The test-simulation comparison should be quantitative
  - The process and results should be documented

ASME V&V 10-2006

- V&V 10-2006: Guide for Verification and Validation in Computational Solid Mechanics
  - V&V10.1-2012: Illustration of the Concepts of V&V in CSM

- "V&V are the processes by which evidence is generated, and credibility is thereby established, that the computer models have adequate accuracy and level of detail for their intended use."

Guide Outline

1. ***Introduction*** – the general concepts of verification and validation are introduced and the important role of a V&V Plan is described.

2. ***Model Development*** – from conceptual model, to mathematical model, and finally the computational model are the keys stages of model development.

3. ***Verification*** – is subdivided into two major components: code verification - seeking to remove programming and logic errors in the computer program, and calculation verification – to estimate the numerical errors due to discretization approximations.

4. ***Validation*** – experiments performed expressly for the purpose of model validation are the key to validation, but comparison of these results with model results depends on uncertainty quantification and accuracy assessment of the results.

Verification vs. Validation (Colloquially)

Verification – are the equations being solved correctly -> math

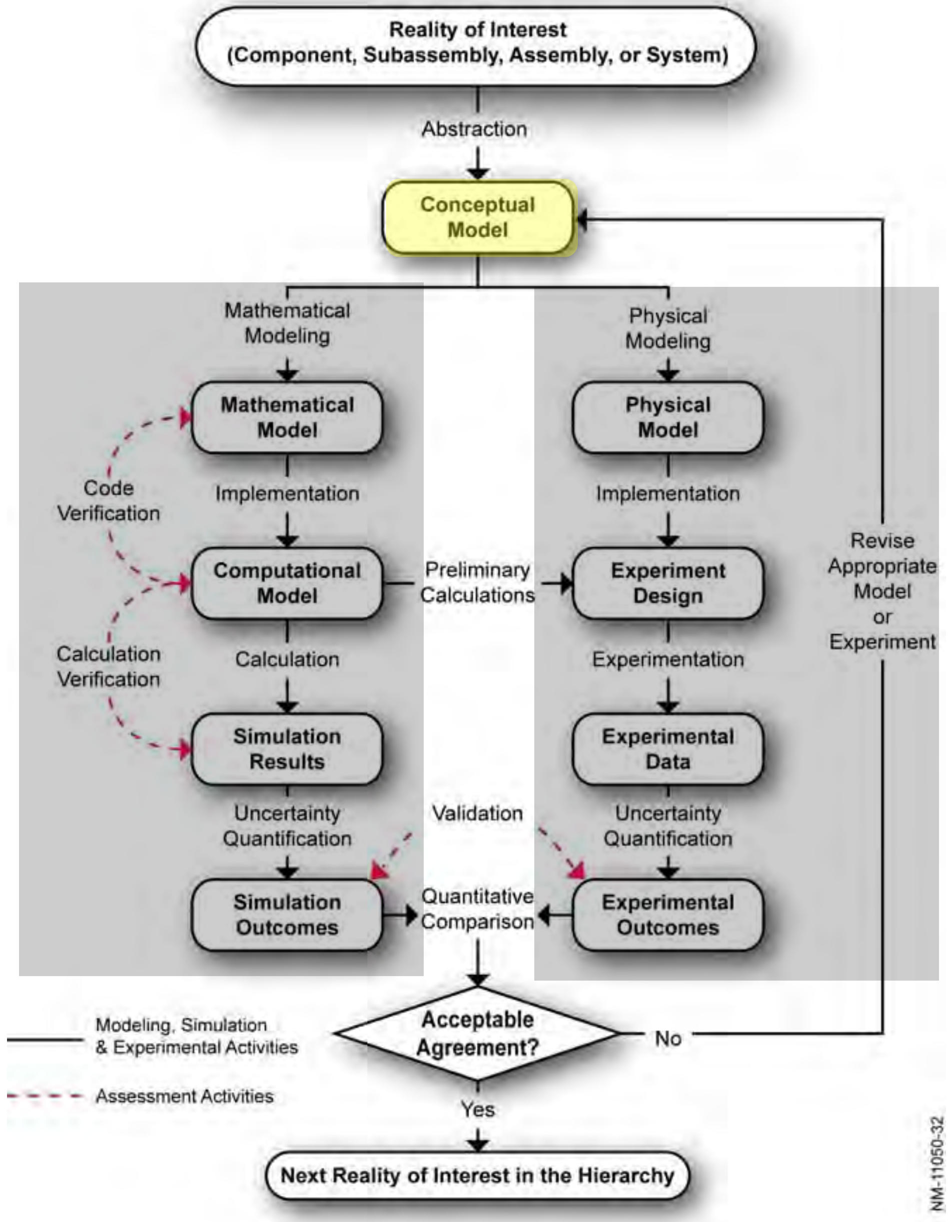
Validation – are the right equations being solved -> physics

Right answer for the right reason

e.g. don't want 2 wrongs to equal right

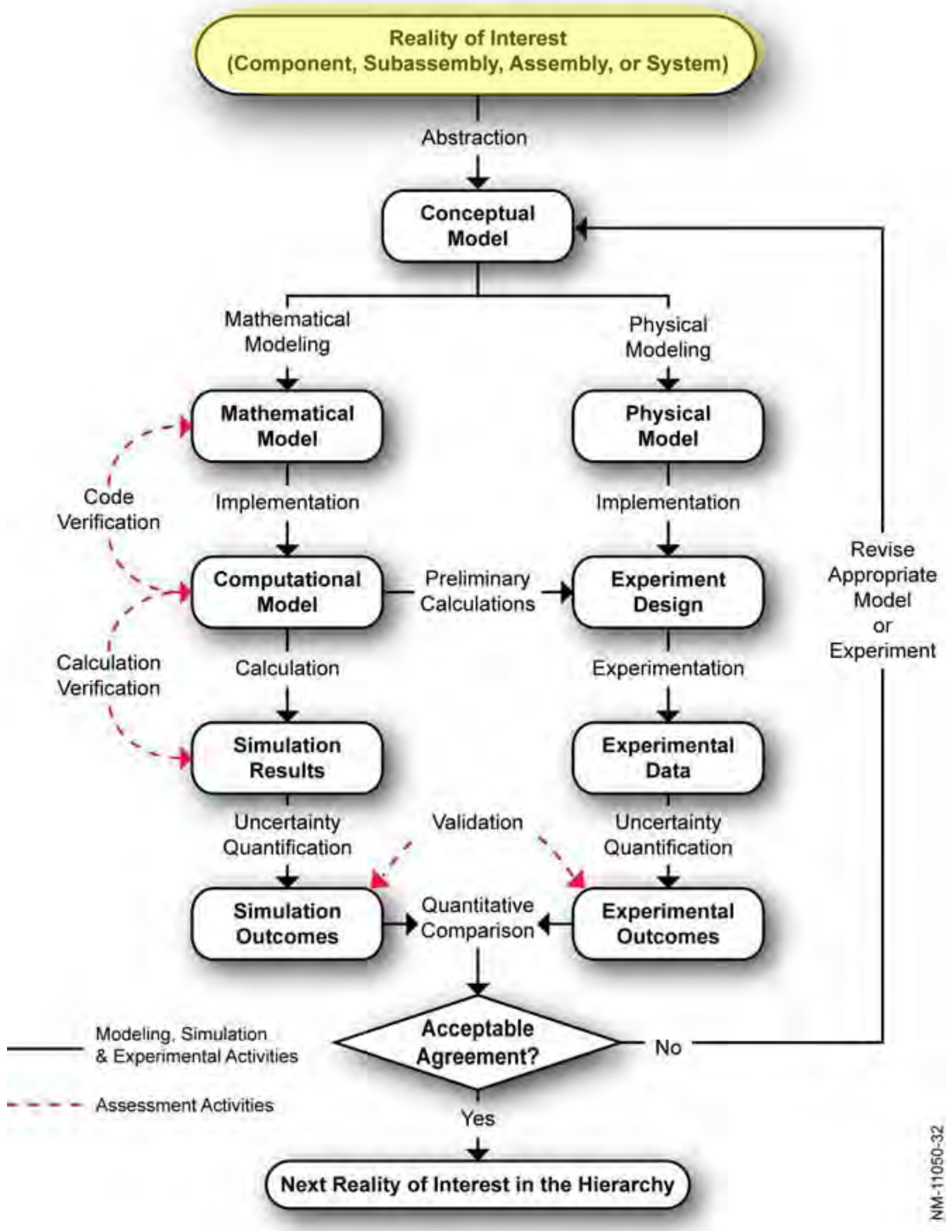
ASME V&V Process

Mathematical Modeling



Physical Modeling

ASME V&V Process



Systems and Phenomena

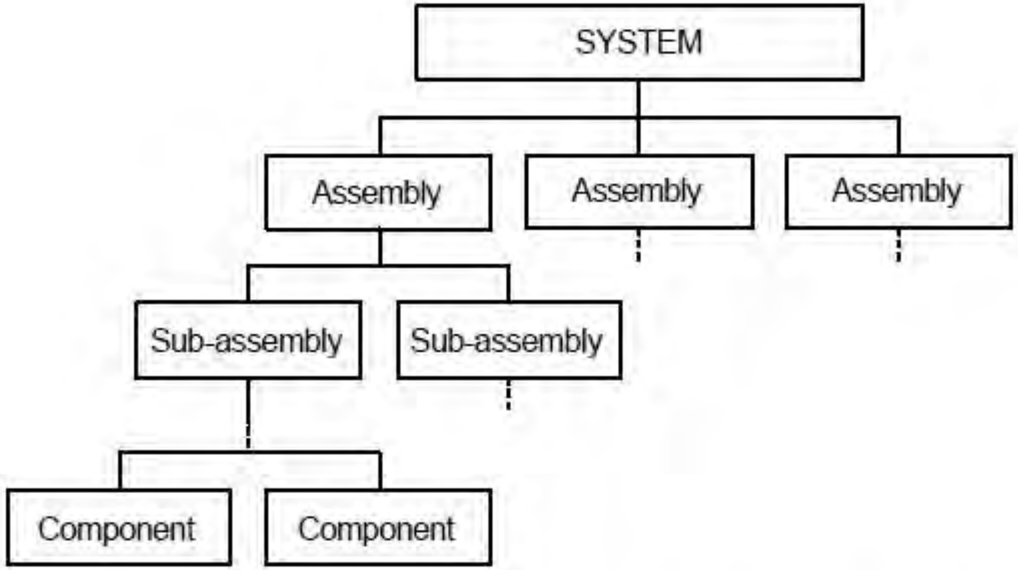
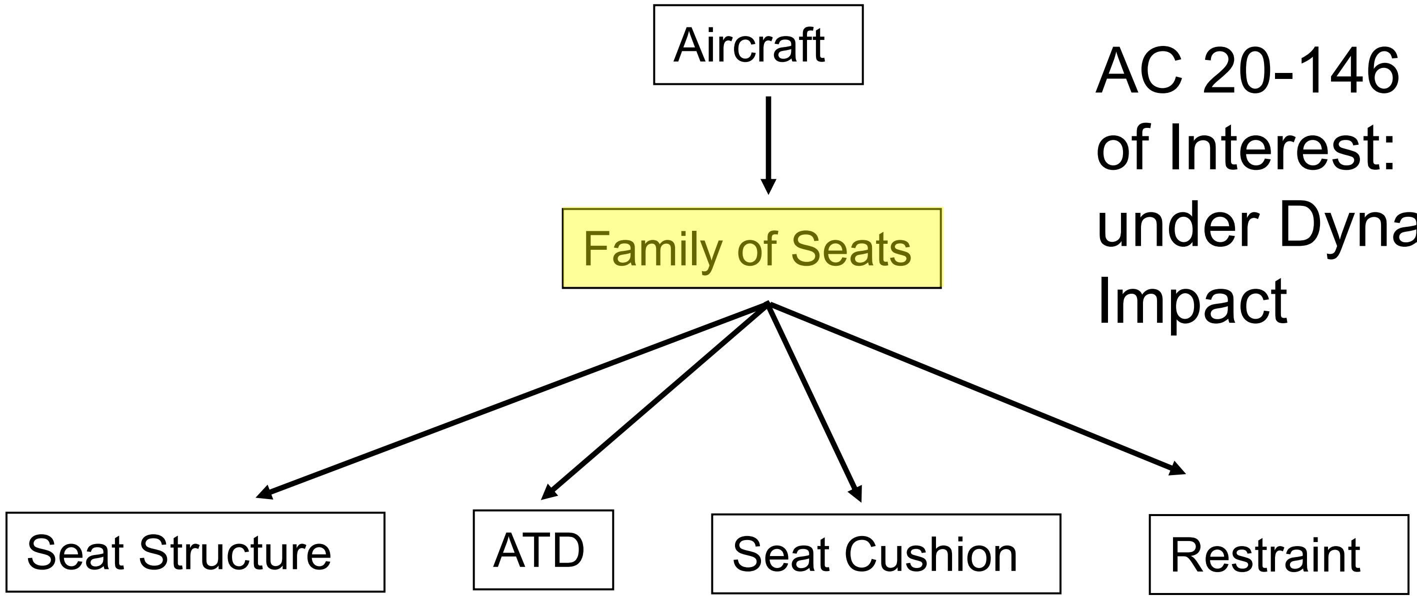


Figure 1. Hierarchical nature of physical systems and phenomena.

The defined process can be applied to any level of the hierarchy and information gained from one level is passed to the next higher level

System Hierarchy



AC 20-146 Reality of Interest: Seat under Dynamic Impact

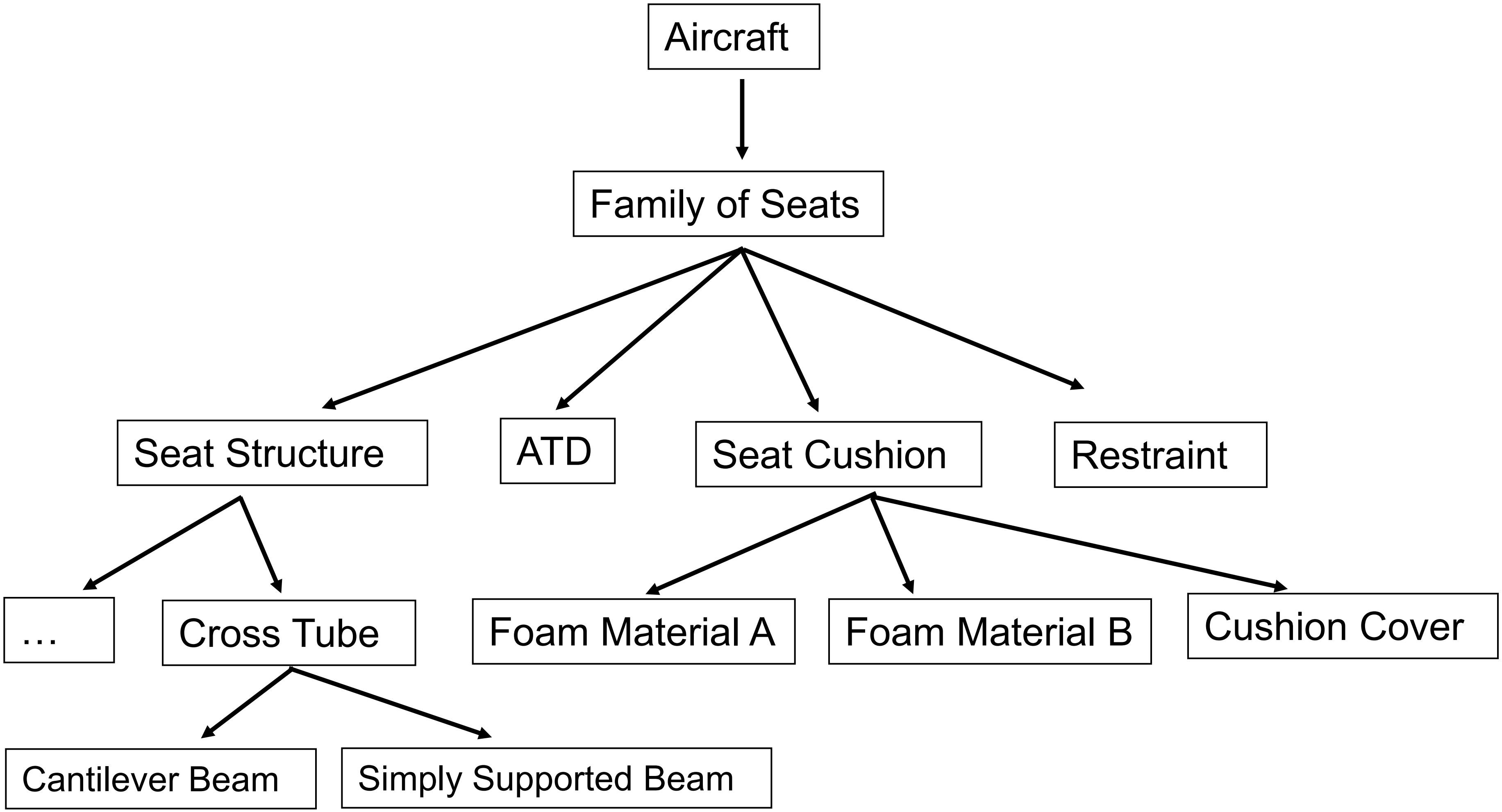
V&V Plan

Define:

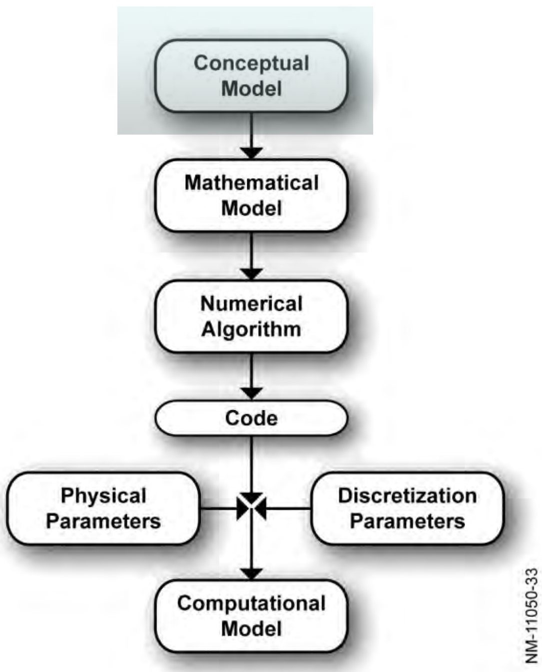
- **Reality of Interest**
- **Intended Use**
  - Development, Certification
  - Application (structural, occupant injury, installation)
- **Validation Hierarchy**
- **System Response Quantities**
- **Accuracy Requirements**
- **Data Traceability**
- **Conformity**

Intended Use: Predict the performance of a replacement cushion – overhung seat place

System Hierarchy



Model Development



Conceptual Model – “the collection of assumptions and descriptions of **physical processes** representing the solid mechanics behavior of the reality of interest from which the mathematical model and validation experiments can be constructed.”

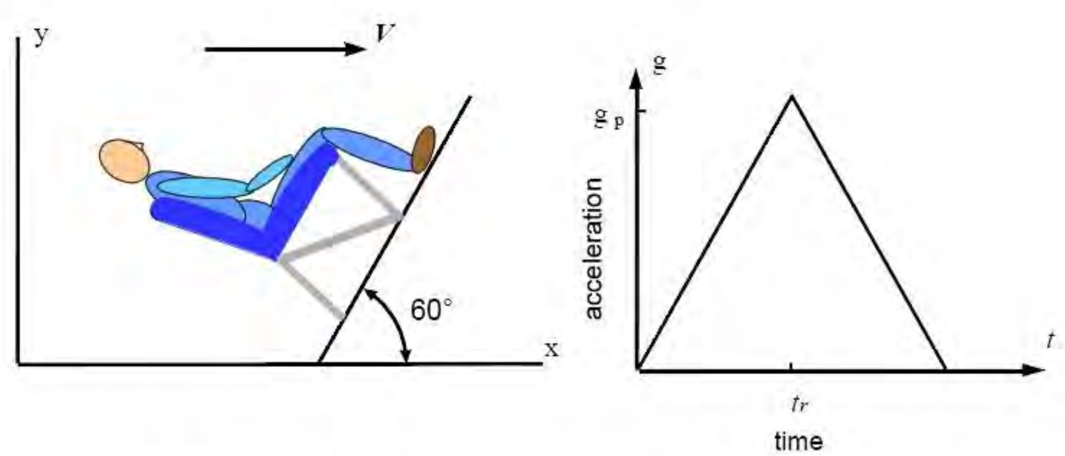


FIGURE 1-1. FOURTEEN-g DYNAMIC SLED TEST CONDITIONS

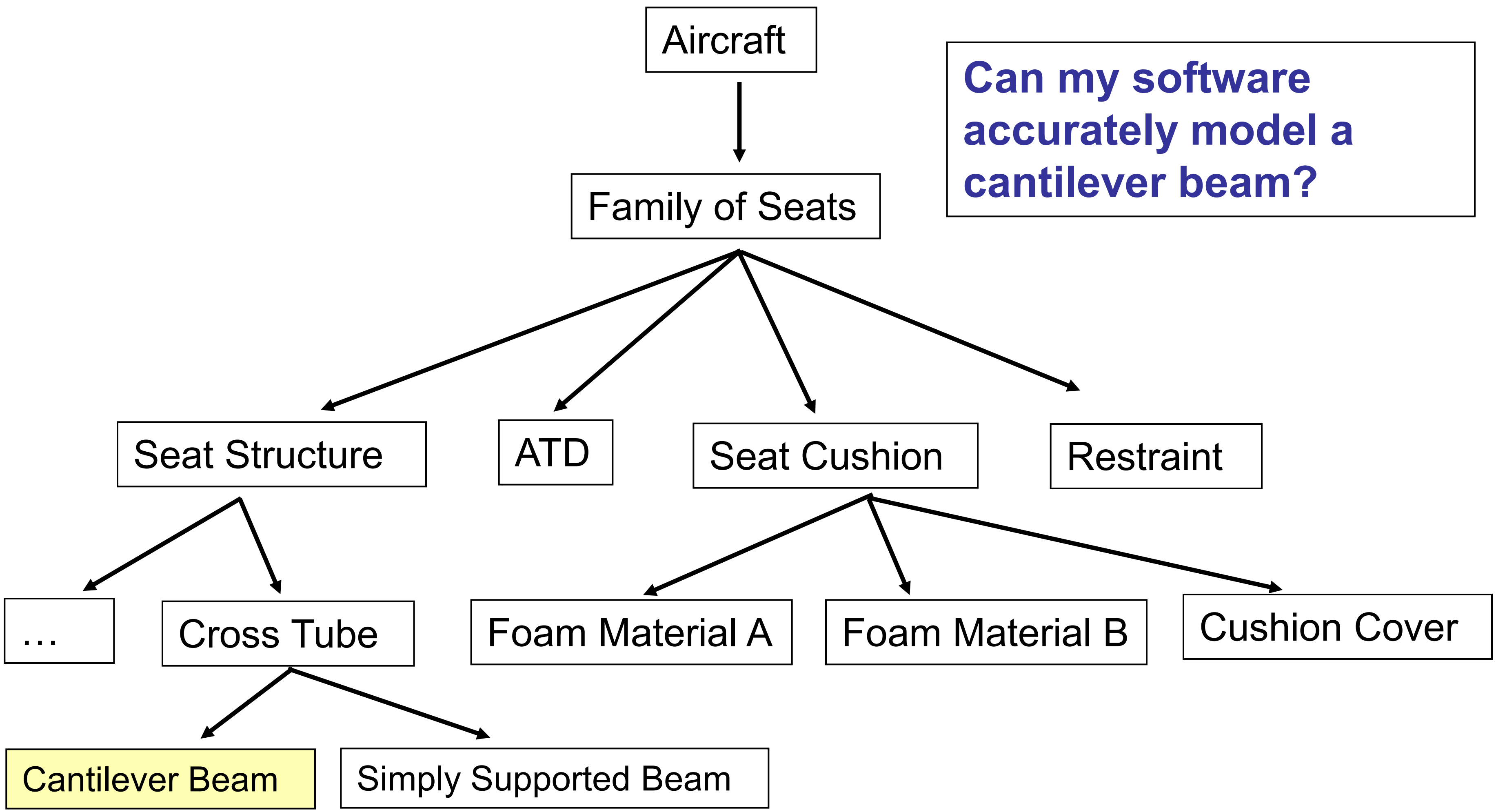
Conceptual Model

- **Dynamic interaction between ATD-Seat-Cushion**
  - 14g peak, 160 ms, isosceles triangle
    - Initial Condition
  - ATD per 49 CFR Part 572 subpart B
  - Seat
    - Rigid seat pan, cantilevered tubes, rigid seat legs
  - Cushion is a build-up of two foams
    - Non-linear elasto-plastic behavior, homogenous
    - Strain independent, negligible Poisson's effect
  - Belts, clothing, seating procedure, etc.
    - AS 8049, AC 25.562

Conceptual Model - Assumptions

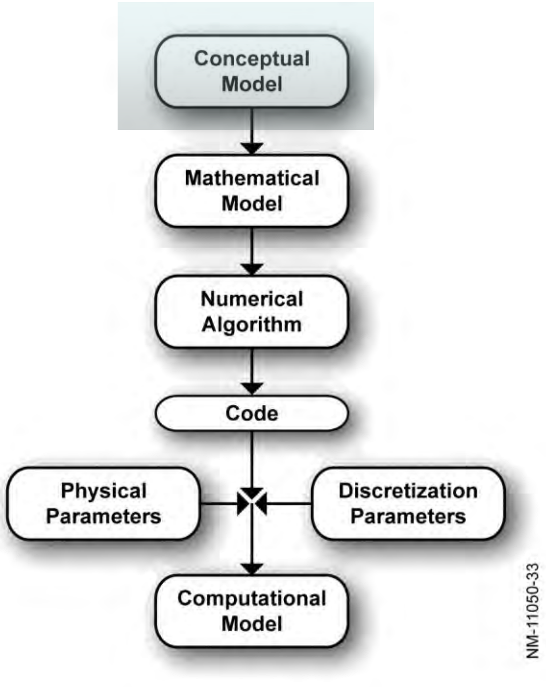
- **Dynamic interaction between ATD-Seat-Cushion**
  - 14g peak, 160 ms, isosceles triangle
    - What does my facility produce?
  - ATD per 49 CFR Part 572 subpart B
  - Seat
    - Does the pan have local deformation, is Bernoulli-Euler beam theory appropriate for the tubes?
  - Cushion is a build-up of two foams
    - Are the foams truly strain-independent, batch to batch variation of material properties?
  - Belts, clothing, seating procedure, etc.

System Hierarchy



Can my software accurately model a cantilever beam?

Model Development



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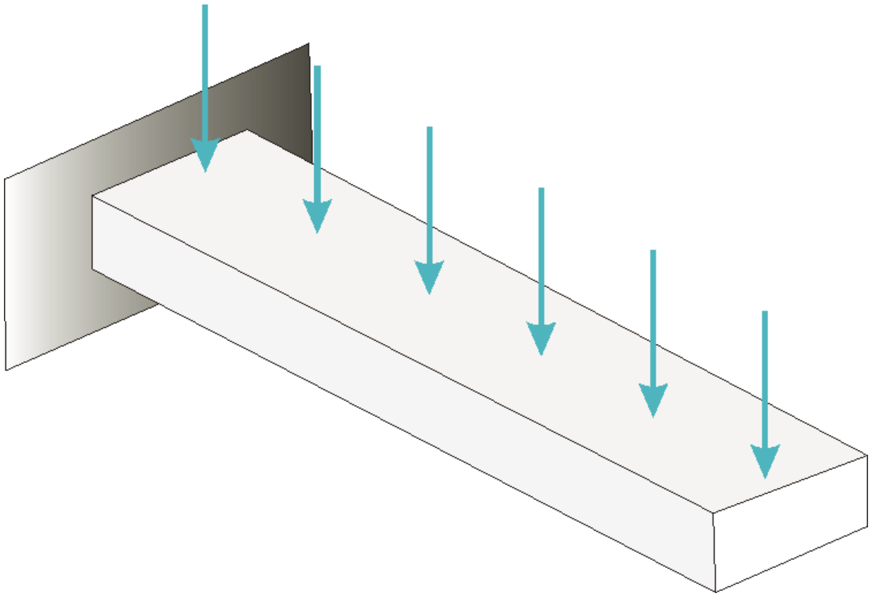
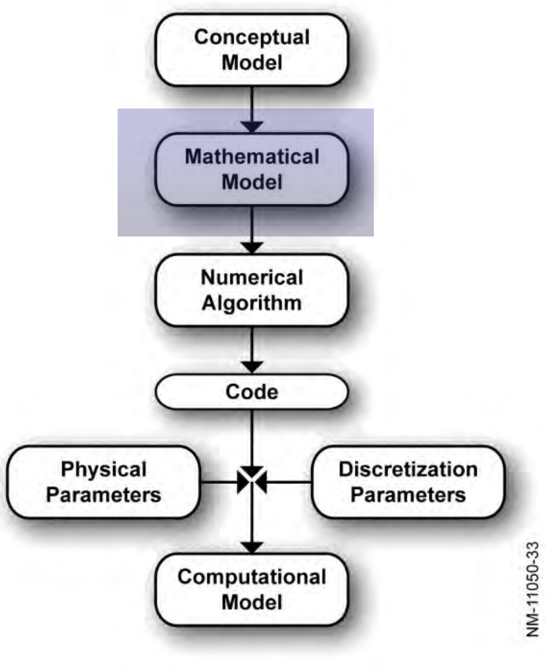


Model Development

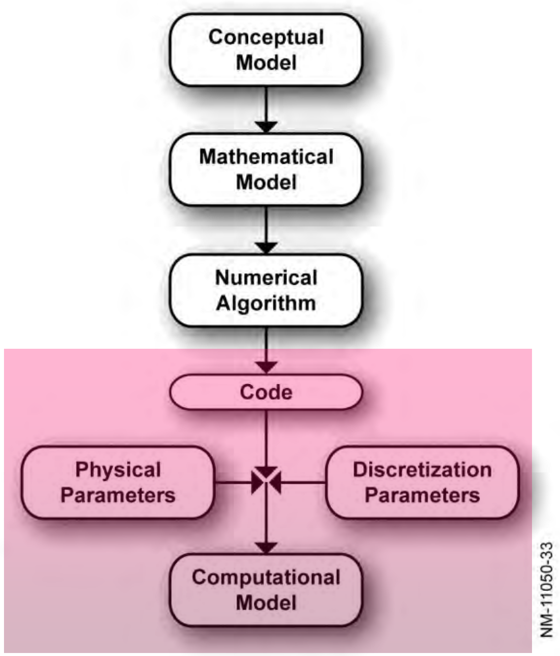


Mathematical Model – "The mathematical equations, boundary values, initial conditions, and modeling data needed to describe the conceptual model."

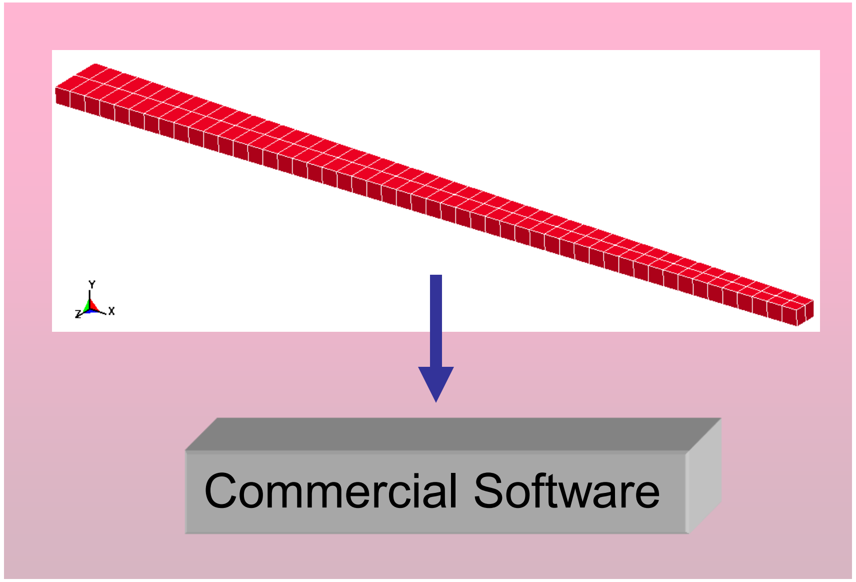
$$\left[EI(x)y''\right]'' = w(x) \qquad 0 < x < L$$

$$y(0) = y'(0) = y''(L) = y'''(L) = 0$$

Model Development

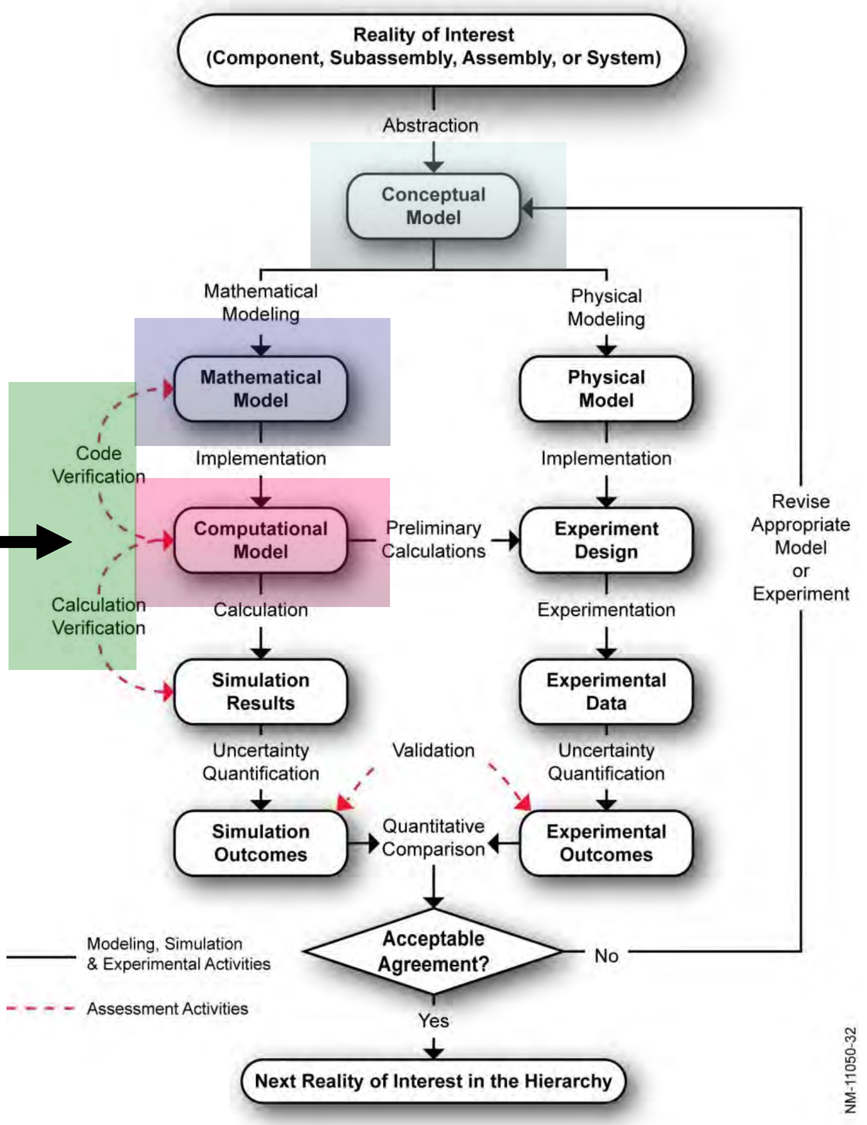


Computational Model – "The numerical implementation of the mathematical model, usually in the form of numerical discretization, solution algorithm, and convergence criteria."



V&V Process

Verification



Verification

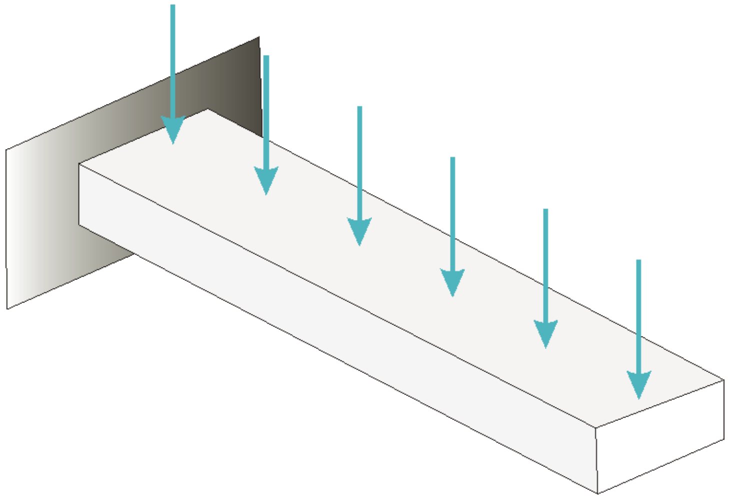
Verification: The process of determining that a computational model accurately represents the underlying mathematical model and its solution.

Code Verification – establish confidence, through the collection of evidence, that the mathematical model and solution algorithms are working correctly.

- Code Solution = Analytical Solution?
- ***Developers*** & Users

Code Verification

- **Problem closely related to the problem of interest**
- **Has an exact analytic solution**



- **Analytic Solution:**
  - 0.0552 in
- **Numerical Solution:**
  - 0.0552 in

Verification

Verification: The process of determining that a computational model accurately represents the underlying mathematical model and its solution.

Code Verification – establish confidence, through the collection of evidence, that the mathematical model and solution algorithms are working correctly.

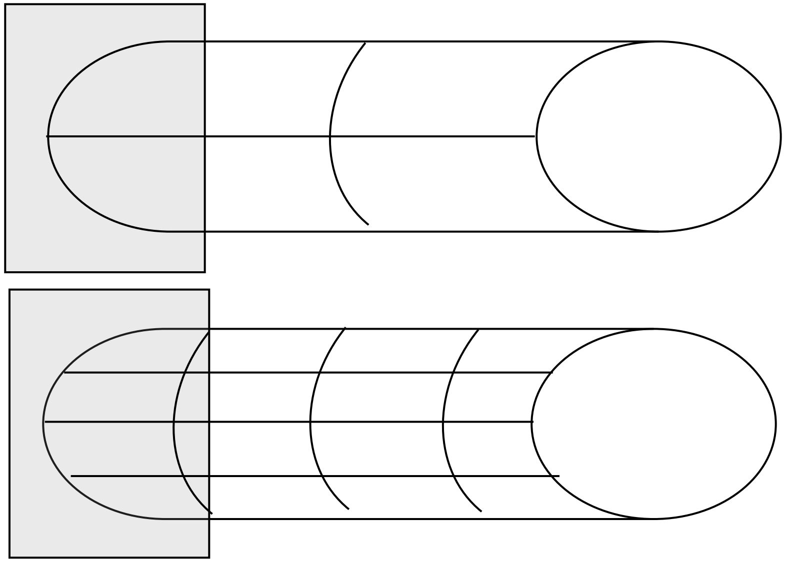
- Code Solution = Analytical Solution?
- ***Developers*** & Users

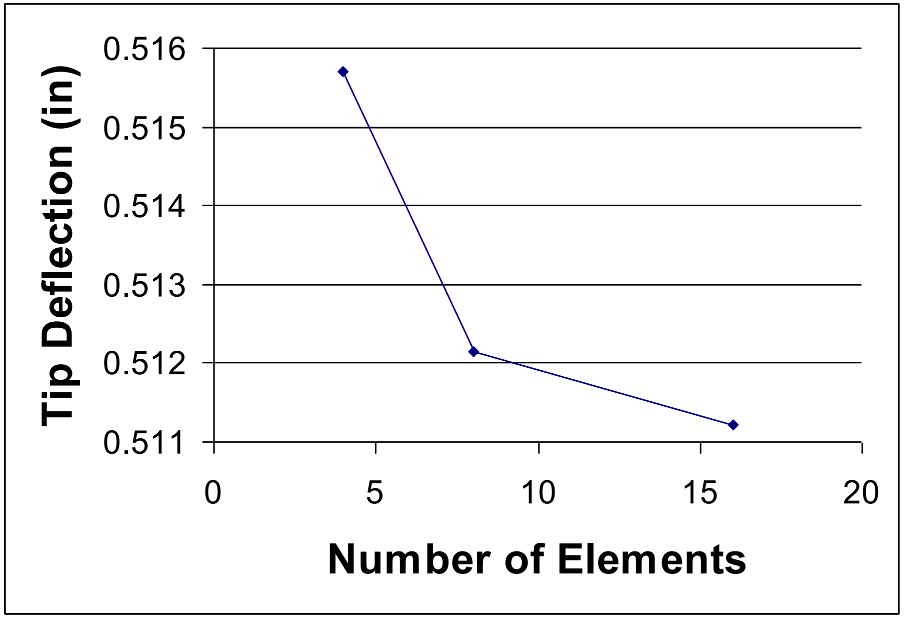
Calculation Verification - establish confidence, through the collection of evidence, that the discrete solution of the mathematical model is accurate.

- Discretization Error?
- Developers & ***Users***

Calculation (Solution) Verification

- Estimate the numerical errors due to discretization approximations
- Using the problem of interest
- Example: Spatial Discretization





Calculation (Solution) Verification

- *Grid Convergence Index* (GCI) – an estimate of the percentage that the computed value is away from the ***asymptotic*** numerical value.

Number of Elements	h (in)	Tip Deflection (in)
4	19.68504	0.515698386
8	9.84252	0.512140433
16	4.92126	0.511224409

$$GCI = F_s \frac{|\varepsilon|}{(h_2 / h_1)^p - 1}$$

where $\varepsilon = (w_1 - w_2) / w_1$ $F_s = 1.25$, $p = f(w, h)$

Calculation (Solution) Verification

- *Grid Convergence Index* (GCI) – an estimate of the percentage that the computed value is away from the ***asymptotic*** numerical value.

$p = 1.958$ [theoretical = 2 -> asymptotic region]

$GCI = 0.000104 = 0.010\%$

Error band about w_1 is (0.51122, 0.51128)

- exact solution is likely to fall within this band

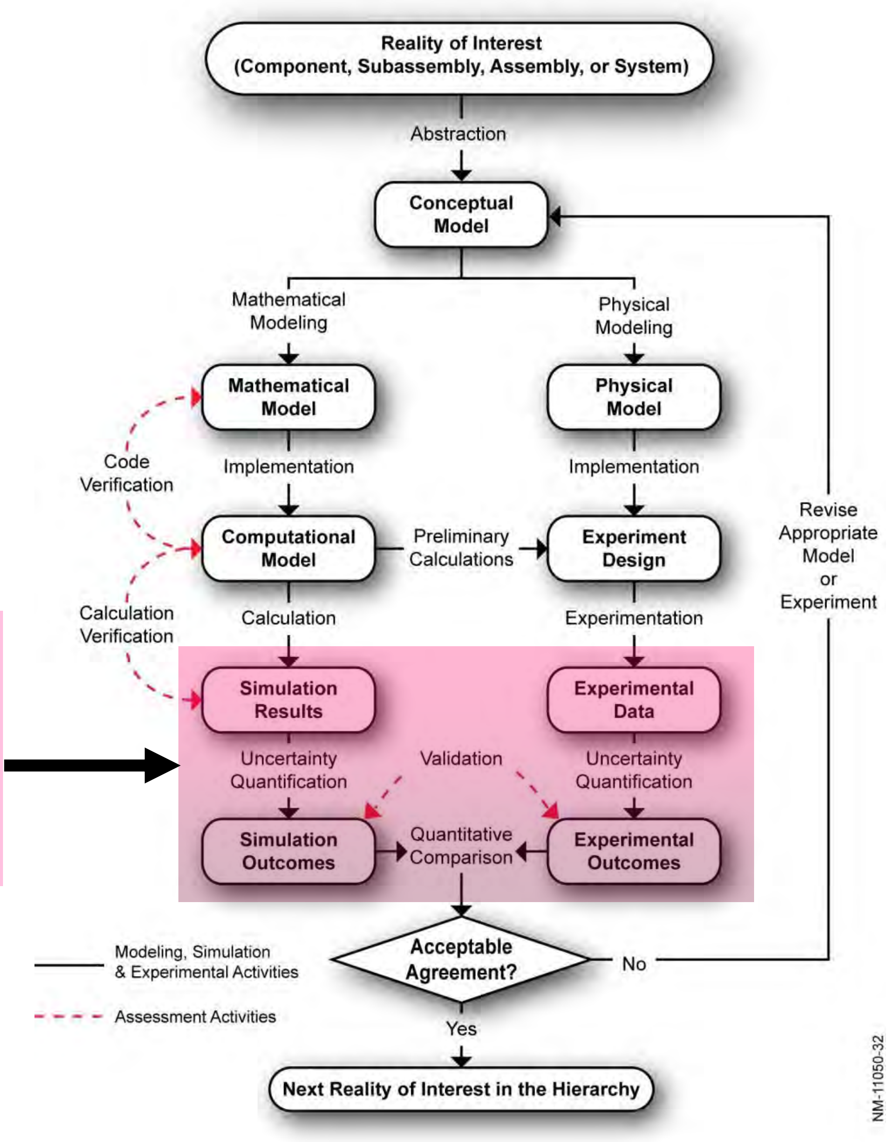
At This Point …

- We have evidence that the code properly solves a Bernoulli-Euler beam problem
- We have evidence that the spatial discretization error is small enough to be ignored (tube GCI = 0.01%)
- But, we still do not know if Bernoulli-Euler beam theory is an accurate description of a cross tube

Validation

The *validation process* has the goal of assessing the predictive capability of the model by comparing the predictive results of the model with validation experiments.

Three key elements of Validation:
1. Precision Testing
2. Uncertainty Quantification
3. Comparative Metrics



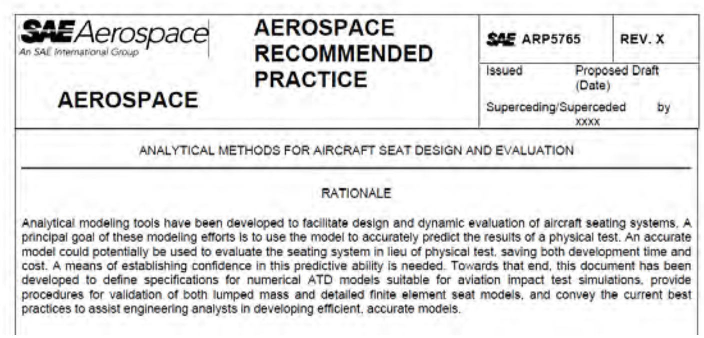
Validation Experiments

The goal of a ***validation experiment*** is to be a physical realization of an initial boundary value problem, since an initial boundary value problem is what the computational model was developed to solve.

Redundancy of the Data – repeat experiments to establish experimental variation.

Supporting Measurements - not only are measurements of the important system response quantities of interest recorded, but other supporting measurements are recorded. An example would be to record the curvature of a beam to support a strain gauge measurement.

Uncertainty Quantification - errors are usually classified as being either random error (precision) or systematic error (bias).



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SAE ARP5765 | REV. X

Issued Proposed Draft (Date)

Superceding/Superceded by xxxx

ANALYTICAL METHODS FOR AIRCRAFT SEAT DESIGN AND EVALUATION

RATIONALE

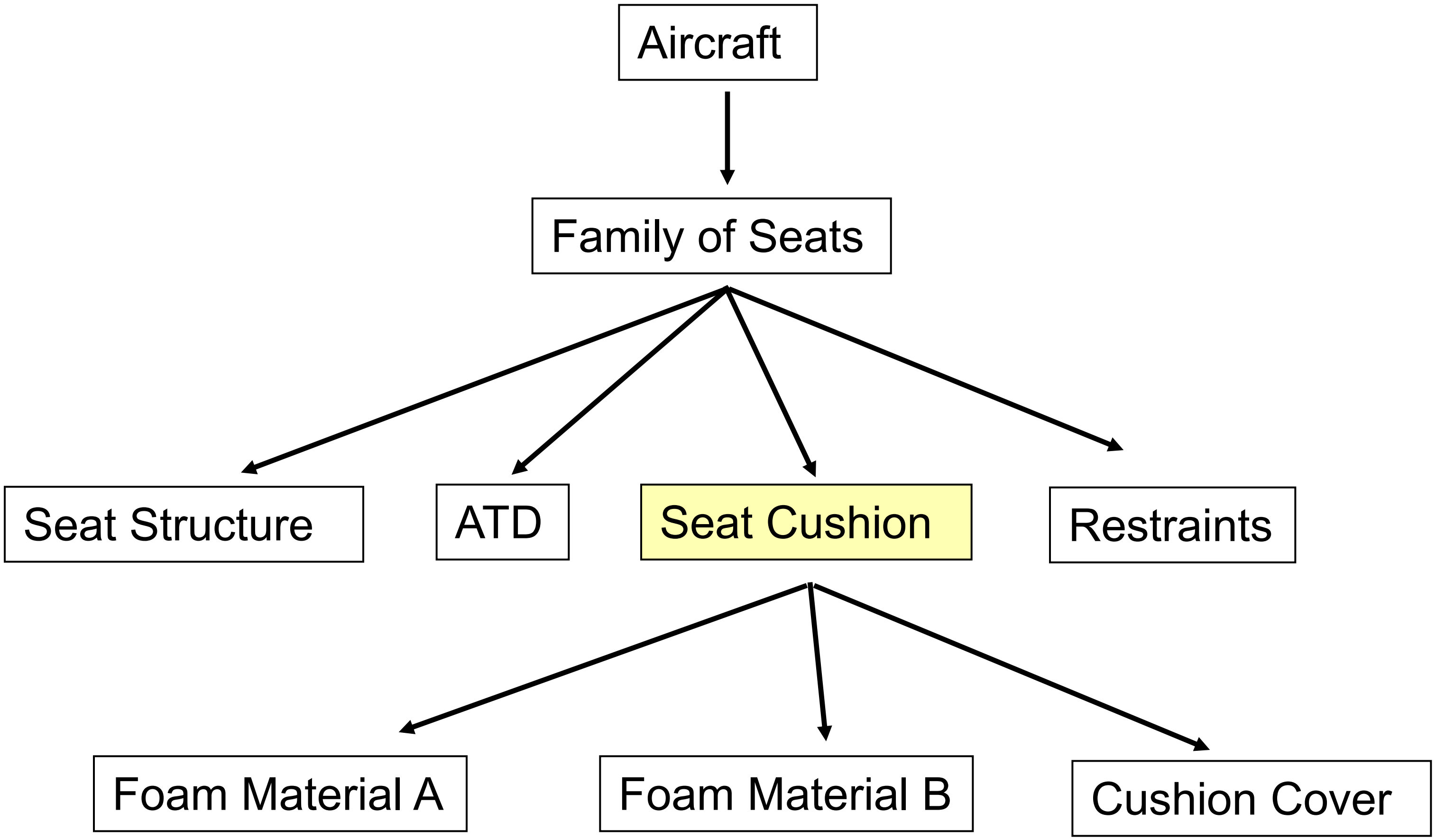
Analytical modeling tools have been developed to facilitate design and dynamic evaluation of aircraft seating systems. A principal goal of these modeling efforts is to use the model to accurately predict the results of a physical test. An accurate model could potentially be used to evaluate the seating system in lieu of physical test, saving both development time and cost. A means of establishing confidence in this predictive ability is needed. Towards that end, this document has been developed to define specifications for numerical ATD models suitable for aviation impact test simulations, provide procedures for validation of both lumped mass and detailed finite element seat models, and convey the current best practices to assist engineering analysts in developing efficient, accurate models.

6.1 Testing Best Practices

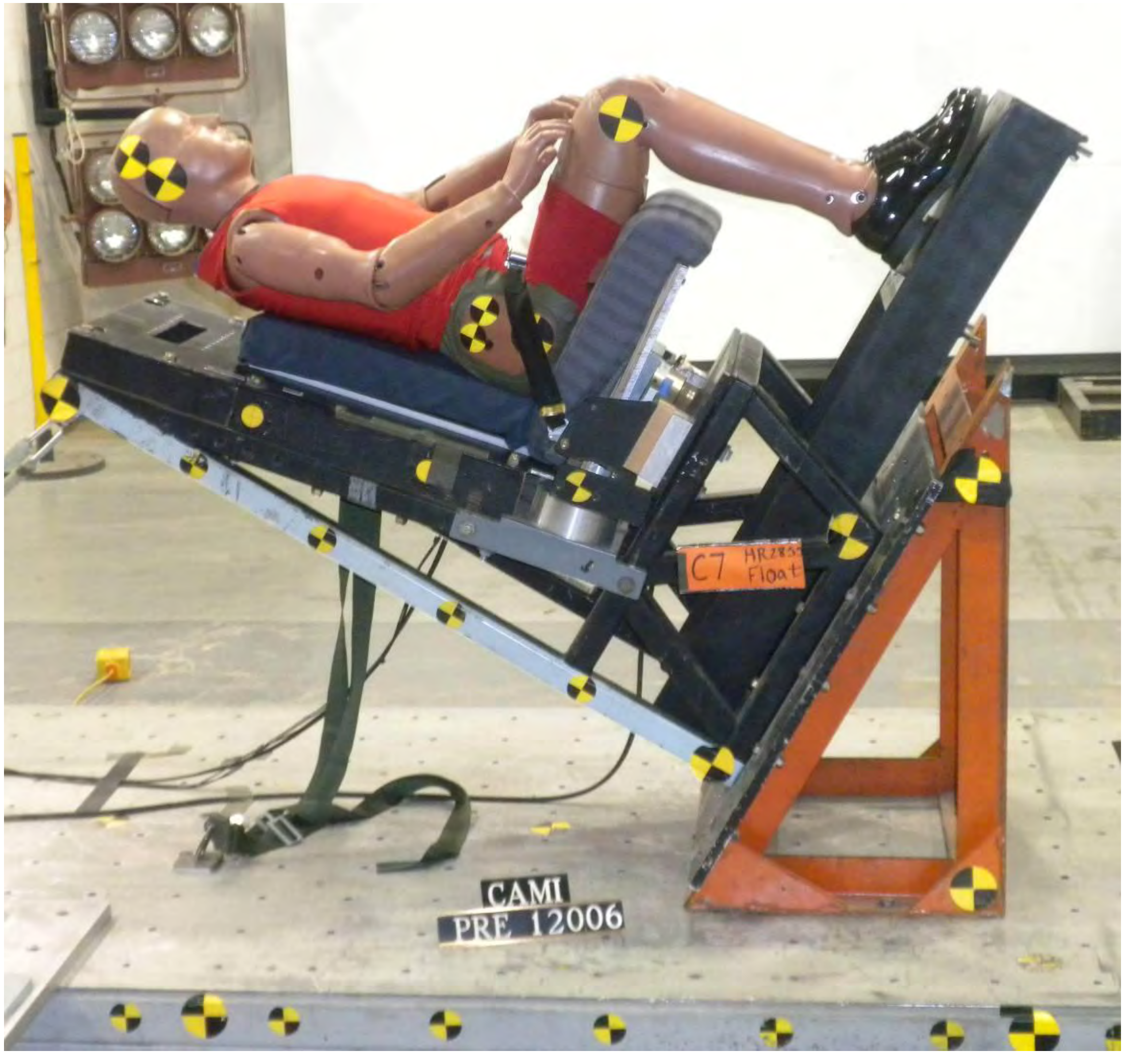
Validation

- We can run a test, measure tube motion/deformation, add strain gauges, etc., to validate our model
- For today's example, we will switch to looking at the seat cushion

System Hierarchy

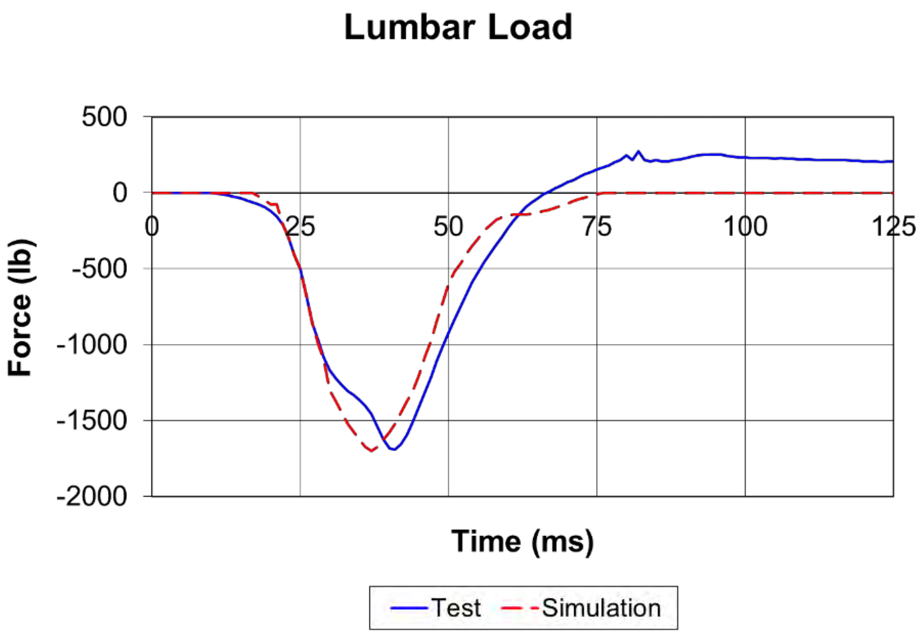


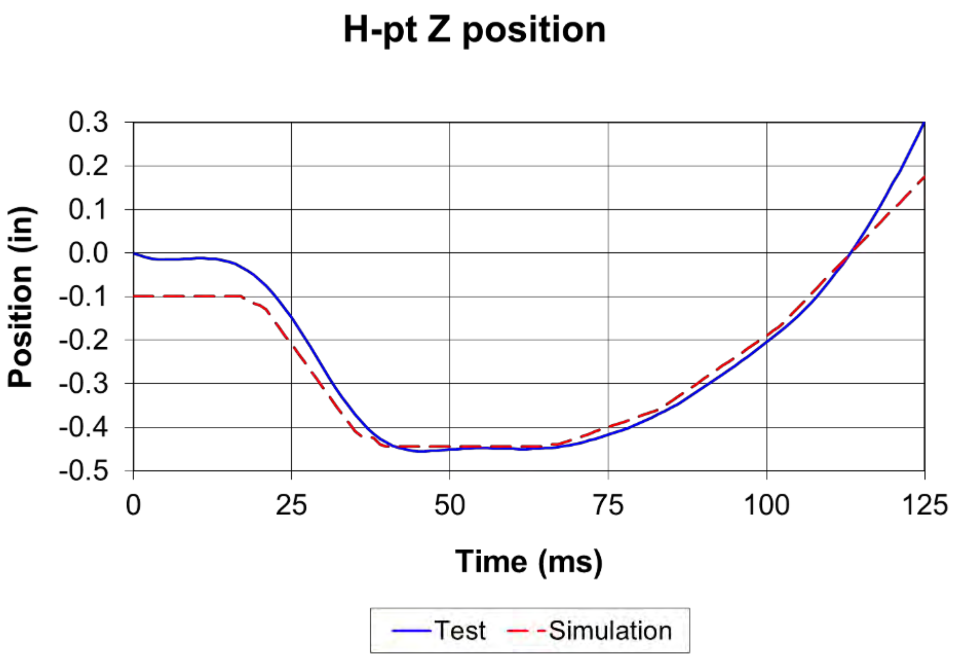
Evaluation of Original Seat Cushion



Validation Example

- **System Response Quantities**
  – Lumbar load, H-pt motion, Head CG motion





Validation Example

- **System Response Quantities**
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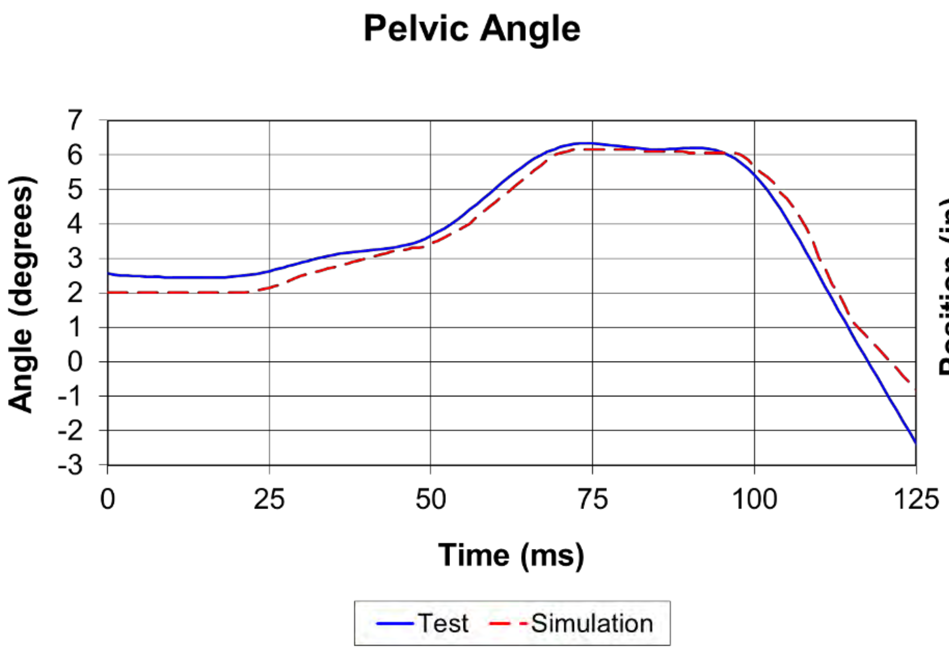
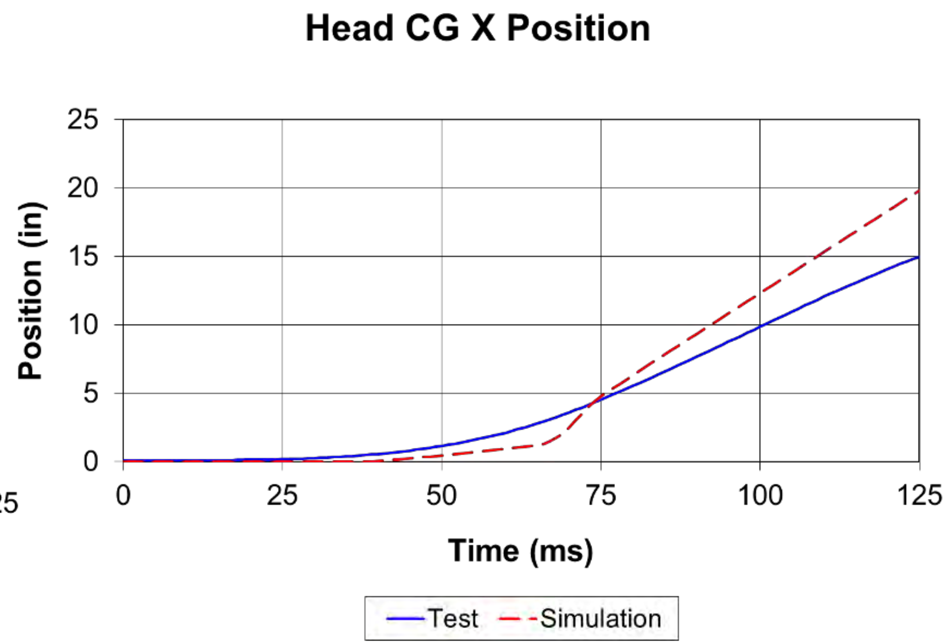




Validation Example

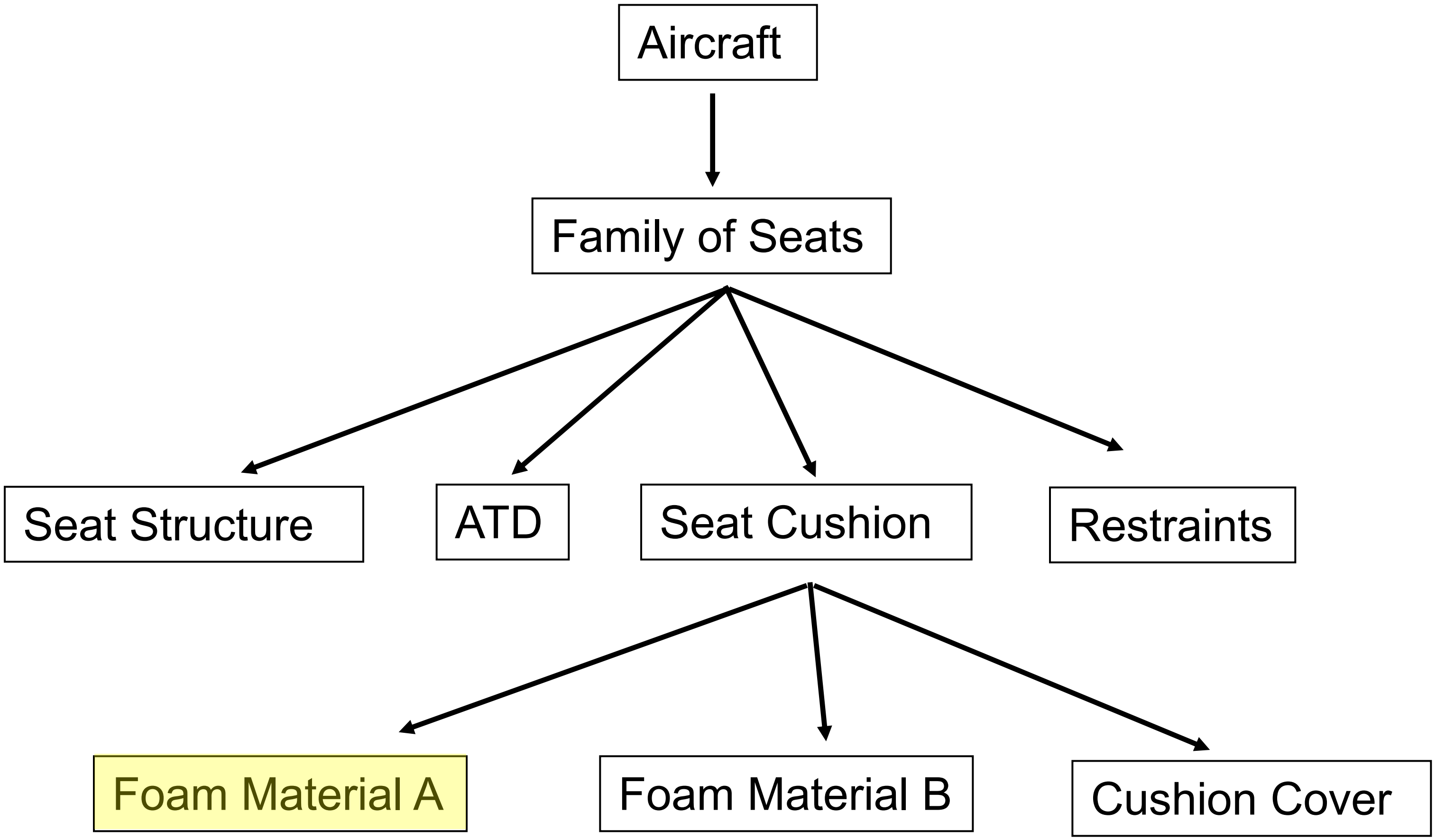
- **Quantitative Metrics**
  - Relative Error on the Peak
  - Sprague and Geers for Shape

- **Accuracy requirements**

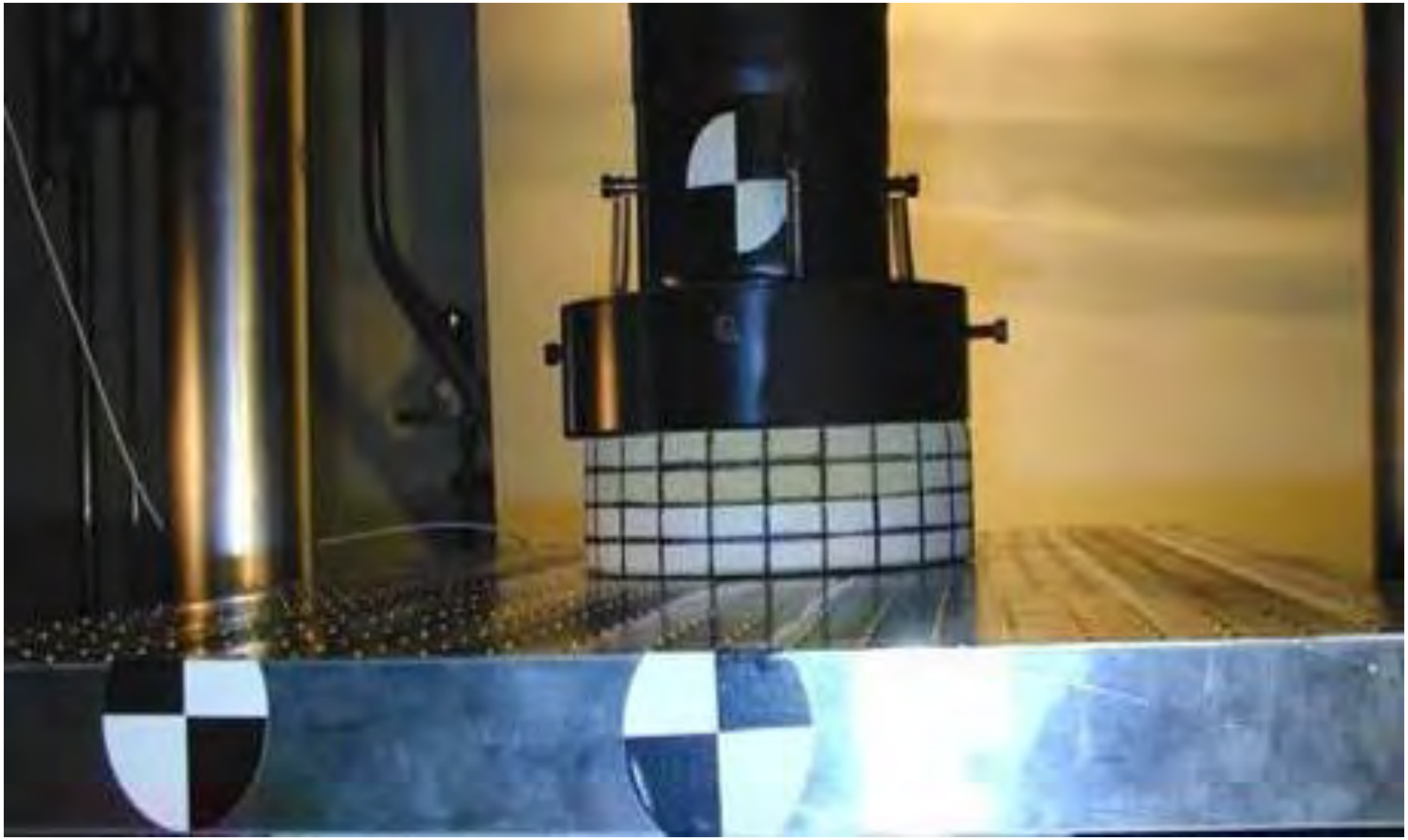
Channel	Magnitude	Shape
Lumbar Fz	0.57%	8.8%
Head CG X	32.2%	25.2%
H-point Z	0.13 in	4.5%
Pelvic Angle	0.19°	4.4%

Evaluation of Replacement Seat Cushion

System Hierarchy



New Foam Material A



Intended Use: Predict Lumbar Load on a Replacement Cushion

- **Ultimately, we want to:**
  - Generate evidence that we accurately modeled the seat structure
  - Generate evidence that we accurately modeled the original and new foam cushions
  - Generate evidence that we accurately model the interaction of the ATD to the seat through the cushion

Process Overview

1. **V&V Plan**
2. **Define Intended Use**
   - Development, Certification
   - Application (structural, occupant, installation)
3. **Code Verification**
   - Evaluate portions of code which are used in the model (ex. mat’l models)
4. **Calculation Verification:**
   - Spatial and Temporal Discretization
   - Error << Validation Requirement
   - Load Path
5. **Validation:**
   - Test Data
   - SRQs
   - Parameter Estimation (calibration)
   - Sub-systems
6. **Sensitivity Analysis / Uncertainty Quantification**
7. **Documentation**

Development of a V&V Plan

- **Example of questions that should be answered in the V&V plan:**
  - What is the application domain over which the model is expected to make predictions?
  - What system response quantities (SRQs) is the model expected to predict?
  - What are the code and solution verification requirements?
  - What validation hierarchy is appropriate for the system of interest?
  - What is the validation domain for each tier of the validation hierarchy?
  - What validation metrics are to be used?
  - What are the accuracy requirements for the model in the validation domain?
  - What are the accuracy requirements for the model in the application domain?
  - What are the costs, schedule, and manpower requirements to complete the V&V plan?

System Verification and Validation for ARP 5765