The Role of Model Validation and Verification for Defining Component Specifications and Margins

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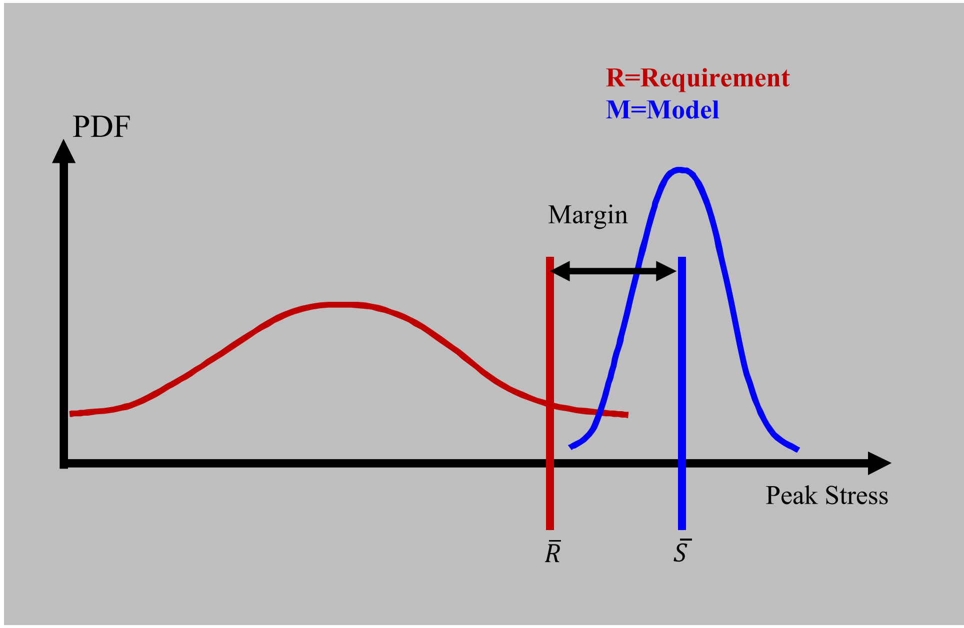

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Overview

- Motivation
- Component Specification Background
- Shock Specification from a Characterized Model
- Random Vibration Specification from a Characterized Model
- Quantifying Margins and Uncertainties
- Conclusions

Motivation

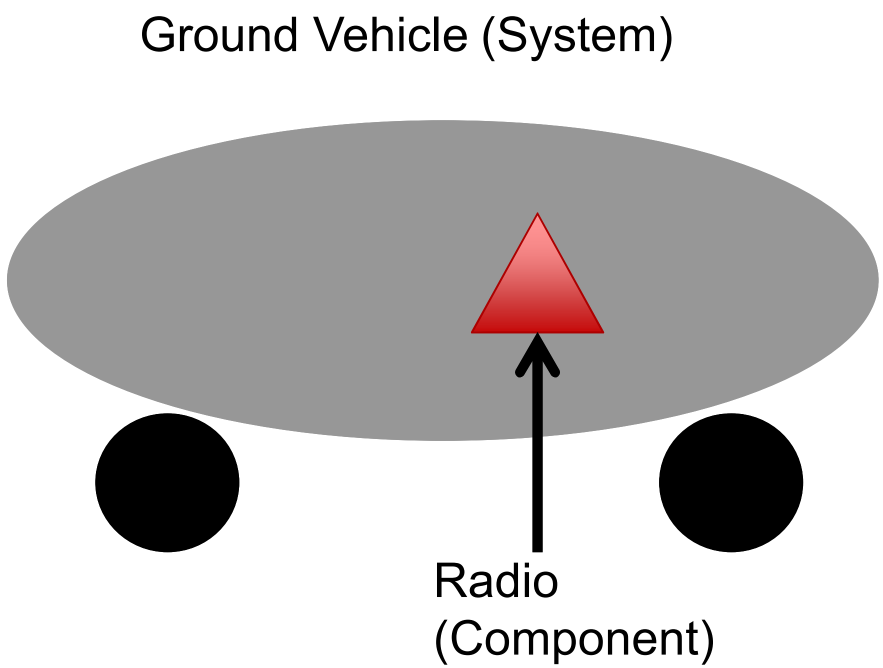
- CompSim is extensively used throughout industry for a variety of purposes
  - Design
  - Qualification
  - Problem solving
- Model use determines confidence requirement
  - Drop-in replacement for tests (Highest confidence)
  - Relative Comparisons between designs (Medium to low confidence)
  - Assessing new design concepts (low confidence)
- Model is rarely useless
  - It can always provide insight
  - Characterization of model drives confidence/use in results

Definitions

- *Verification*: The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.
- *Validation*: The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model

Component Specification Background

- Component level environmental and test specifications derived from system level CompSim or test
- Component level tests allow testing without building full system
  - Allows quick turnaround assessment of design
  - Provides qualification evidence at component level

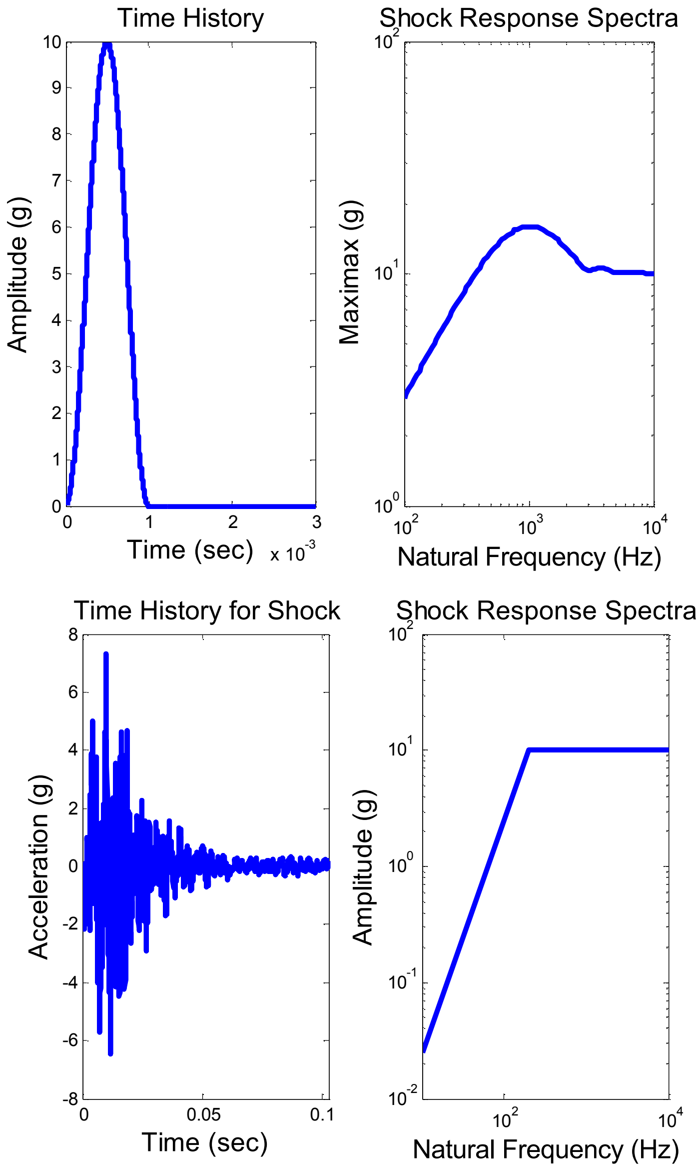


Background (cont)

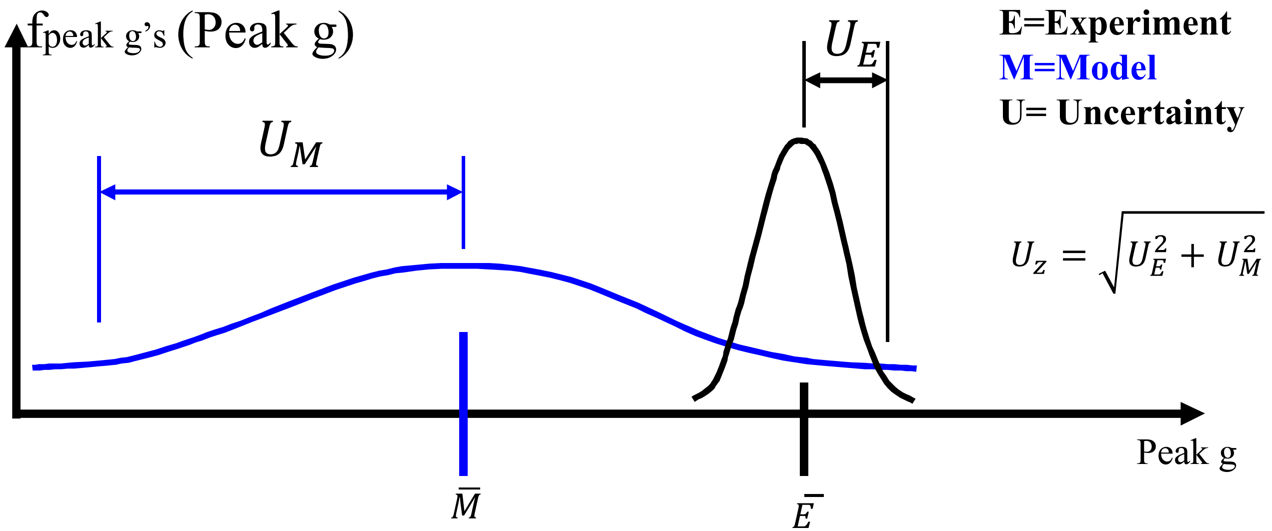
- Component Specifications cover separated, expected operational environments
  - Random vibration
  - Shock
  - Sine
  - Combinations of above
- CompSim fills in holes in the environments that cannot be tested.
  - Limited hardware
  - Environments beyond capability of test equipment
  - Limited test instrumentation
  - Boundary condition differences
- Model Validation and Characterization can determine how the CompSim results should be utilized.

Shock Specification with a Validated Model

- Shock represents a "short" transient into the system
  - Car running over a rock or a trench
  - Pyroshock event
  - Ejection
  - Drop
- Can be represented by either a haversine or a resonant beam test
  - Dependent on character of operational event
  - Can also be replicated on a shaker if amplitude/frequency is low enough

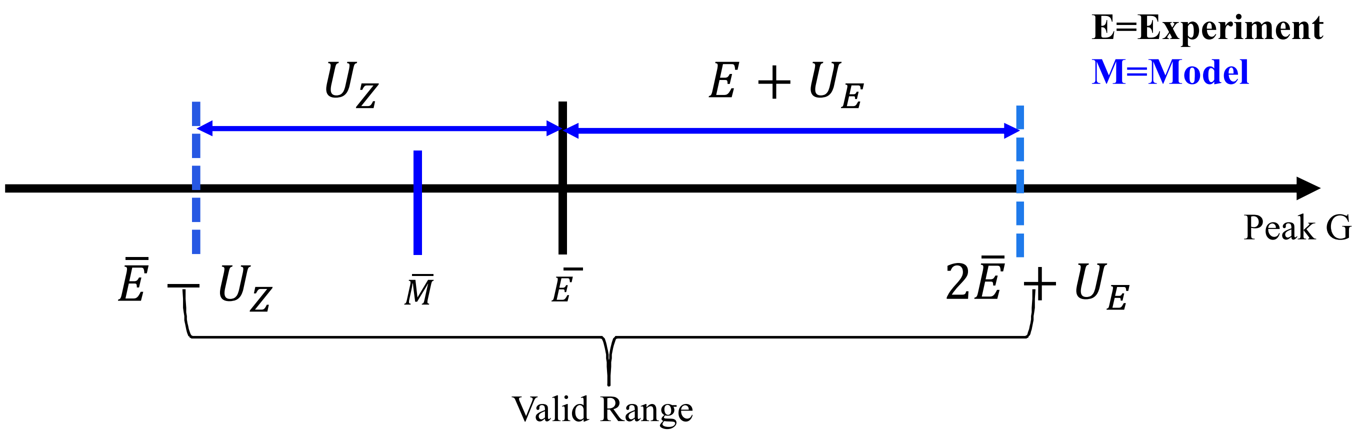


Validating the model



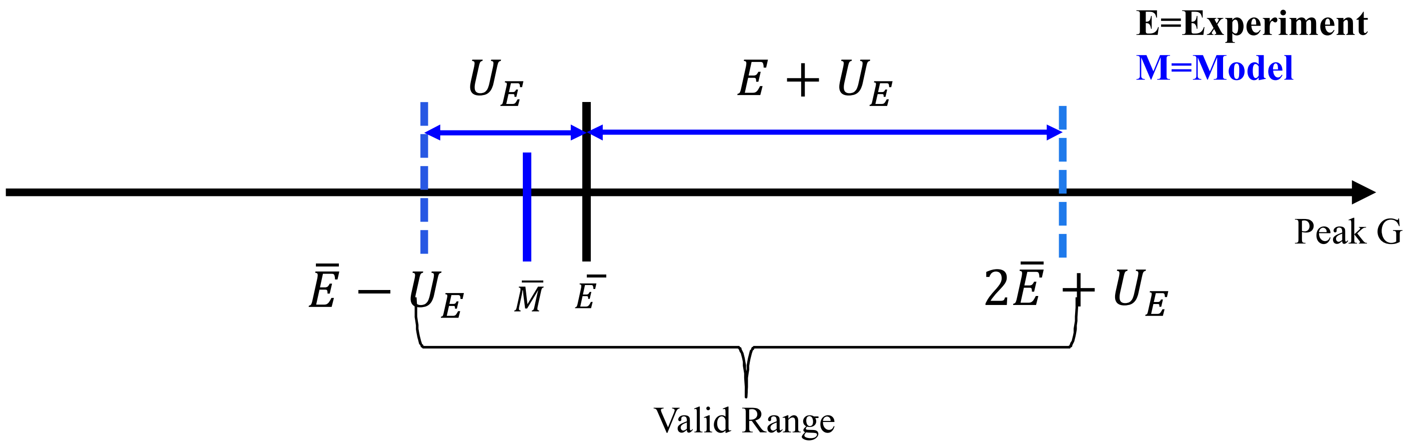
- Model and experimental uncertainty accounted for
- In this example, peak g is quantity of interest (QOI) in both a resonant plate and haversine test
  - Duration/Frequency has been evaluated as acceptably represented
- Metric evaluated at every location of interest
  - Model can be better in some regions than in others

Regions that have been assessed to behave linearly



- Lower bound of model validity (experimental mean-Uz)
- Upper bound of model validity (2*Experimental mean+UE)
- Allows a factor of 2 error in the predicted peak g.
  - Based on discussions with customer
- Defining haversine/resonant plate specification
  - For valid but under-prediction, 2*(peak g)
  - For valid but over prediction, peak g
  - For invalid, other sources used to define specification

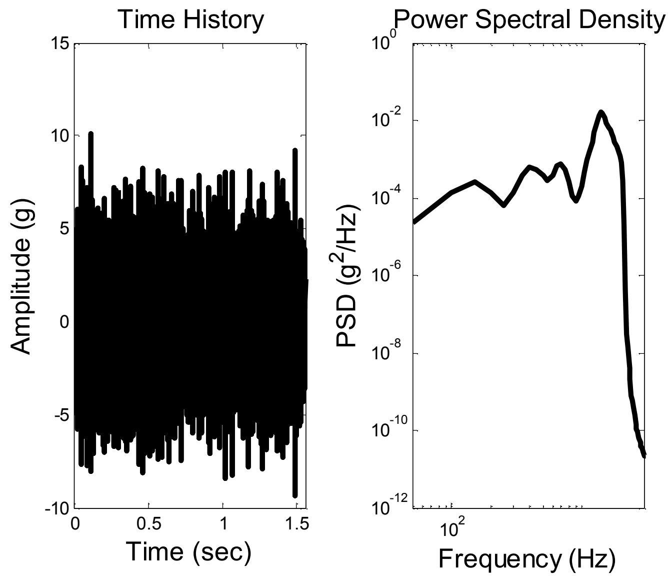
Regions that behave non-linearly



- Model must be conservative
  - Model should over-predict nonlinearities (slipping, etc.)
  - Only experimental uncertainty for lower bound
- Defining haversine/resonant plate specification
  - For valid but under-prediction, 2*(peak g)
  - For valid but over prediction, peak g
  - For invalid, other sources used to define specification

Random Vibration Specification with an Assessed Model

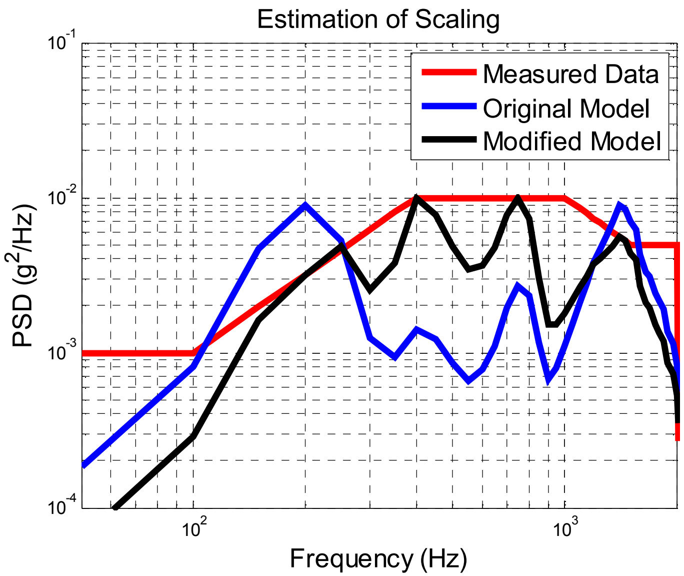
- Random Vibration represents a long duration, stationary event
  - Gaussian typically assumed
  - Stationarity sometimes not met
    - Amplitudes could change through time
    - Frequency content could vary
- Simulated on a shaker and defined by a power spectral density (PSD)
- Time duration defined by operational environment

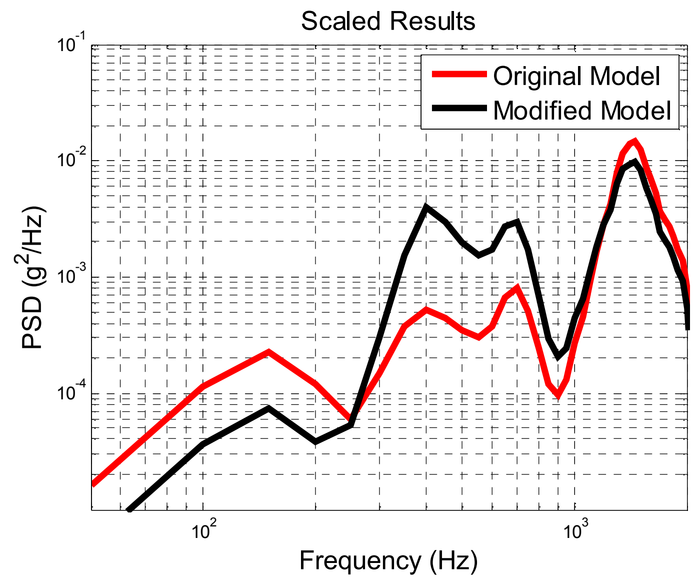


Random Vibration Model Validation

- Test specification derived by using straight line approximations for the environment
  - Sometimes modified to account for impedance of next level of assembly
  - Accounts for unit to unit variability
- Validation metrics vary
  - Error bounds on natural frequencies (~5%, for example)
  - Least favorable response
    - Weighted integrals of experimental and CompSim PSD
    - Smoothens PSD to provide a clean comparison
- Once the level of confidence of the model has been established, model bias is identified and used to define specification
- Model is used to define environment for unmeasured locations

Localized Bias Correction



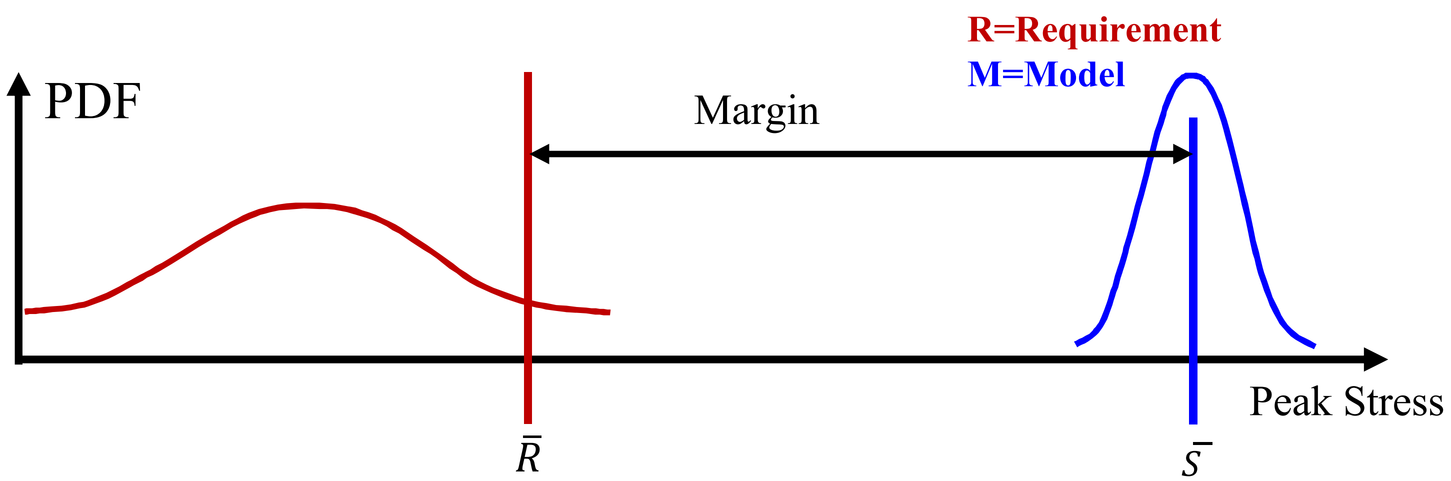


- Bias correction requires identifying a frequency dependent bias function based off of the peaks of the PSD
  - Develop an envelop based off of location that is measured and modeled
  - Scale nearby responses using the same function
- Provides a plausible model correction for developing test specifications from a imperfect model

Quantifying Margins and Uncertainties

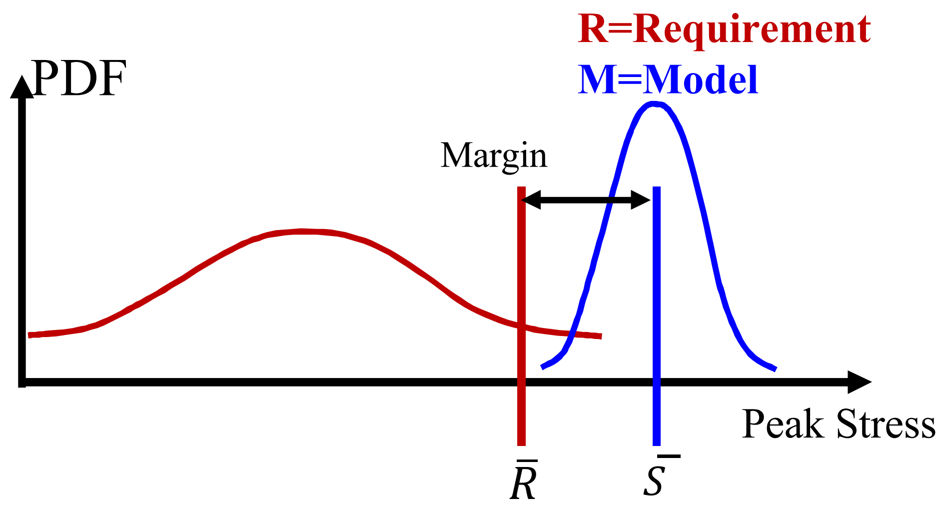
- Quantifying the extent of satisfaction of a requirement is crucial to establish confidence in component performance
- Margin testing is common
- Margin can also be established through modeling
  - Limited to mechanical failures
  - Functional failures not yet modeled
- Fidelity of model to establish margin is circular
  - A high fidelity model is required if margin is small
  - A low fidelity model is required if margin is large

Large Margin



- Model uncertainty and requirement uncertainty doesn't overlap
  - A large margin is identified
- Model uncertainty can be high
  - Margin is excessive
  - Exact margin definition not necessary

Small Margin



- Model uncertainty and requirement overlap
  - A small or negative margin is identified
  - Knowing the exact margin is important to understand if requirement is met or not
- High confidence in the model is required to properly identify margin.

Conclusions

- Define end use of the model up front
- Formal definitions of how model results will be combined with test data can be made
- Quality of model defines end use
  - Model is hardly ever useless if it is verified
- How results are used is determined by model fidelity
  - Use results from model for high confidence
  - Use modified model results for less confidence
  - Use mostly other sources of data for low confidence models