Towards a V&V Hierarchy for Fatigue Crack Growth Lifetime Analysis

ASTM E08.04 Workshop
Verification and Validation of Life Prediction Software
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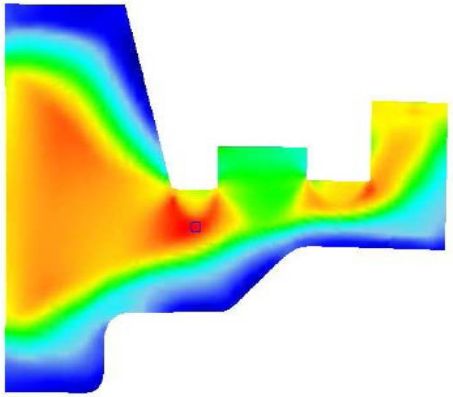
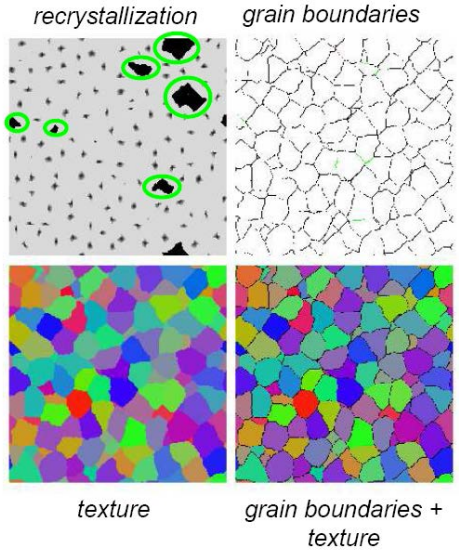
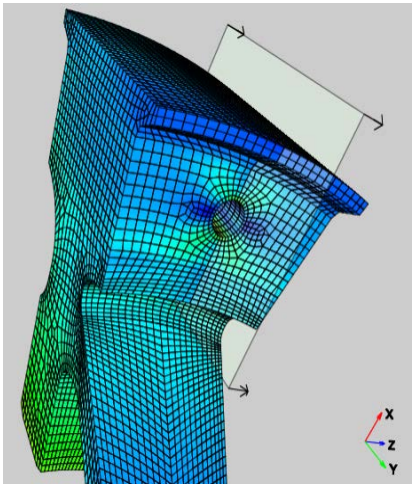
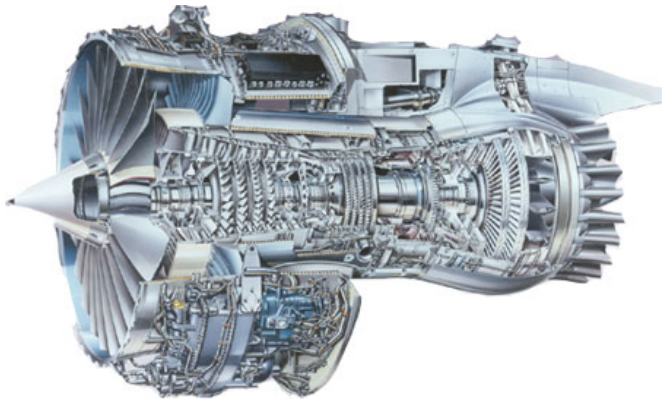
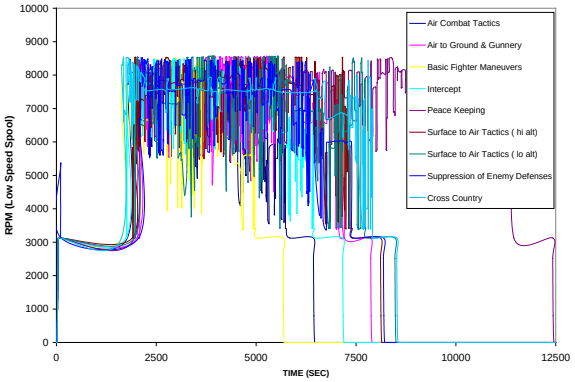
Current Lifing Models Contain An Unprecedented Level of Detail

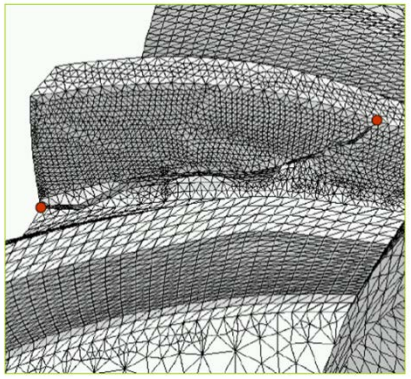












But How Credible Are These Models for Decision Making?

Credibility from Model V&V

- Verification
  - Credibility from understanding the mathematics
  - Are the equations being solved correctly?
  - Compare computed results to known solutions
- Validation
  - Credibility from understanding the physics
  - Are the correct equations being solved?
  - Compare computed results to experimental data
- Uncertainty Quantification
  - Credibility from understanding the uncertainties
  - How accurate is the model prediction?
  - Quantify uncertainty & variability from all sources

Mathematical Evidence

Experimental Evidence

Statistical Evidence

Model Verification & Validation

- ***Verification:*** Process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model

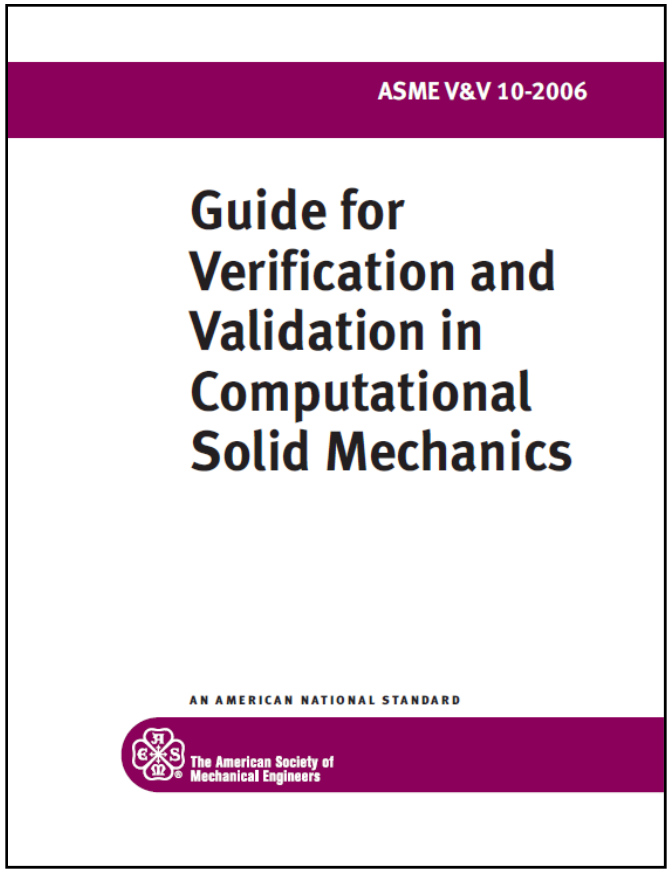
  Math issue: "Solving the equations right"

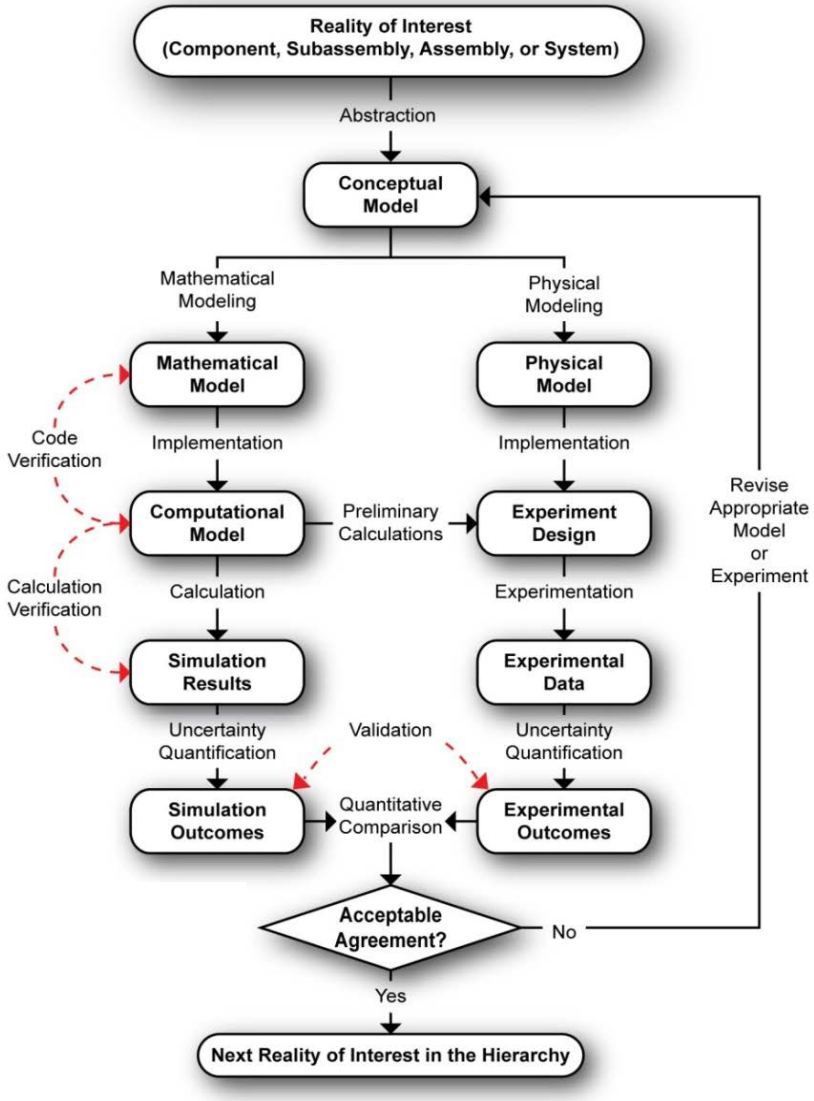
- ***Validation:*** Process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model

  Physics issue: "Solving the right equations"

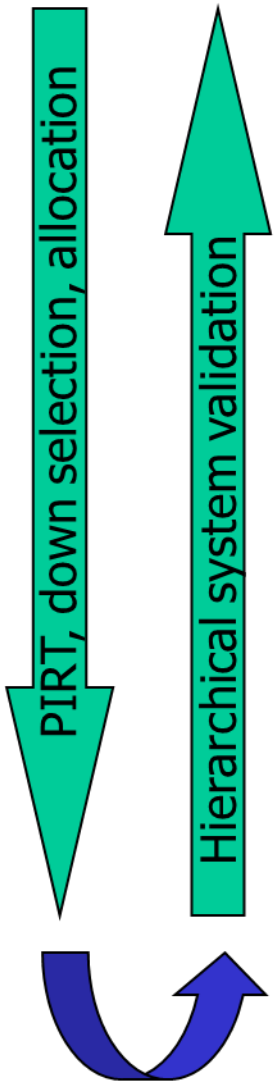
V&V Framework

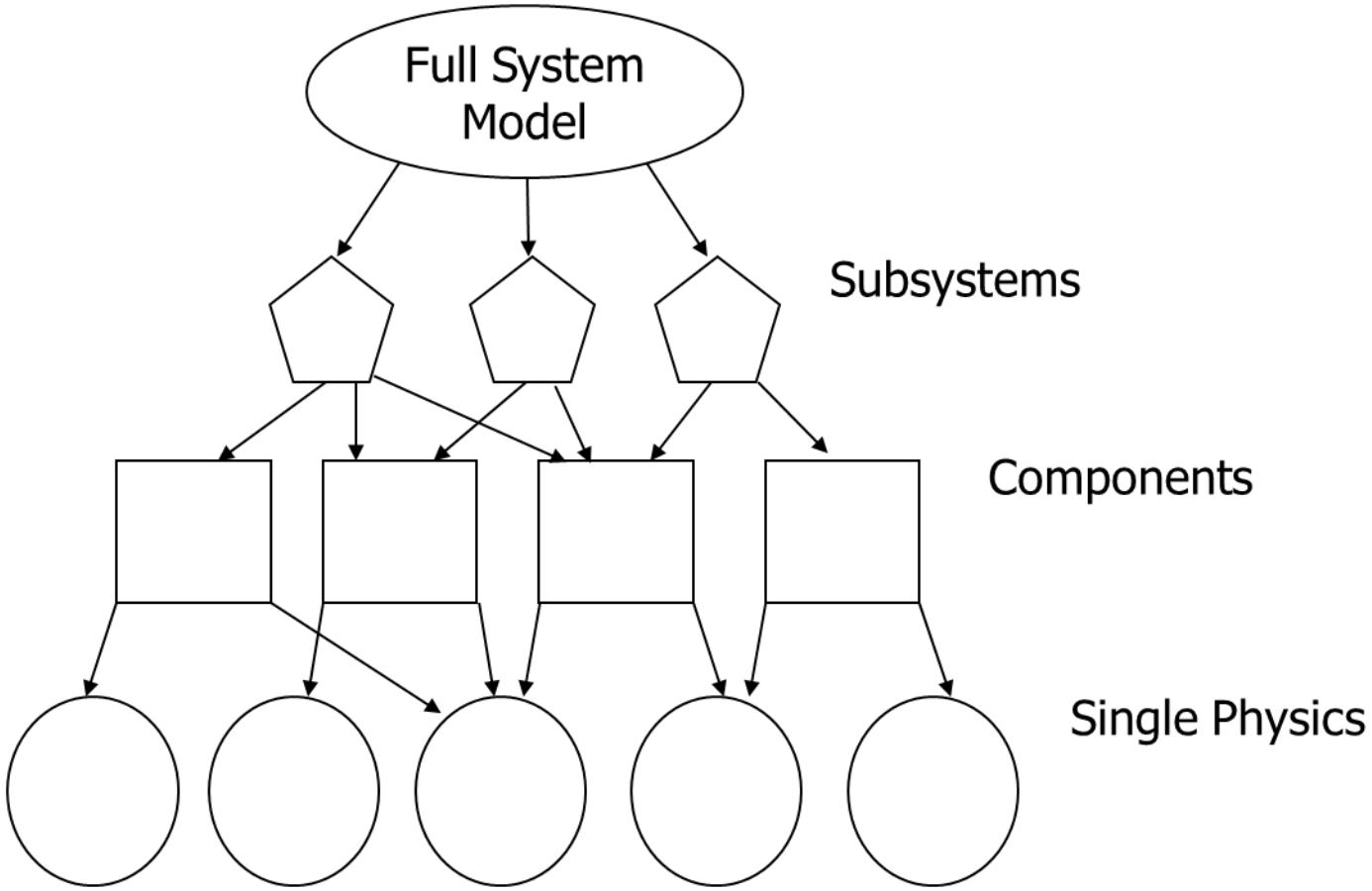
- Approach based on ASME V&V 10-2006





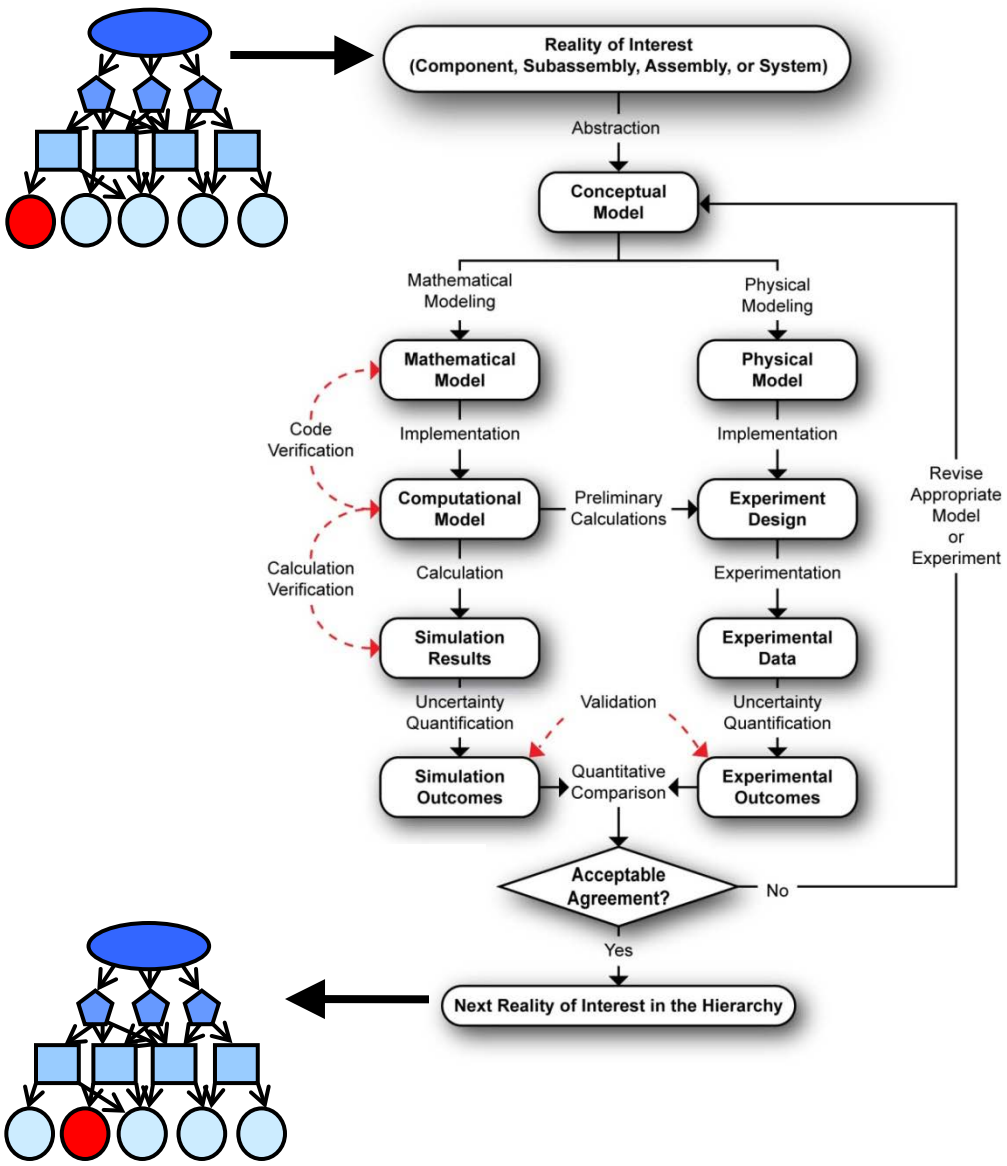
Validation Hierarchy





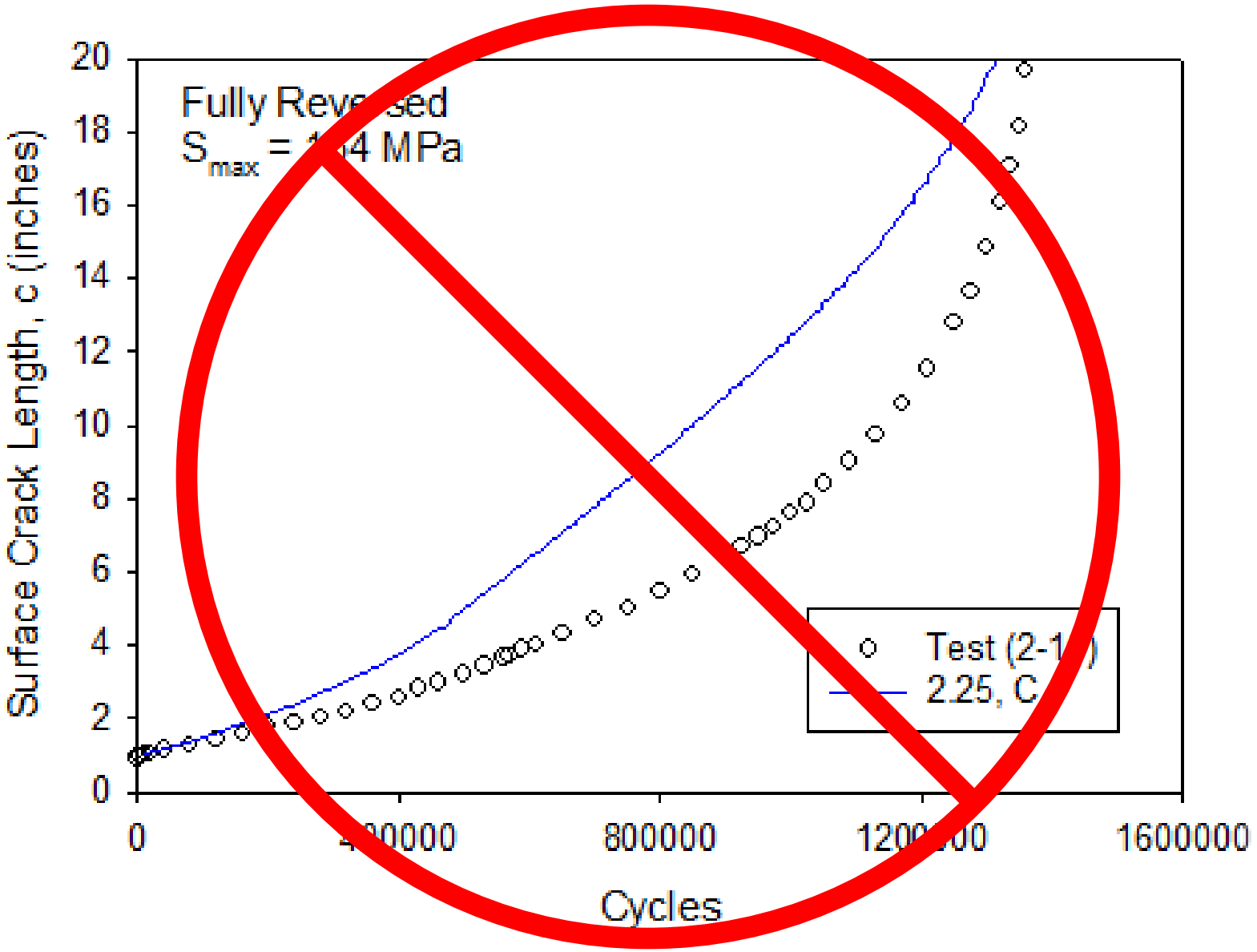
Approach: Bottoms up guided by sensitivity analysis of (un-validated) full system model

Validation Hierarchy

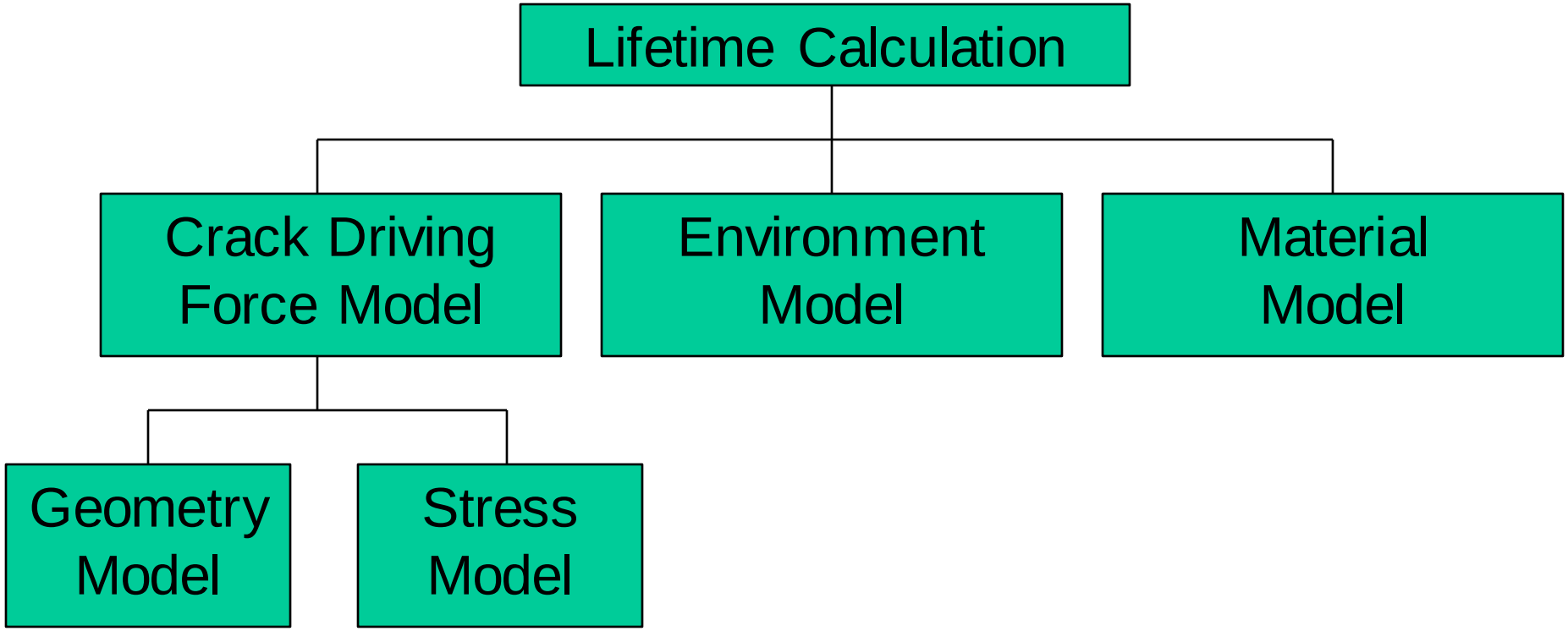


- Validation hierarchy adds credibility:
  - Breaks the problem into smaller parts
  - Validation process employed for every element in the hierarchy (ideally)
  - Allows model to be challenged (and proven) step by step
  - Right answer for right reason
- First establish intended use and top-level validation requirement
- Construct hierarchy, establish sub-level metrics and validation requirements
- In general, validation requirements will be increasingly more stringent in lower levels
  - Full system sensitivity analysis can provide guidance

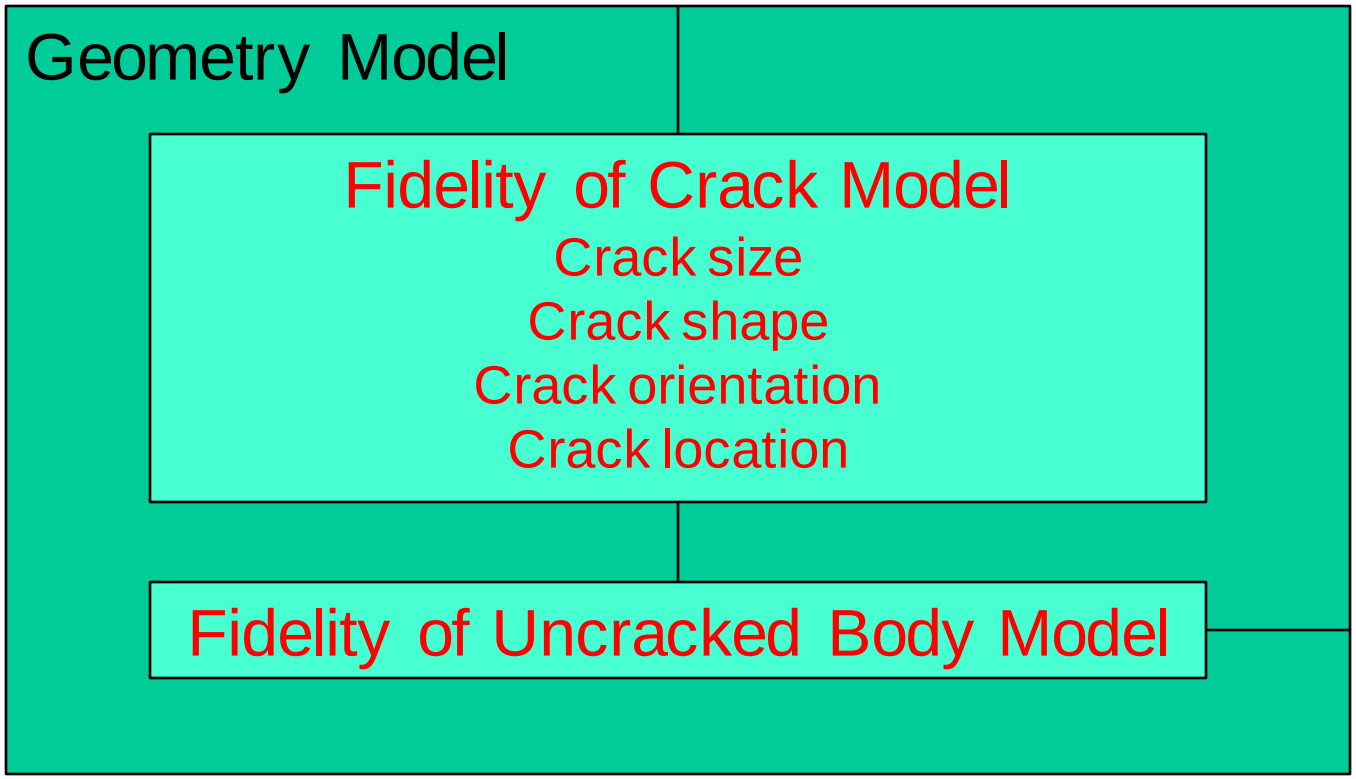
How NOT to do V&V of FCG Life Calculations

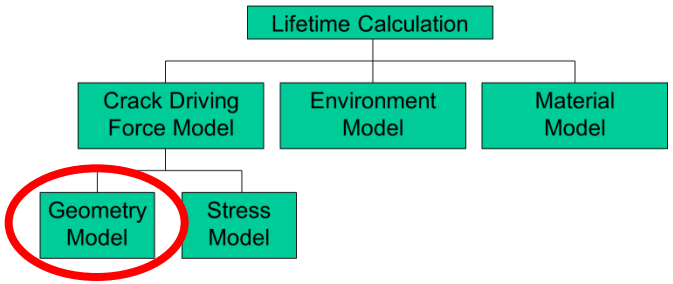


Draft Hierarchy for FCG Lifetime Analysis

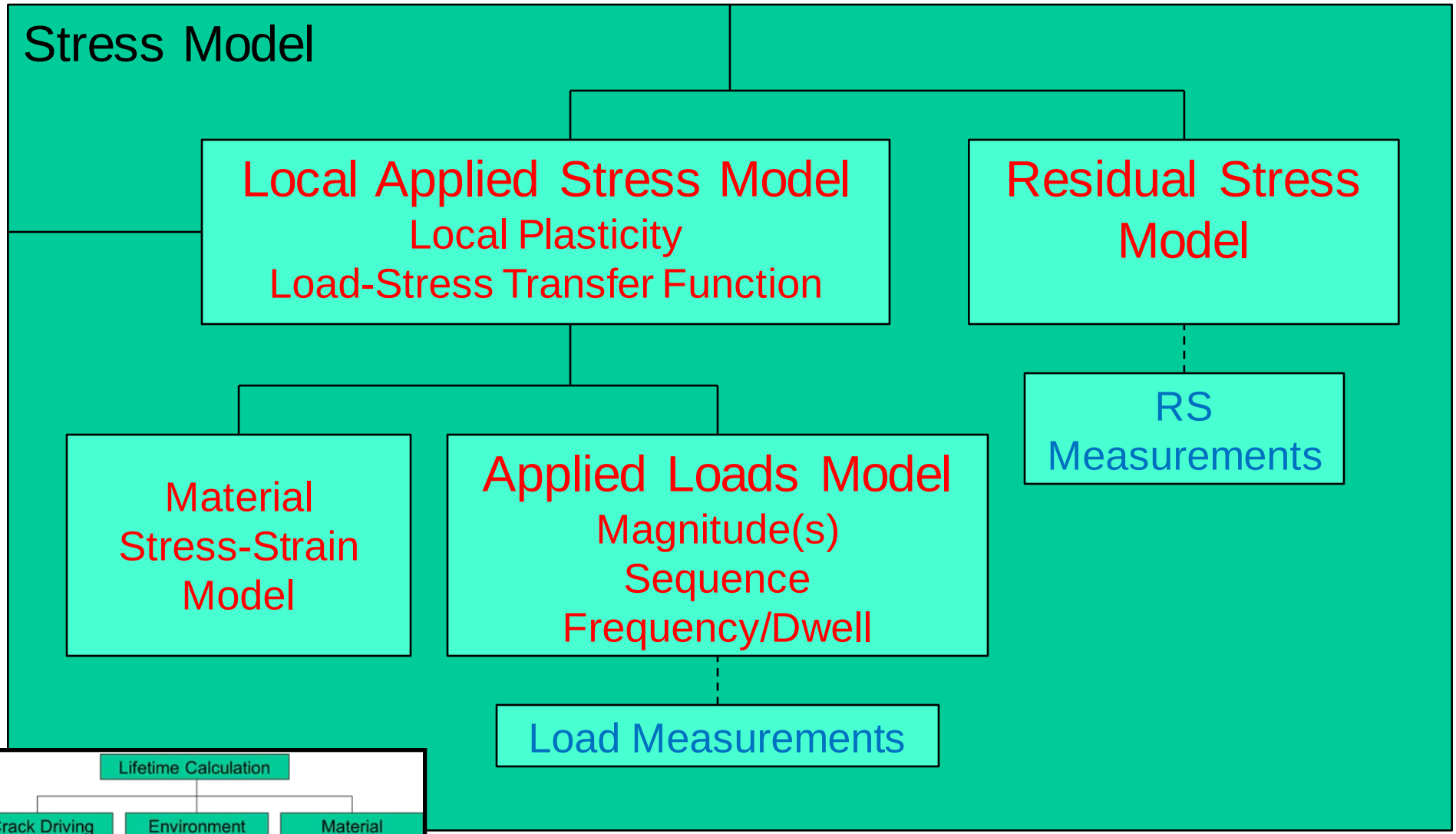


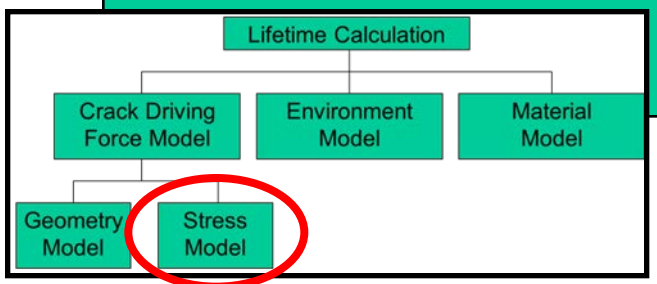
Sub-Hierarchy for Geometry Model



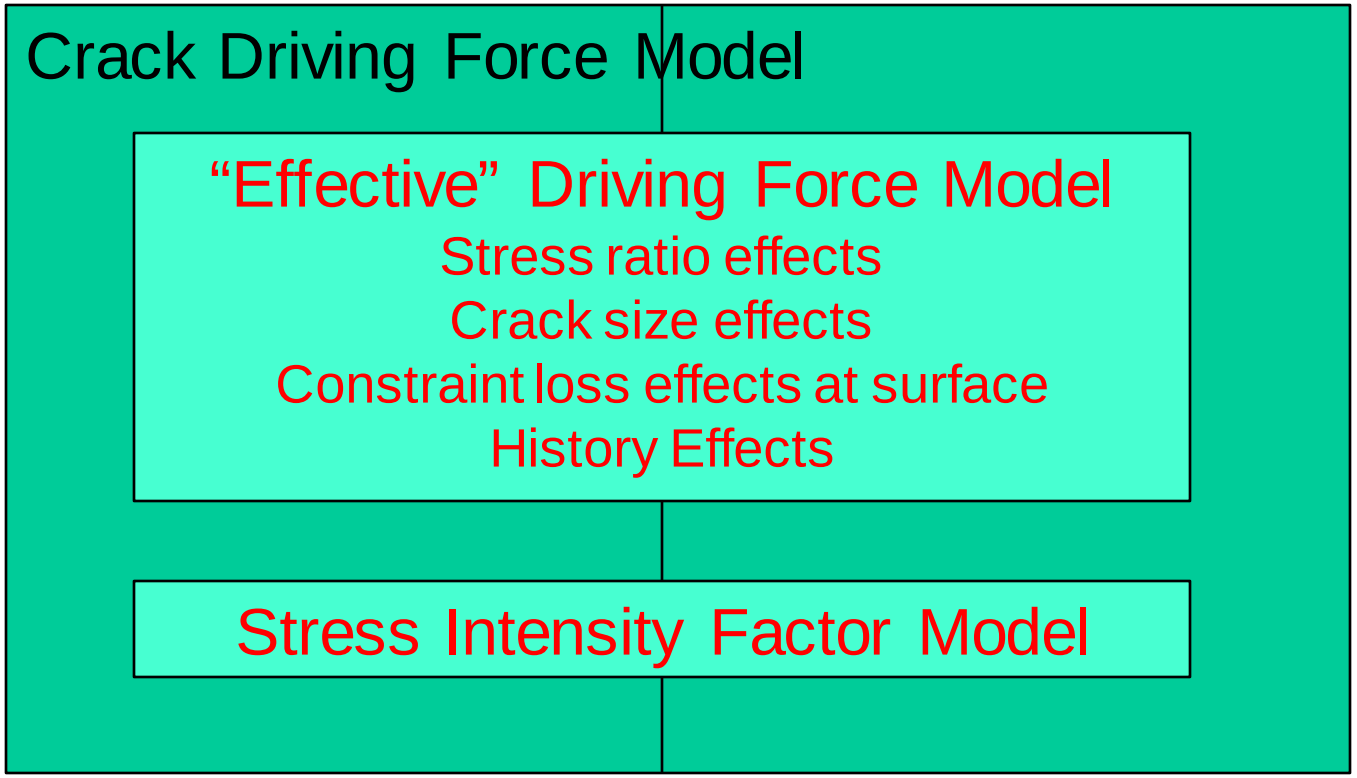


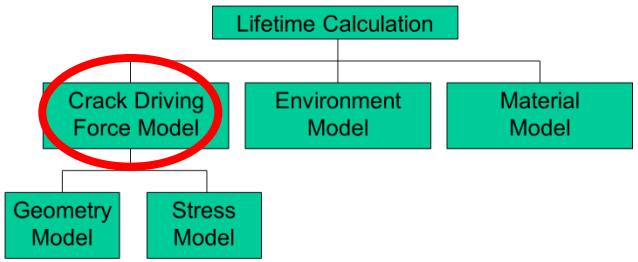
Sub-Hierarchy for Stress Model



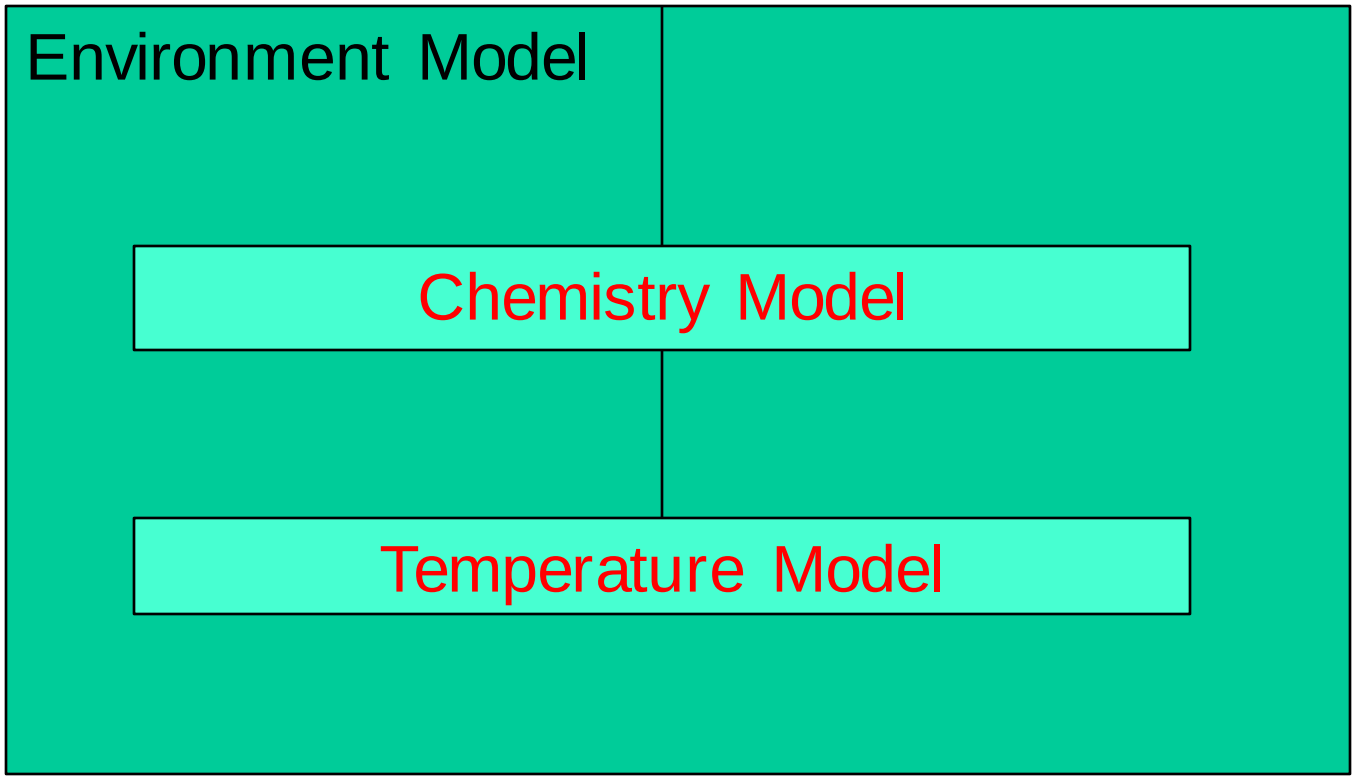


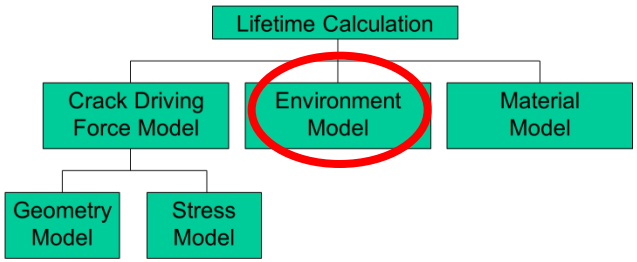
Sub-Hierarchy for Crack Driving Force Model



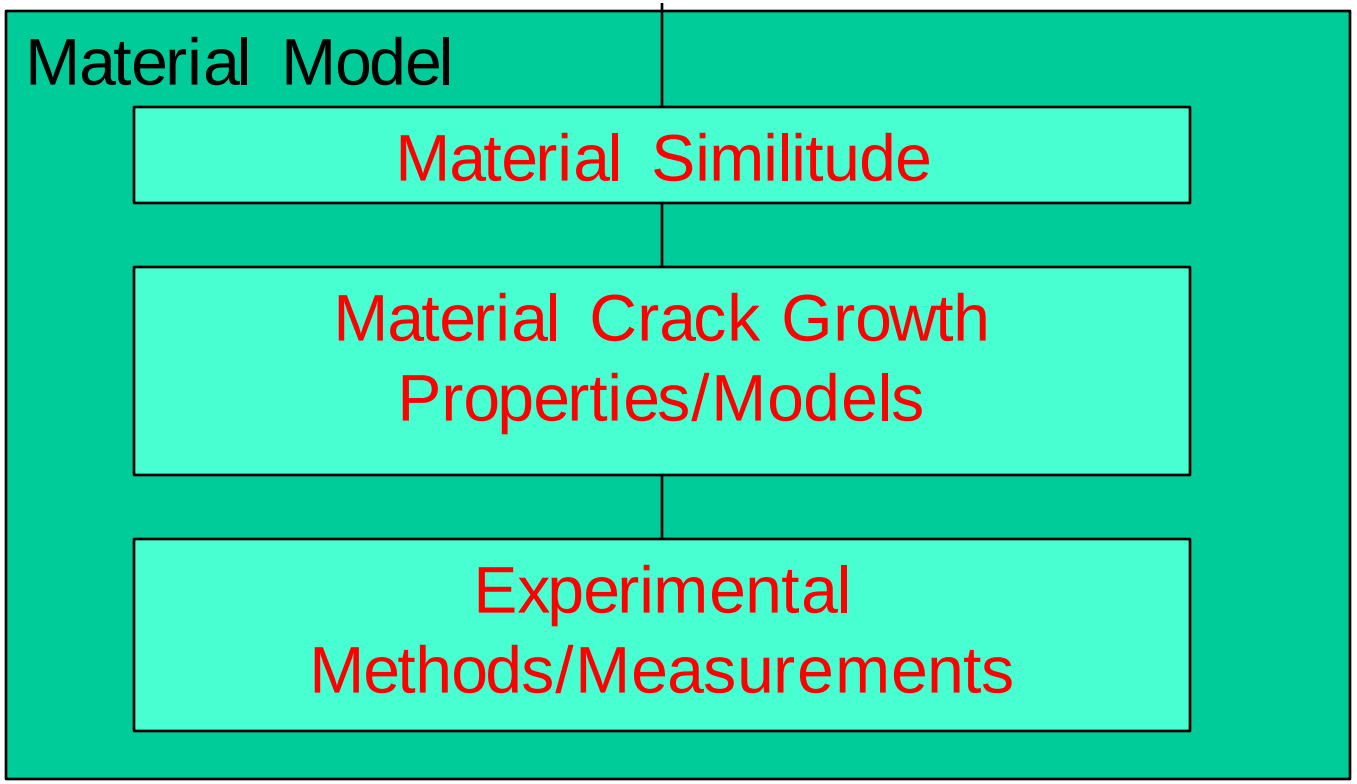


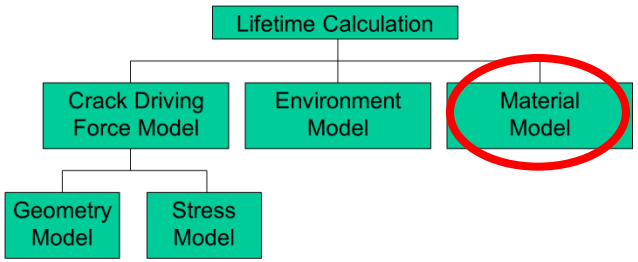
Sub-Hierarchy for Environment Model



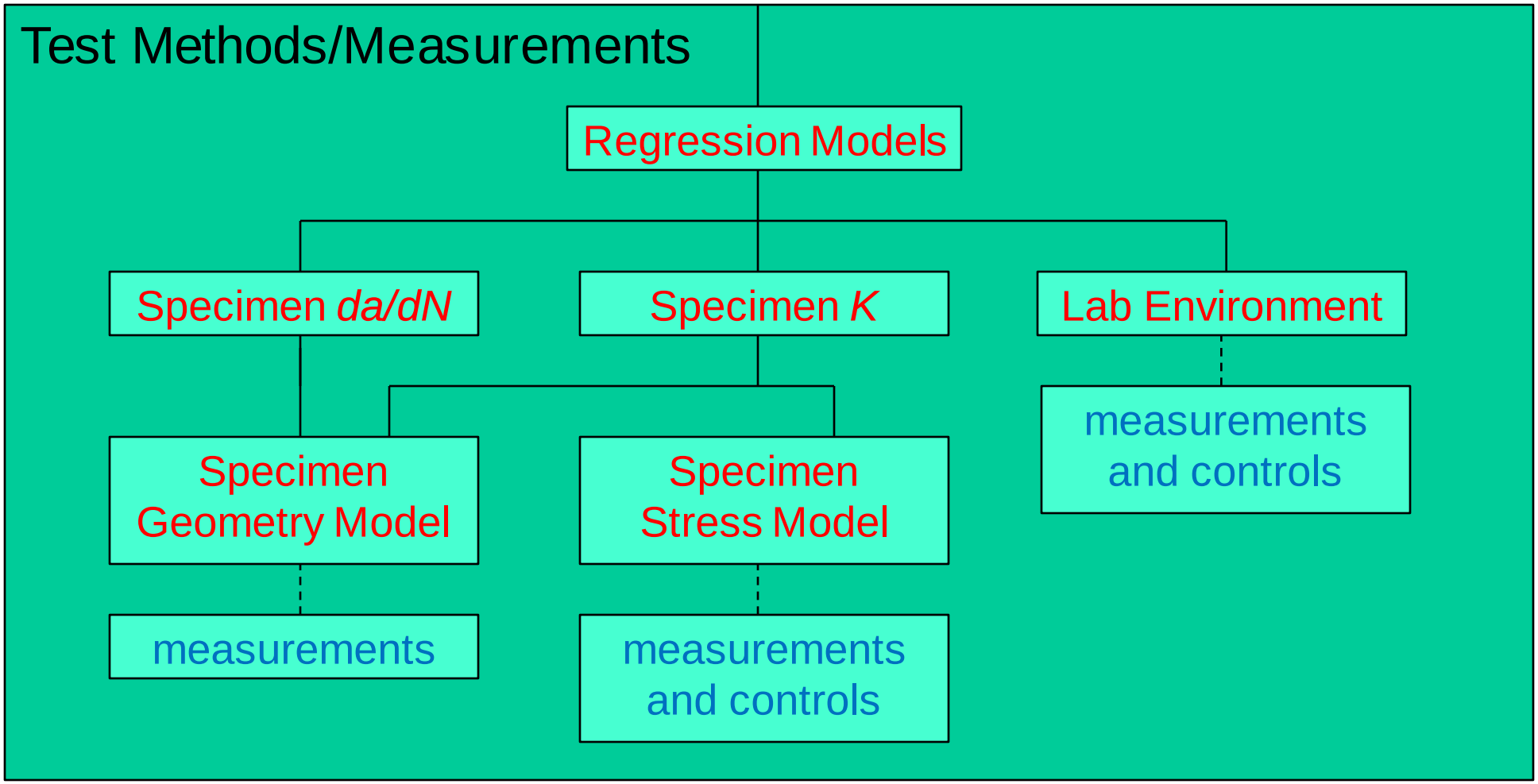


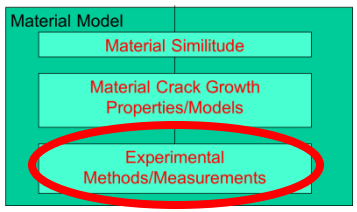
Sub-Hierarchy for Material Model





Sub-Sub Hierarchy for Test Methods/Measurements

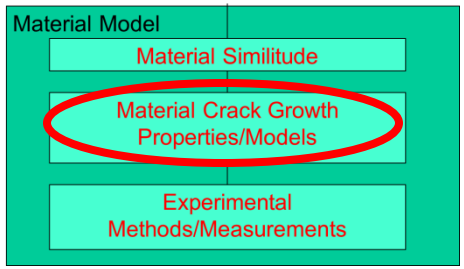




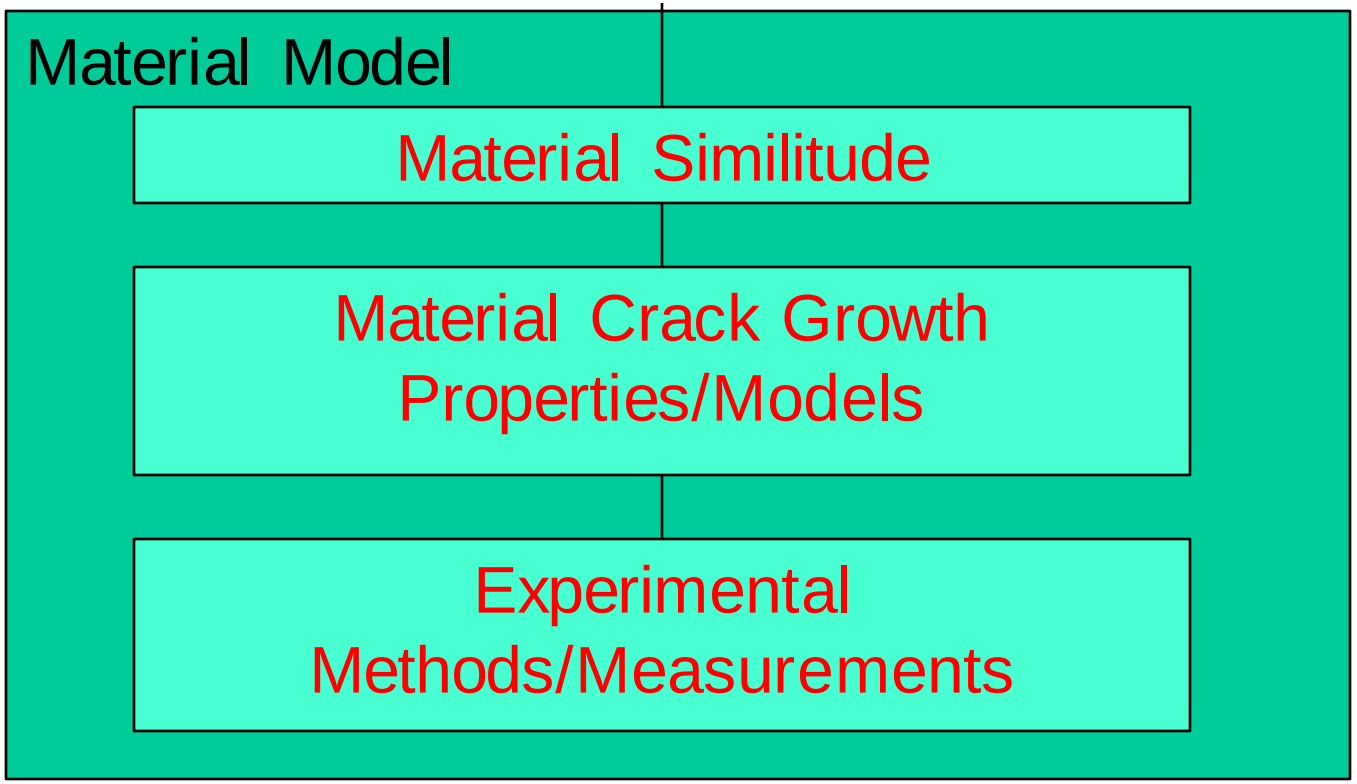
Matrix for Material Crack Growth Properties/Models

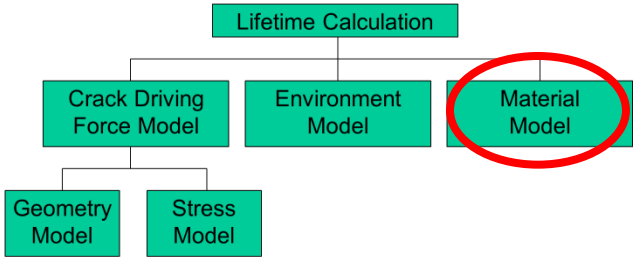
Material Crack Growth Properties/Models

	R	T	t	chem
Paris regime	x	x	x	x
Threshold	x	x	x	x
Instability		x	x	x
Load interaction	x	x	x	x

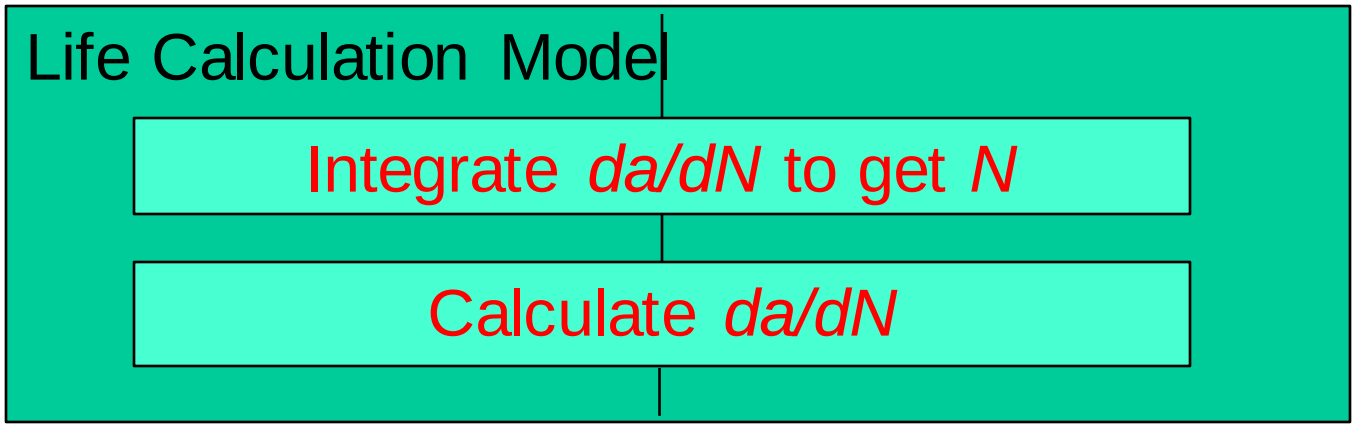


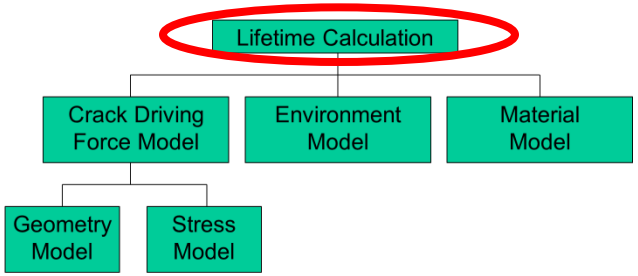
Sub-Hierarchy for Material Model



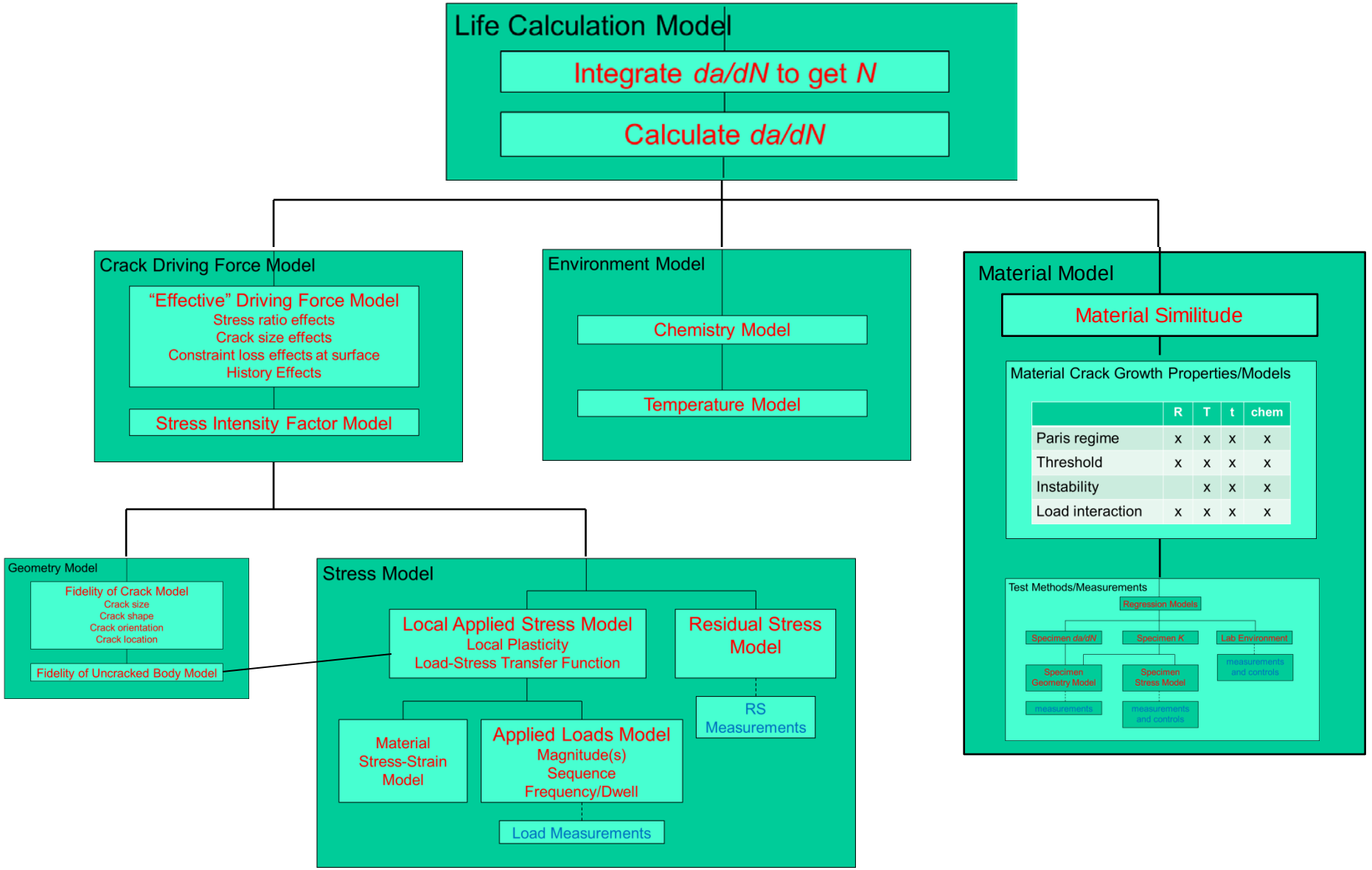


Sub-Hierarchy for Life Calculation Model





Detailed Draft Hierarchy for FCG Lifetime Analysis



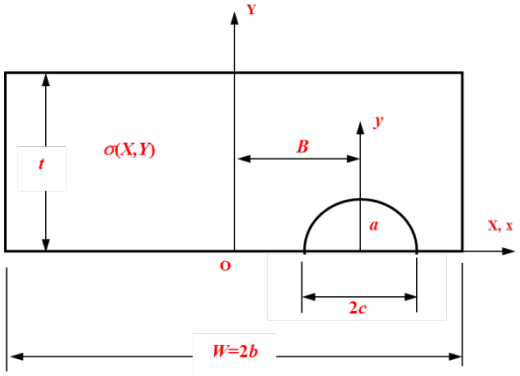
For Each Element…

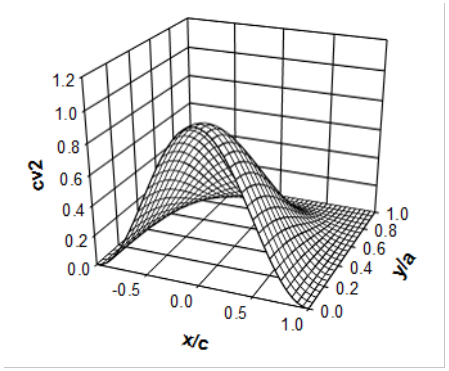
- Verification
  - Code Verification
    - Detect/eliminate algorithmic/programming errors
  - Calculation Verification
    - Numerical precision and discretization accuracy
- Validation
  - Direct comparison with tailored validation experiments
  - Do uncertainty quantification of both model and experiment
- Any calibration should be kept separate from validation and performed before validation

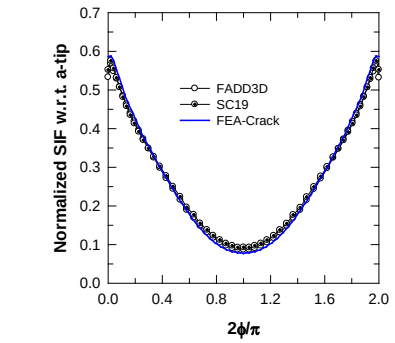
What is Most Significant?

- The relative significance of the different sub-models depends on the intended use of the life model
- For a given situation, some [many] sub-models may be trivial or insignificant
- Sensitivity analysis based on uncertainty quantification can be used to identify the most significant sub-models

Some Observations on One Element: K Solution







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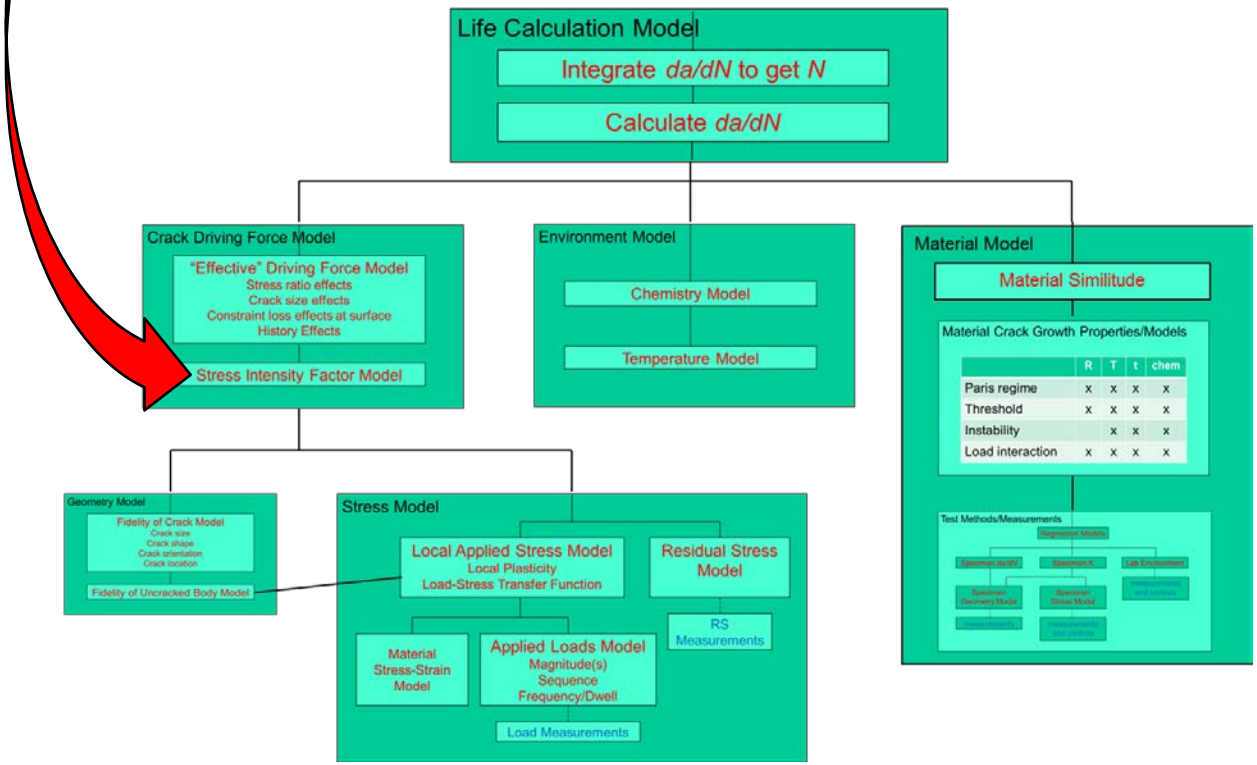
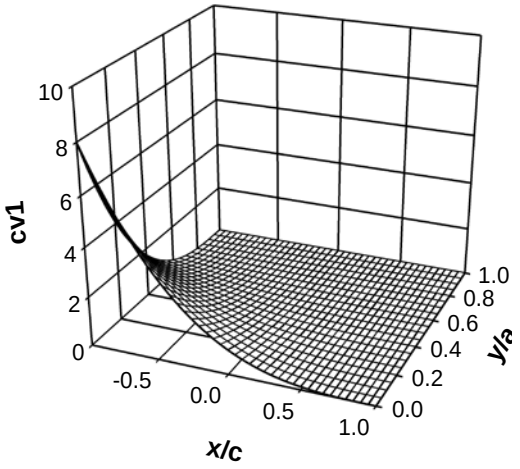
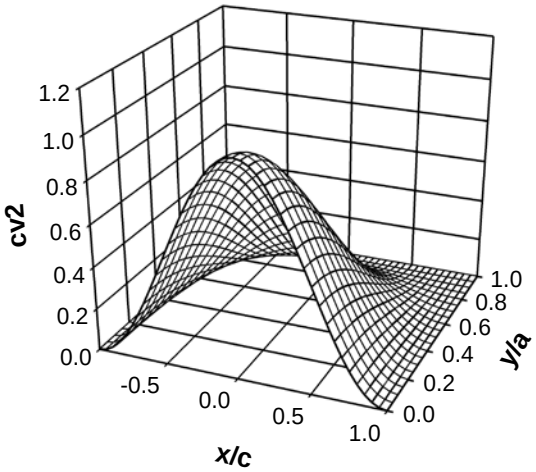
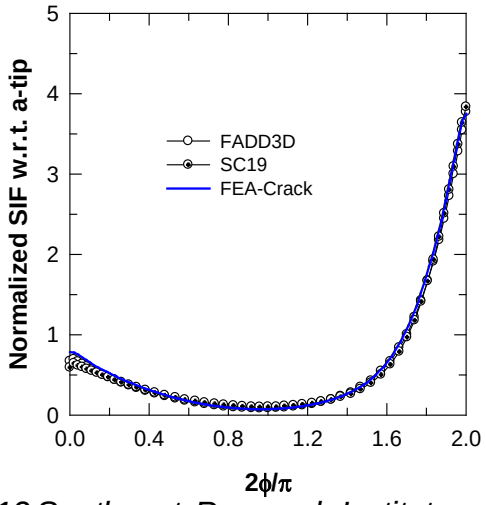


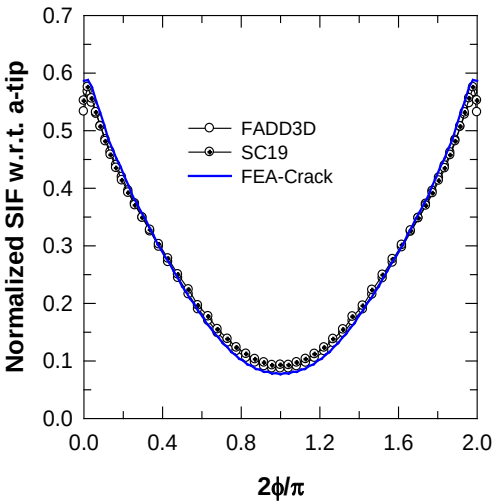
Some Observations on One Element: K Solution

- Verification of weight function K solutions by comparison to independent 3D numerical solutions
- No direct experiment
- What is absolute truth?
- How to cover entire range of solutions?









What To Do Next?

- This draft hierarchy is incomplete and imperfect
  - Further iteration is needed to improve it
  - Some sub-models may need to broken down into finer sub-sub-models
  - Additional interdependencies may need to be flagged
- Additional questions need to be asked
  - How best to isolate each individual model? (usually from the bottom up)
  - How best to quantify the validation?