Lecture 5 - Design Optimization

Optimization, what can be changed to improve result:

- Design variables (What are the limits)
- Design responses (What outputs calculated)
- Design objective (What needs to be minimalized)
- Design constraints (What is limit of the response)

Objective and constraints are based on responses of design subjected to given loading cases.

Design Sensitivity Analysis aims at answering the question: how much the output parameters are influenced by the input ones.

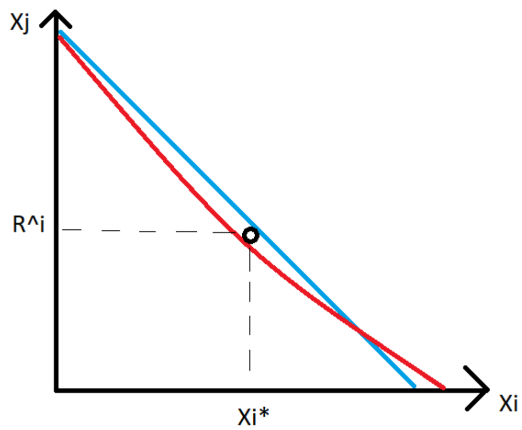
2 DSA approaches:

Local

Sensitivity coefficient is partial derivative of response x_i to a design parameter in a mathematical model.

$S_{ij} = \frac{\partial R^j}{\partial x_i}$

Sij, Param



Local DSA classification:

- absolute sensitivity coefficient $\frac{\partial R}{\partial P}$
- relative sensitivity coefficient $\frac{\partial R}{\partial P} \cdot P$
- normalized sensitivity coefficient $\frac{\partial R}{\partial P} \cdot \frac{1}{R}$
- normalized relative sensitivity coefficient $\frac{\partial R}{\partial P} \cdot \frac{P}{R}$

Local DSA ways of calculation:

- analytical differentiation
- semi-analytical differentiation
- FDM = Finite difference method

Issues with local DSA:

- Same combination of parameters and response maybe calculated differently in different points
- Only one parameter changed can cause a combined change in response

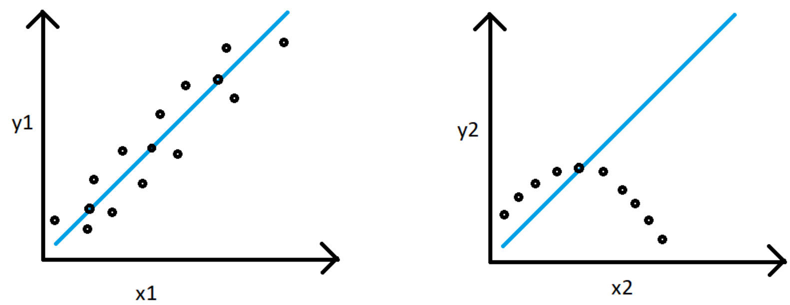
Global

Study how uncertainty in output relates to uncertainty in input.

Methods for global DSA:

- Screening
- Regression-based
- Variance-based

$S_{i_1 \dots i_s} = \frac{D_{i_1 \dots i_s}}{D}$ D = total output variance, D_i.. = Each individual variance, S = pseudo-random sampling is used



Design of Experiments strategy to get empirical knowledge based on experimental data. Applied when investigating a phenomenon.

Approach to DOE:

1. Screening
2. Generative design = input parameters allow software to generate design alternatives.
3. Response Surface Method - unknown function approximation taking most characteristic points of the model. We try to approximate using a simple polynomial or spline

Optimization types:

- size (structural properties of object - stiffness, thickness, mass)
- shape (boundaries of structure - grid points and their location)
- topology (for given space, optimal shape and mass distribution)
- topometry (identify initial regions - weds and their optimal location)
- topography (introducing stamped beads for a better structural performance)

Gradient based optimization:

- local minima influence
+ deterministic
+ less node points need to be checked

Evolutionary based optimization:

+ instead of sequence, generate randomly distributed points and keep subset of best fitted points based on genetic features
- more computational resources necessary

Multiobjective optimization:

- trade-off between criteria
+ optimized for multiple goals even conflicting ones:

Robust optimization:

+ Optimizing where robustness in caught against uncertainty or variability in the value of a parameter for the problem

Lecture 6 - Composites

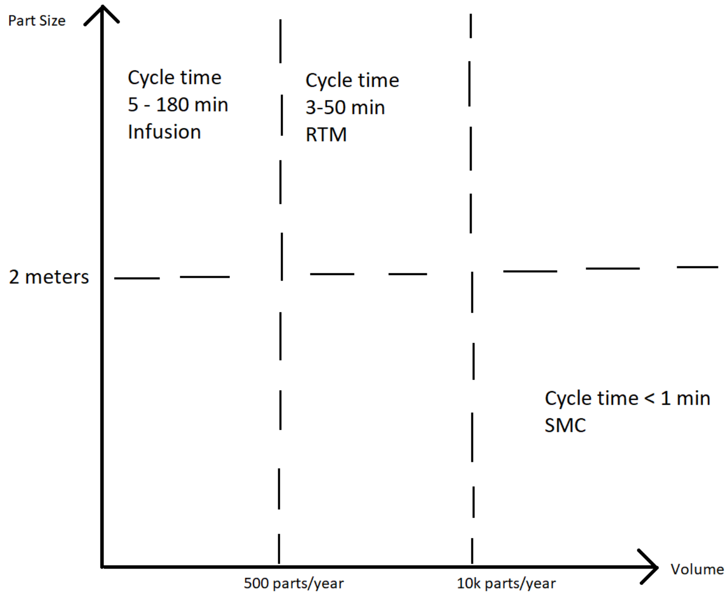
Composite is a material composed of at least two phases. Fiber in a resin or similar medium (matrix). Strength and stiffness provided are by fibers. Fibers have very small diameter and are scattered through matrix ply. When dealing with composites both material fibers need to be considered, when considering stiffness and strength. They are often used in the airplane industry. They have high strength with low mass.

Types of composites:
- Particle-reinforced
    - Large particles
    - Dispersion strengthened
- Fiber-reinforced
    - Continuous
    - Discontinuous
        - Aligned
        - Randomly Oriented
- Structural
    - Laminates
    - Particulate-Reinforced

Structural composites

Manufacture techniques (Reinforcement[fiber] + matrix):
- Pultrusion
- Infusion
- Resin transfer molding
- Sheet molding compound
- Prepegging
- Filament winding

Three types of consolidation



Fibers examples:

- glass fiber
- carbon fiber

Pultrusion

- application : civil, engineering, construction
- isotropic material is result
- used reinforced common elements like beams

Infusion

- application: wind turbine blades
- infused with liquid glass fiber

SMC

- useful for small parts

RTM

- useful for large automotive parts (car floor)

Braiding

- result has high strength
- drive shafts, suspension elements

Filament winding

- Braiding for simpler elements = Regular cross section
- Continuous rowing -> Rotating mandrel -> winding process

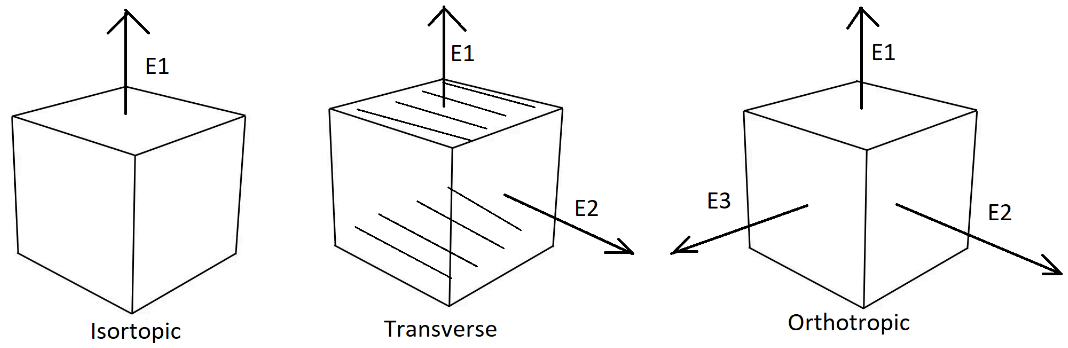
Prerpreging

- Short time to shape

- Carbon fiber wheels, plymatch-ply placement technology

Composites are often complex because of different materials that are bonded. Serviceability and repair process is harder and more expensive and in some cases impossible. It's really an issue to recycle them, because of different materials and their utilization means.

Material orthogonality:



Isotropic material properties (2 constraints):

$G = \frac{E}{2(1+v)}$

Needed constraints increase for Transverse (5) and Orthotropic (12).

Yield criteria

Failure theories are different from isotropic materials.

Tension along and across fibers, so 4 reference values for max strain and stress.
Huben - Von Mises does not apply. Theories for failure of composites:

- Hill
- Hoffmann
- Tsai-Wu <- safe choice

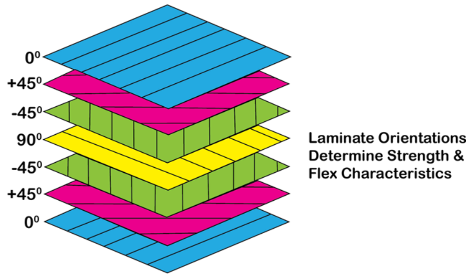
Tsai-Wu takes interaction between longitudinal and shear waves which would have been hard to characterize without inhouse testing.

Criteria for failure theories substituted with characteristics give a failure index. Generally SR is a better indicator than FI.
FI > 1.0 = Failure
SR (Strength ratio) < 1.0 = Failure

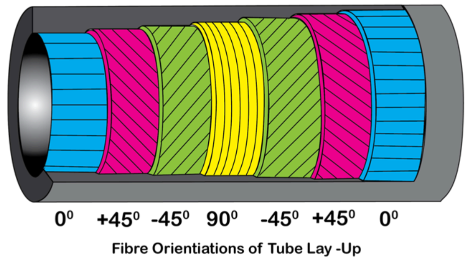
$$SR = \frac{allowable\ loads}{actual\ loads}$$

Ply layup

Sequence naming: [0/45/-45/90], types:



- Balance layup [0/90/-45/45]
  For each ply we use a different angle.
    - No inline curing
- Symmetric layup: [0/45/-45/-45/45/0]=[0/45/-45]s
    - No in plane, out of plane curing
- Balanced Symmetric layup [0/90/-45/45]s



If the layup is different it is harder to predict the behavior of the system. But that can be useful for example in wind turbines, with rotation in bending, reducing drag and allowing a better attack angle.

Do not assume you know the system response if you know boundary condition (Especially for unusual layup)

Fail strategies:

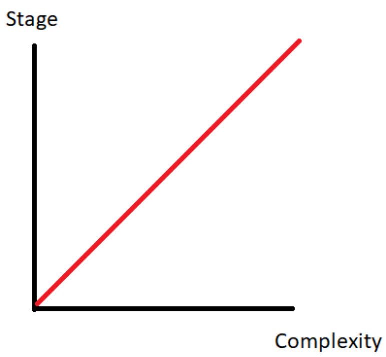
- First ply failure (If first fails)
- Last ply failure (Wait till last fails)
- Progressive damage (Progressively check damage of ply failures)

Damage:

Laminates are prone to impact damage because of lack of reinforcement between plys.

Validation process:

Progressively: Materials->Elements->Assemblies->Components->Product tests



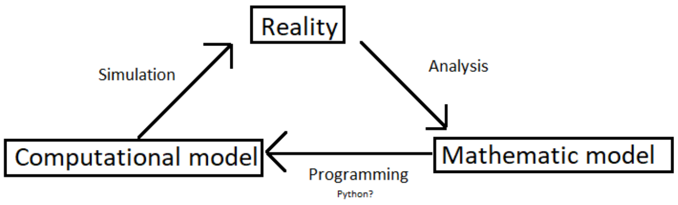
Lecture 7 - Verification and validation

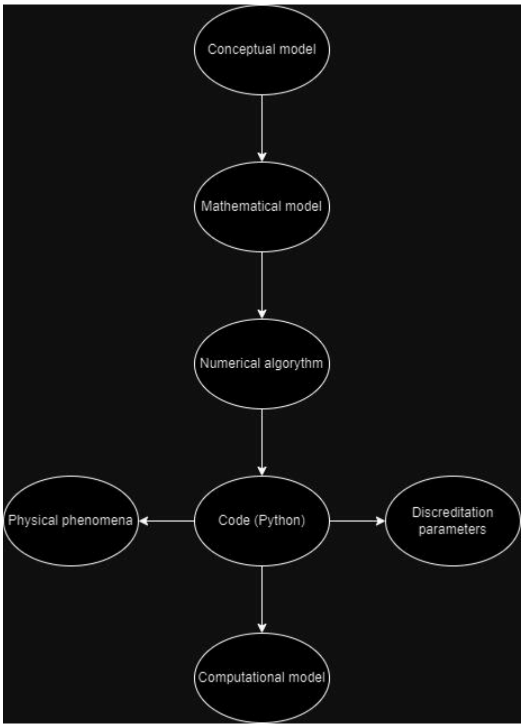
Verification - process of determining that the computational model accurately represents the underlying mathematical model and its solution.

- *Do we solve the equation right?*

Validation - process of determining the degree to which model is an accurate representation of the real world from the perspective of the intended uses of the model.

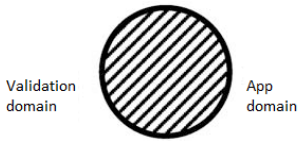
- *Did we solve the right equation?*





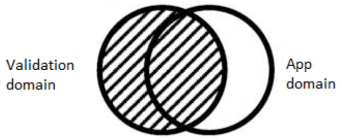
Scenarios for model validation:

- Option 1



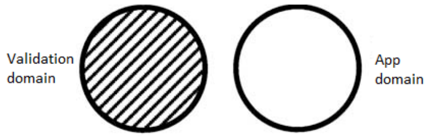
Numerical model is validated successfully and the app is enclosed in validation.

- Option 2



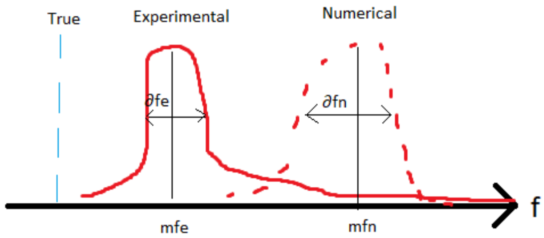
Validation does not overlap completely.

- Option 3



No possibility to obtain measurements for validation case for innovative application (line space)

Deterministic vs Non-deterministic:



- Distance between the expected and numeric results, not a specific value, but rather an interval
- Distance between mean values or type of distribution, we don't know where the true value is, could be outside of scope

Uncertainty - inability to learn the true answer to a question or a problem. Uncertainty is a general limitation of human cognition. In engineering it refers to propagation of uncertainty from system inputs to outputs and exploring the ranges of input variations and studying their consequences.

Types of uncertainty:

1. Reducible:
    - subjective/epistemic

Due to lack of knowledge, cannon be described with probability, can be reduced via obtaining knowledge

2. Irreducible:
    - variable/aleatory

Natural fluctuation of its properties that it can exhibit at different times, environmental cond. Possible to narrow down, but not remove entirely

Sources of uncertainty in design stage:
- choice of solution concept
- method of modeling, topology etc.
- approximations
- numerical errors

Uncertainty Quantification:
1. probabilistic methods
    - Monte Carlo
    - Perturbation method
    - Soft computing
2. non-probabilistic methods:
    - interval analysis
    - fuzzy logic

Probabilistic is working with random numbers and variables, whereas non-probabilistic is limited knowledge on probability, density and statistics of the params.