CV5100 – MUDE
Modeling, Uncertainty, and Data for Engineers
Ch2 – Modelling Concepts

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Numerical Modelling, Linear Algebra, Optimization

Week	Lecture/ Practical	Topic
1	1	**Course overview and Introduction** to modelling - classification
	2	**Modelling concepts –** Choosing a model, validation, performance
	3	**Numerical Modelling –** DE, FDM, Taylor series
	4	**Practical**
2	5	**Numerical Modelling** – Numerical integration
	6	**Numerical Modelling** – IVP/BVP for ODE
	7	**Numerical Modelling** – BVP for ODE numerical methods (accuracy, stability)
	8	**Practical**
3	9	**Numerical Modelling** – PDE basics and PDE types, Nabla and Laplacian operations
	10	**Numerical Modelling** – FEM
	11	**Linear Algebra –** Vector spaces, span, linear dependence
	12	**Practical**
4	13	**Linear Algebra** – Basis, dimension, examples, tensor vs. matrix
	14	**Linear Algebra** – System of linear equations, matrix form, solution approach - direct
	15	**Linear Algebra** – Matrix equations, solution approach - iterative
	16	**Practical**
5	17	**Linear Algebra** – Eigenvalue problem, solution approaches
	18	**Linear Algebra** – Complexity and scaling
	19	**Optimization** – Classification and types of problems
	20	**Practical**
6	21	**Optimization** – Mathematical formulations and key concepts
	22	**Optimization** – Gradient and non-gradient approaches
	23	**Optimization** – Gradient and non-gradient approaches
	24	**Practical**

Outline

- Model classification
- Model decisions
- Verificatio vs. Validation
- *Goodness of Fit (later..)*

https://mude.citg.tudelft.nl/book/2024/modelling/overview.html

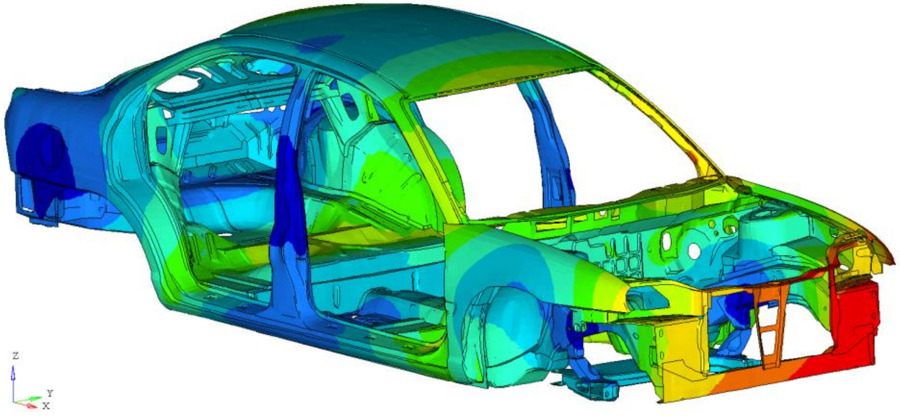
What is *Modeling & Simulation*?

Models: Used to understand/explain/predict something

- Theoretical, Mathematical, Numerical, Computational, Statistical, Phenomenological, …

Simulation: Re-creating a system, (or) a process, (or) a phenomenon, (or) a problem by using a model.

e. g. A **computer simulation** of a car crash is based on the **mathematical model** that is used to represent the structural behavior of the chassis.

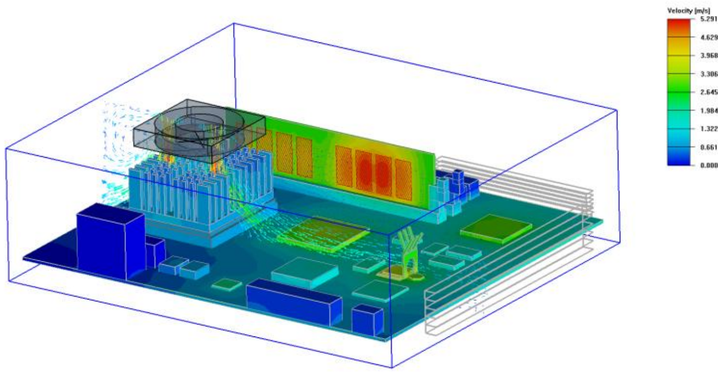


Ref: https://altairuniversity.com/wp-content/uploads/2017/07/modal_anim.gif

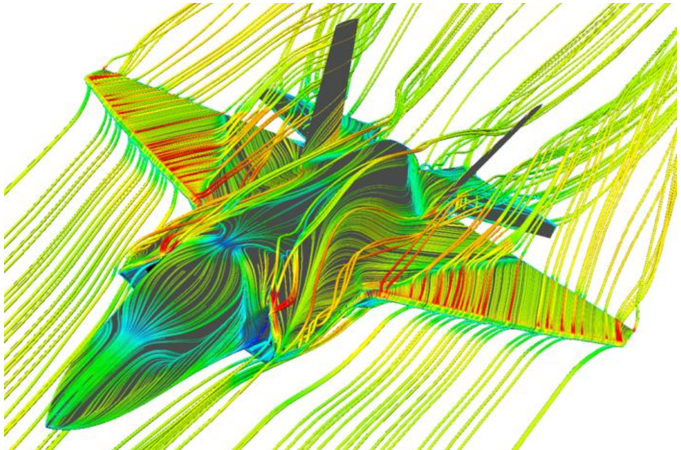
Examples of *Modeling & Simulation*

- Weather forecast
- Financial Engineering

- Atomic/Molecular interactions
- Thermal analysis



- Fluid mechanics



- **Structural analysis**

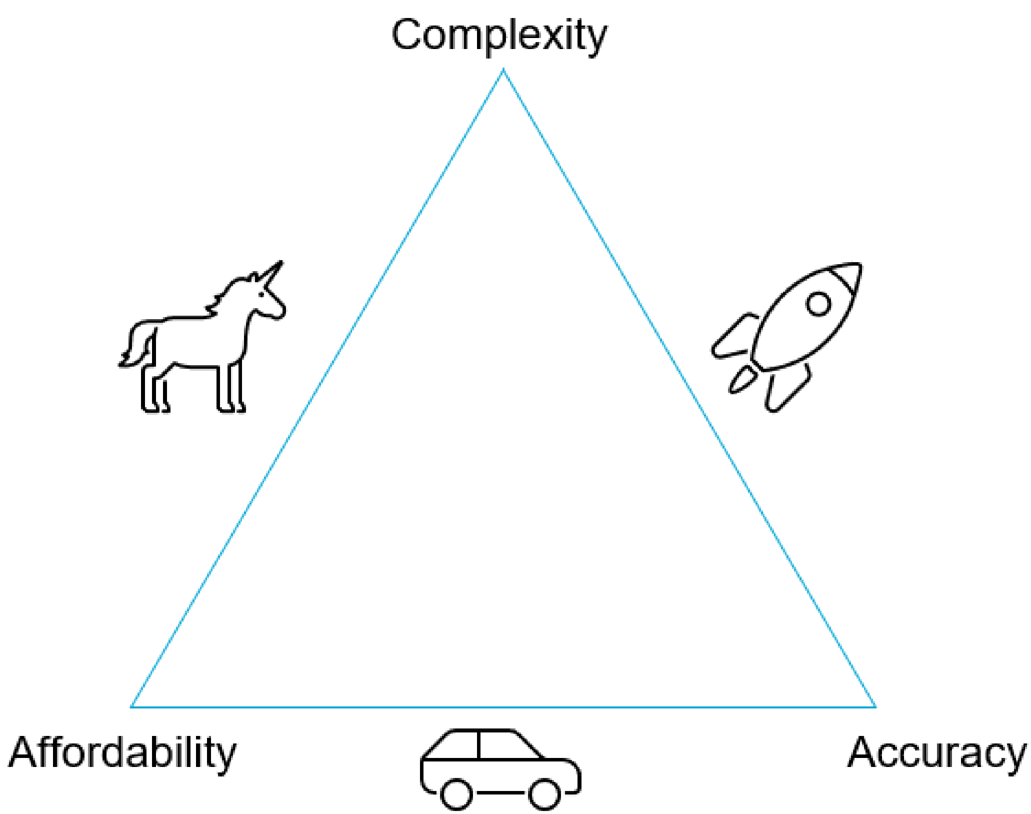
Ref: https://www.ansys.com/blog/5-factors-define-aerospace-and-defense-industry-trends
https://www.finiteelementanalysis.com.au/featured/dcir-analysis-of-pcb-in-ansys-siwave/

Model Classification

- **Conceptual Models** – high level abstraction
  - e.g. Visual representation of a framework, graphical or causal loop diagrams
- **Mechanistic Models** – first principle based, mathematical
  - e.g. Newton's laws, elastic spring model
- **Phenomenological Models** - experimental observations + mathematical/mechanics
  - e.g. drag force formula using drag coefficient $F_D = \frac{1}{2}\rho v^2 C_D A$
- **Data-based** – Only based on observed data
  - e.g. Forces on a wall due to waves

Model – Trade offs

- **Affordability and accuracy:** cheap and functional models, but with a limited scope. i.e., potentially lacking in complexity
- **Accuracy and complexity:** very realistic models, but prohibitively expensive. i.e., not affordable
- **Complexity and affordability:** the unicorn icon might speak for itself - difficult to achieve! i.e., its almost impossible to get an amazing model on a budget, that also accurately shows us what we need!



Model decisions

- **Dynamic vs. Static models**
  - Dynamic equilibrium equation
- **Linear vs. Non-linear models**
  - Superposition; Initial conditions
- **Time-invariant vs. Time-variant models**
  - Life cycle behavior; Climate change; Temporary structures
- **Deterministic vs. Stochastic models**
  - Concrete cube strength; Steel elastic modulus; Dimension measurement

Verification vs. Validation

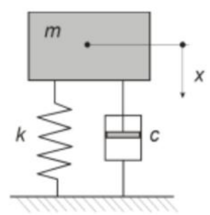
- **Verification** is the process of checking whether the model is correctly implemented with respect to the original conceptual model. It should answer the question: ***Have we built the model right?***
- e.g. You want to model a truss structure. You model it as a 2D (plane) truss. Verify the accuracy. How? By checking for errors in calculations (or) using alternative methods to arrive at the same solution values, for the 2D truss that you modeled.

- **Validation** is the process of testing the ability of the model in answering the research questions as best as possible. It should answer the question: ***Have we built the right model?***
- e.g. You want to model a truss structure. You realize that the structure needs a 3D model and the 2D model is not correct representation (for example, if you consider lateral restraint or buckling effects). This needs a fundamental change in the model so that you use the "right model".

Which of the two models is valid?

- Consider two models for some real structure.

Model 1:
mass on spring system



Model 2:
Numerical model – Finite Element Model

- Depends on the aspect of interest? (e.g. natural frequency, deformations)