UNIVERSITY OF LEICESTER

School of Engineering

Finite Element Analysis
what are simulations for?

Gebril El-Fallah

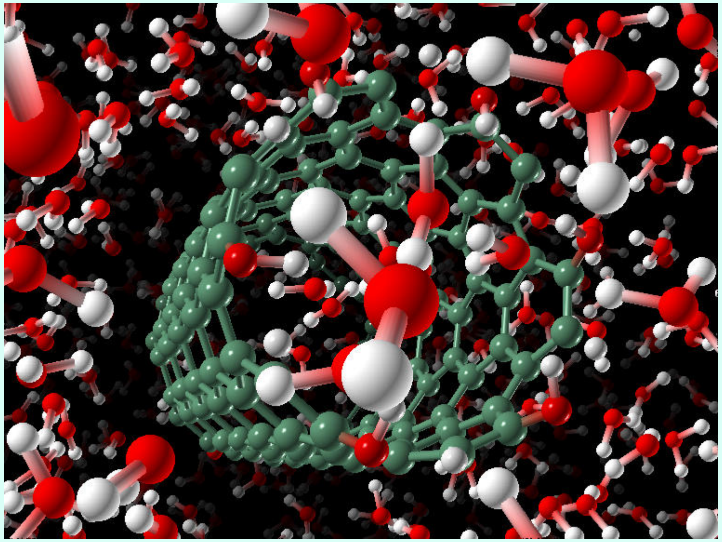
EG3111 – Finite Element Analysis and Design

gmae2@leicester.ac.uk

1a. Why should we do simulations?

- We can generate equations from simple physical laws which model the world around us.
- These can only usually be solved by computer simulation in realistic cases.
- Engineering is pushing the boundaries at both ends of the scale spectrum.

Atomic (nano) scale

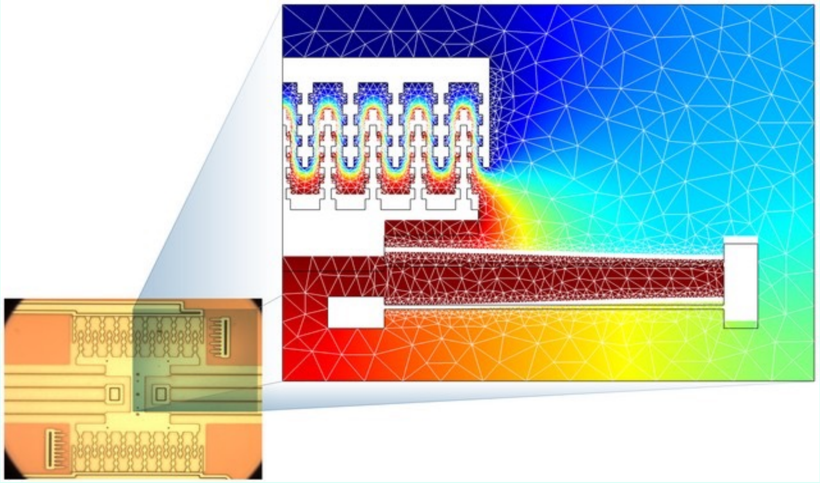


Simulation of flow of water molecules through carbon nanotubes. "www.cscs.ch"

Doping the borders of a carbon nanotube with OH groups changes its behaviour in the presence of water. The nanotube changes from hydrophobic to hydrophilic allowing a chain of water molecules to pass through it

1a. Why should we do simulations?
(continued)

Micron scale



Electrostatic comb drive actuator

This is a model of an electrostatically actuated comb drive used to open and close a pair of microtweezers. Electrostatic forces attract the combs to each other. Colours show the electric field, white areas are the drive.

Kilometre scale

Simulated image of the Strait of Messina bridge, Sicily

This simulation of a new bridge built across the Strait of Messina pushes the limits of large-scale structural engineering. The bridge has a span of 3km.

UNIVERSITY OF LEICESTER

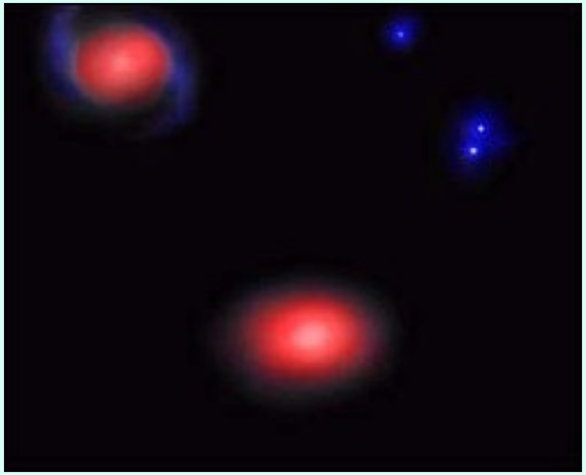
1a. Why should we do simulations?
(continued)

And beyond…….

Cosmological scale

After 0 - 0.5 billion years

Starting out with a very smooth distribution of matter directly after the Big-Bang, gravity of the more massive clumps of stars starts to attract more matter.



After 4 - 13 billion years

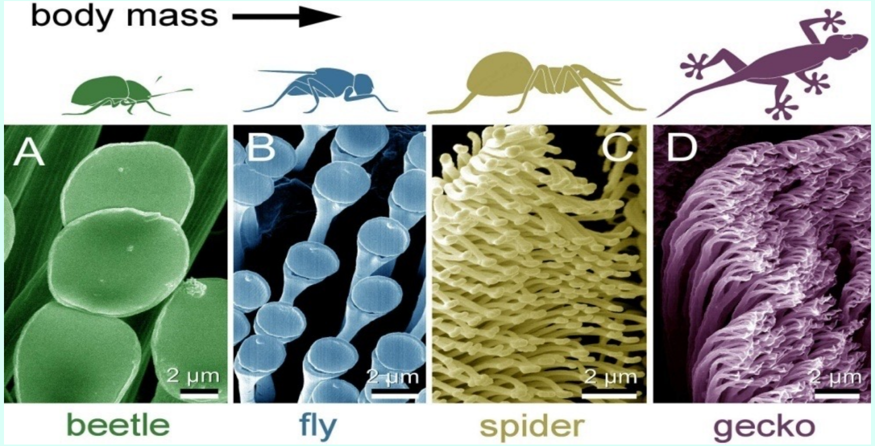
Galaxies as we see them today form, and take their final shapes.

(www.oarval.org)

UNIVERSITY OF LEICESTER

1a. Why should we do simulations?
(continued)

Understanding



Understanding how biological systems do things can help engineers create new technologies. For instance, study of the adhesion of insects and reptiles to walls could lead to development new adhesives.

Optimization

A 1% increase in efficiency of a steam turbine in a power-generating plant can save millions of pounds and help environment.

UNIVERSITY OF LEICESTER

1a. Why should we do simulations?
(continued)

Innovation

The Boeing Dreamliner 777-200LR (Long Range) allows direct flights from London-Sydney. This is possible because of the extensive use of carbon-fibre in its construction. It is not possible to design and build such a complicated object by trial and error.

Nearly all structural components are now designed and tested “in silico” (ie. by simulation in a computer) before a real prototype is constructed.

1a. What is Finite Element Analysis (FEA)?

There are two widely used numerical methods for finding **approximate solutions** to *Partial Differential Equations* (PDEs):

- **Finite Element Method (FEM)**
- **Finite Difference Method (FDM)**

This module introduces the **FEM** and how it is used to solve practical engineering problems in **solid mechanics**.

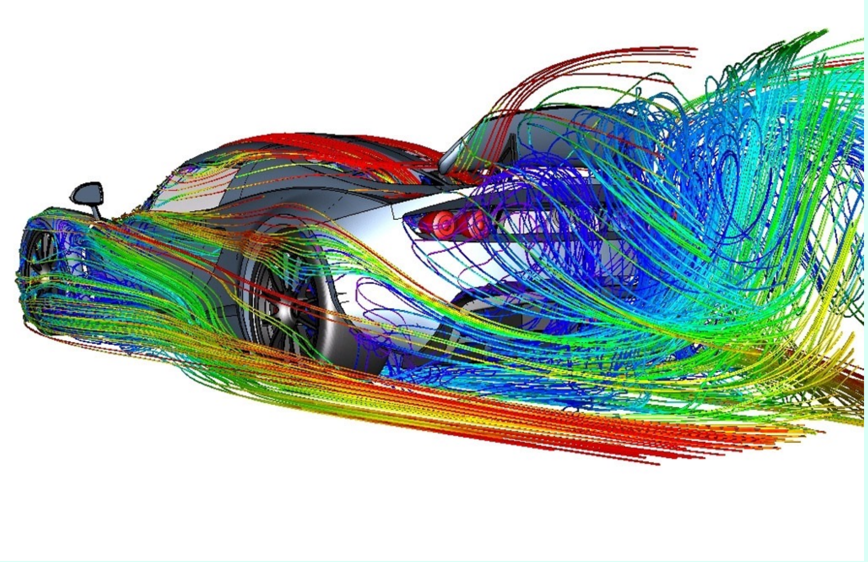
The **FDM** is more commonly used in the field of **fluid mechanics**.

Why is that the case?

1a. FEM vs FDM

FDM

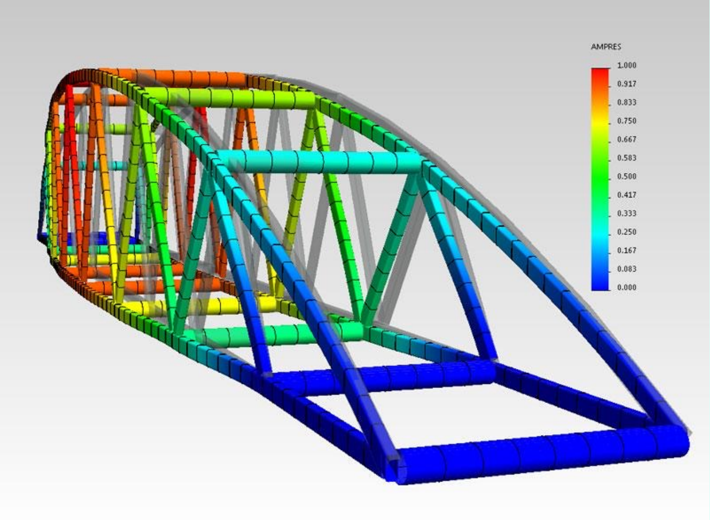
- Differential method
- Calculates values **locally** from neighbouring cells
- Good for weakly coupled problems evolving over time.
- Based on a (typically square) grid (usually
- Commonly used in Computational Fluid Dynamics (CFD), particularly for compressible air flow.



https://engineering.eckovation.com/cfd-cfd-projects/

FEM

- Integral (averaging) method
- Calculates values **globally** analysing the entire connected system as a whole.
- Finds the solution in **one** iteration.
- Based on an unstructured mesh (usually triangles)
- Commonly used in Structural Mechanics



https://www.exportersindia.com/motovated-design-and/finite-element-analysis-services-3119735.htm

Finite Element Analysis and Design

- 15 credits
  - 20 Lectures:
    - 2 Pre-recorded lectures/week
    - 1 Live lecture/week

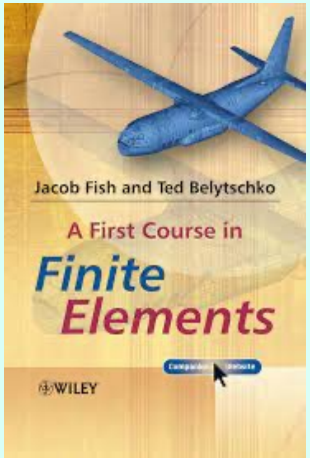
- Assessment:
  - Exam - May 2023

UNIVERSITY OF LEICESTER

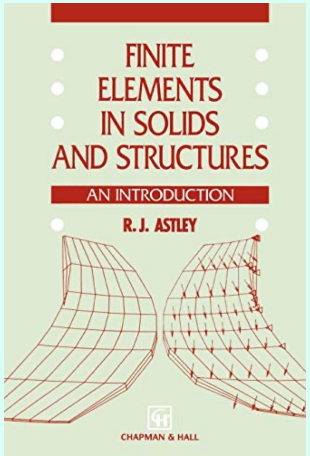
Finite Element Analysis and Design

Reference book (recommended reading):

- **A First Course in Finite Elements**
  Fish J. and Belytschko T
  Wiley Blackwell



- **Finite Elements in Solids and Structures: An Introduction.**
  Astley R.J
  Chapman and Hall



UNIVERSITY OF LEICESTER

1a. Session schedule

I. Theory

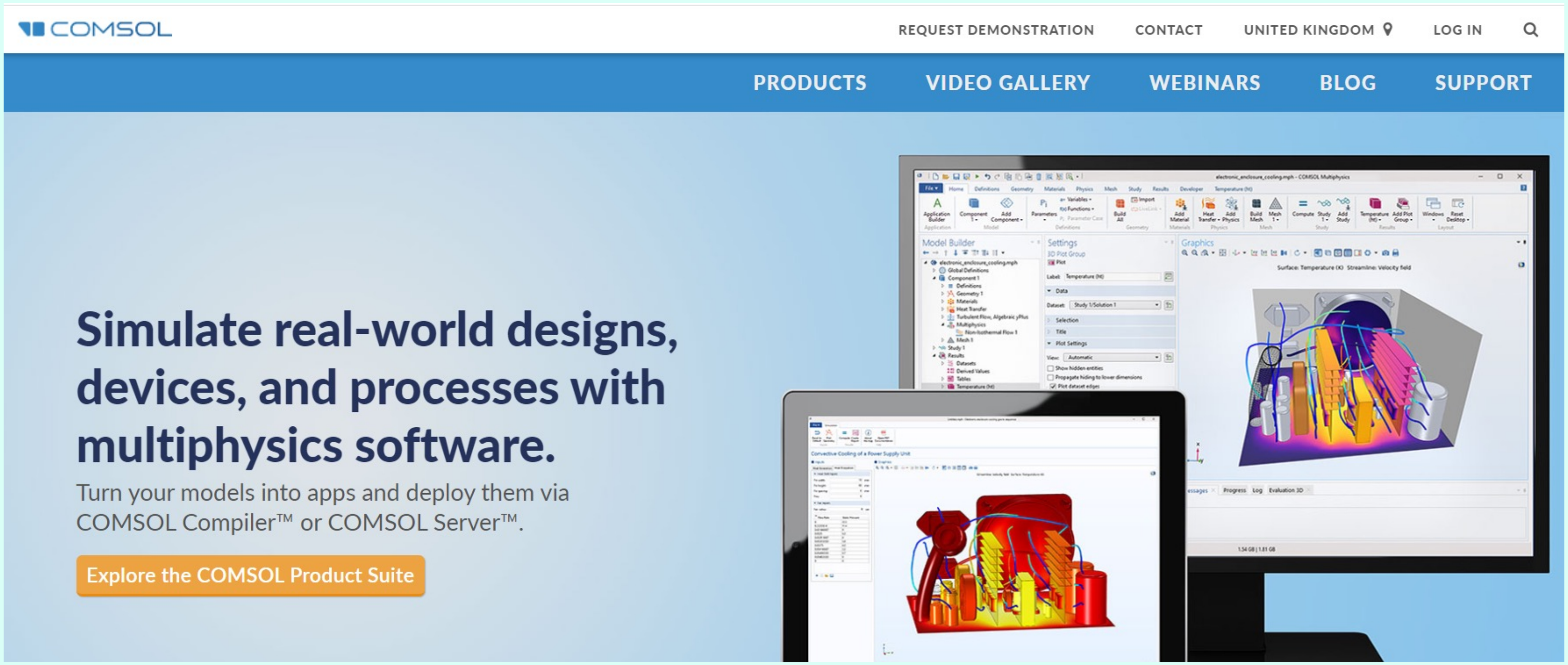
II. Application & Design

Section	Title	Approx. no. of hours
1	Introduction	1
2	Elasticity Theory	2
3	Bar Elements	2
4	Beam and Frame Elements	1
5	Solid Elements	4
6	Membrane, Plate and Shell Elements	3
7	Elastic FEA in practice	3
8	Different loading types	3
9	Non-linear analysis	2
10	Practical examples	3

UNIVERSITY OF LEICESTER

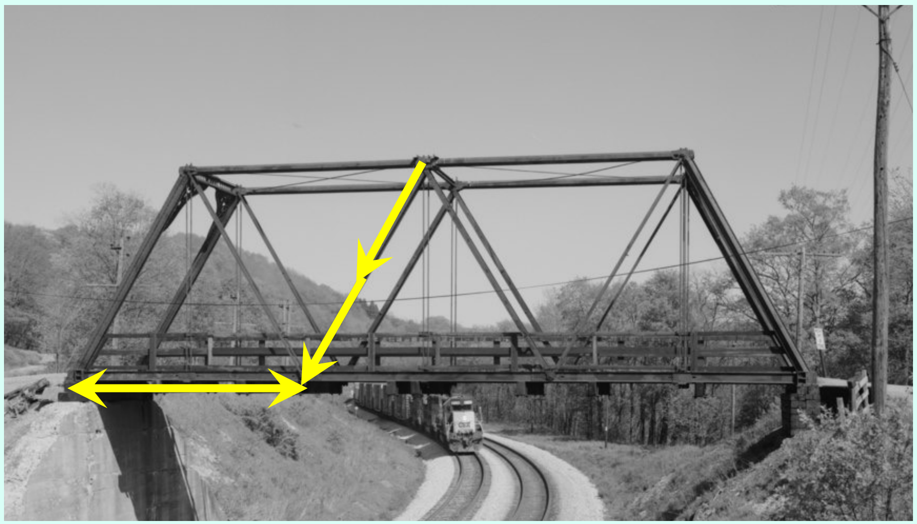
1a. Eight practical sessions using COMSOL Multiphysics

https://uk.comsol.com/



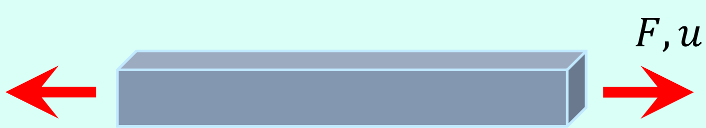
UNIVERSITY OF LEICESTER

1a. 1D Elements

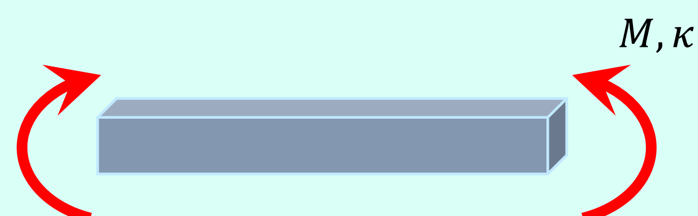


Bar Element

Beam Element



$$F = \frac{EA}{L} u$$

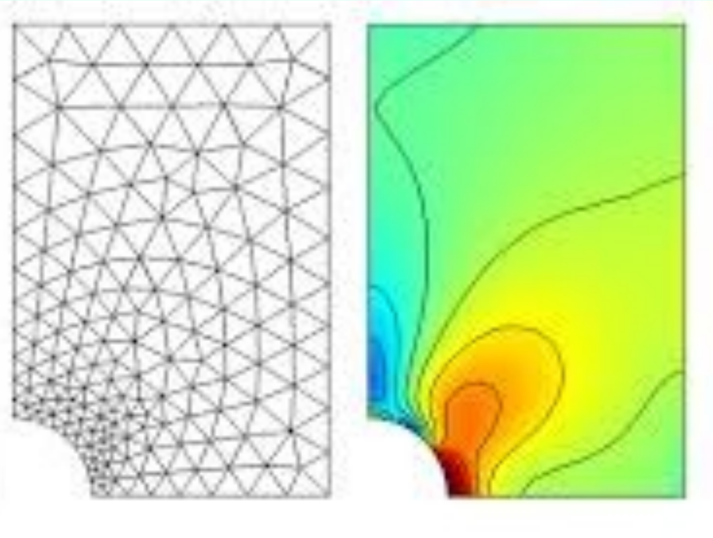


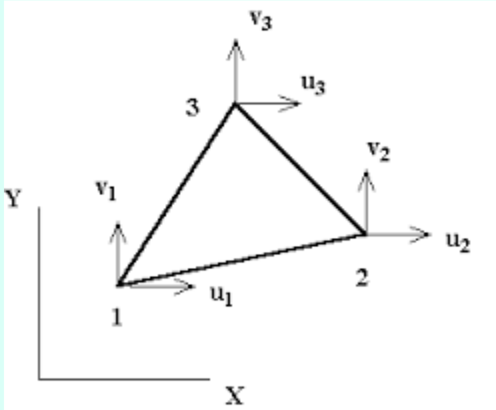
$$M = EI\kappa$$

UNIVERSITY OF LEICESTER

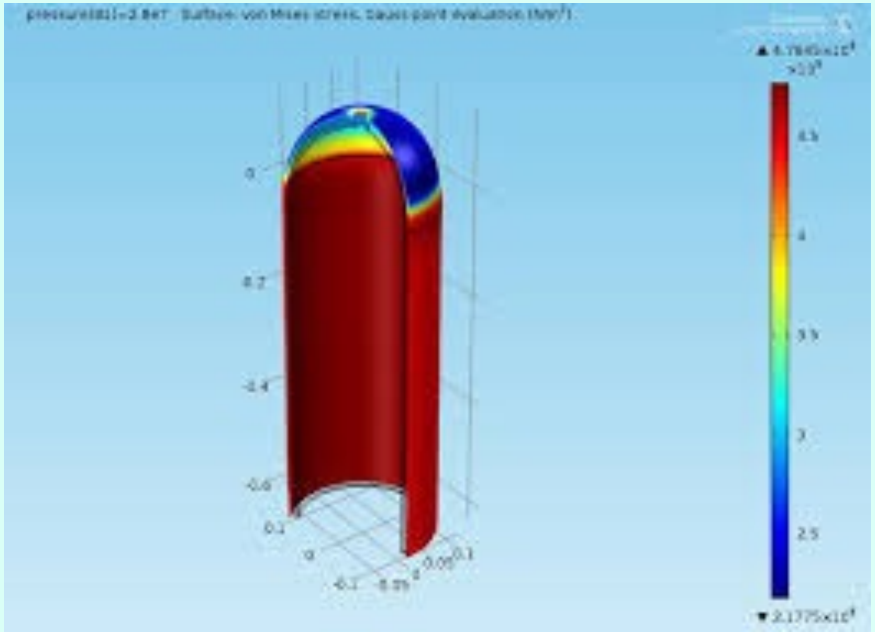
1a. 2D Elements

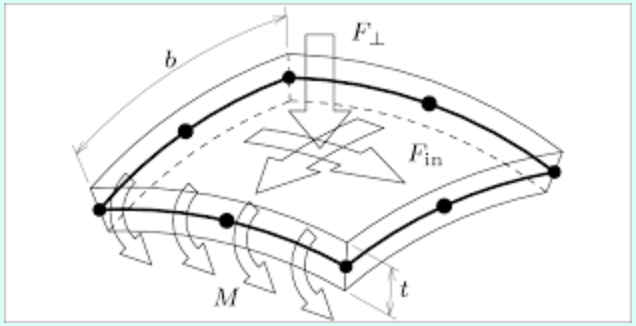
Triangular Solid Elements





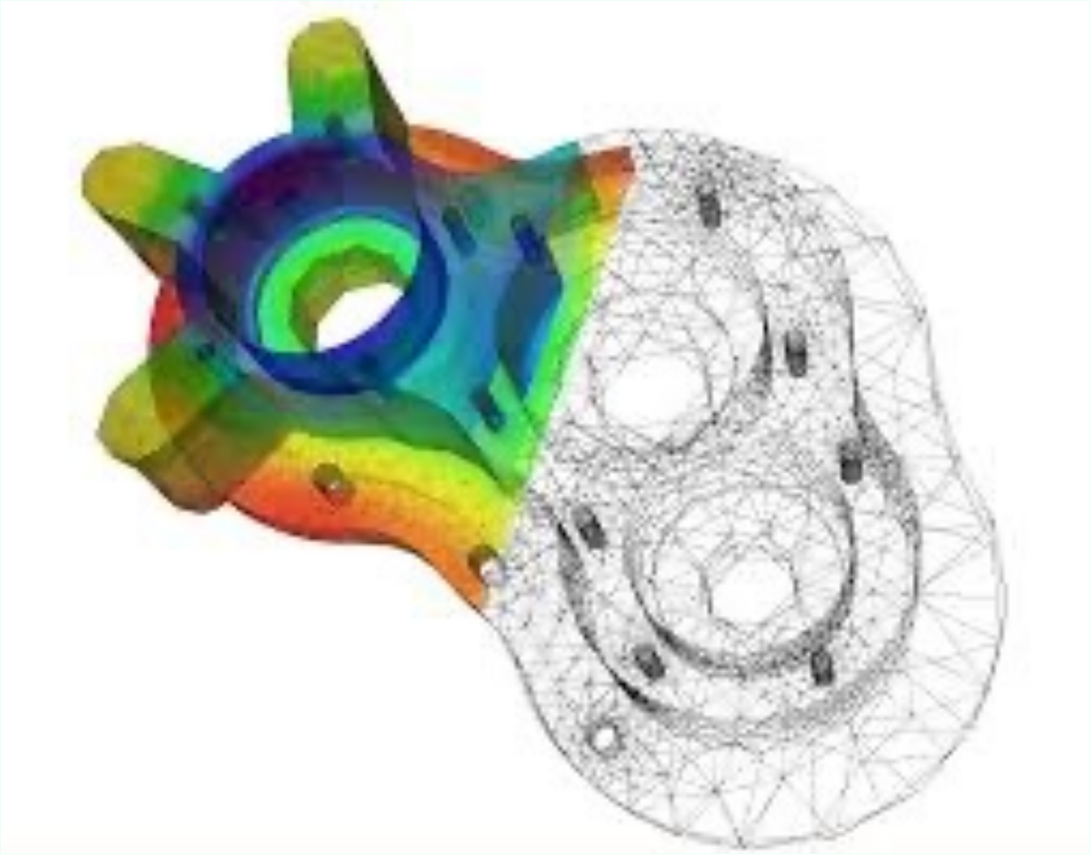
Shell Elements

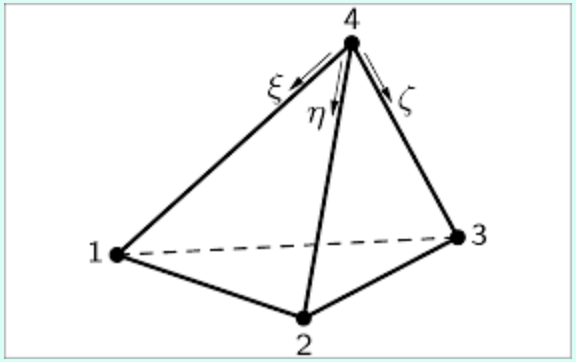




1a. 3D Elements

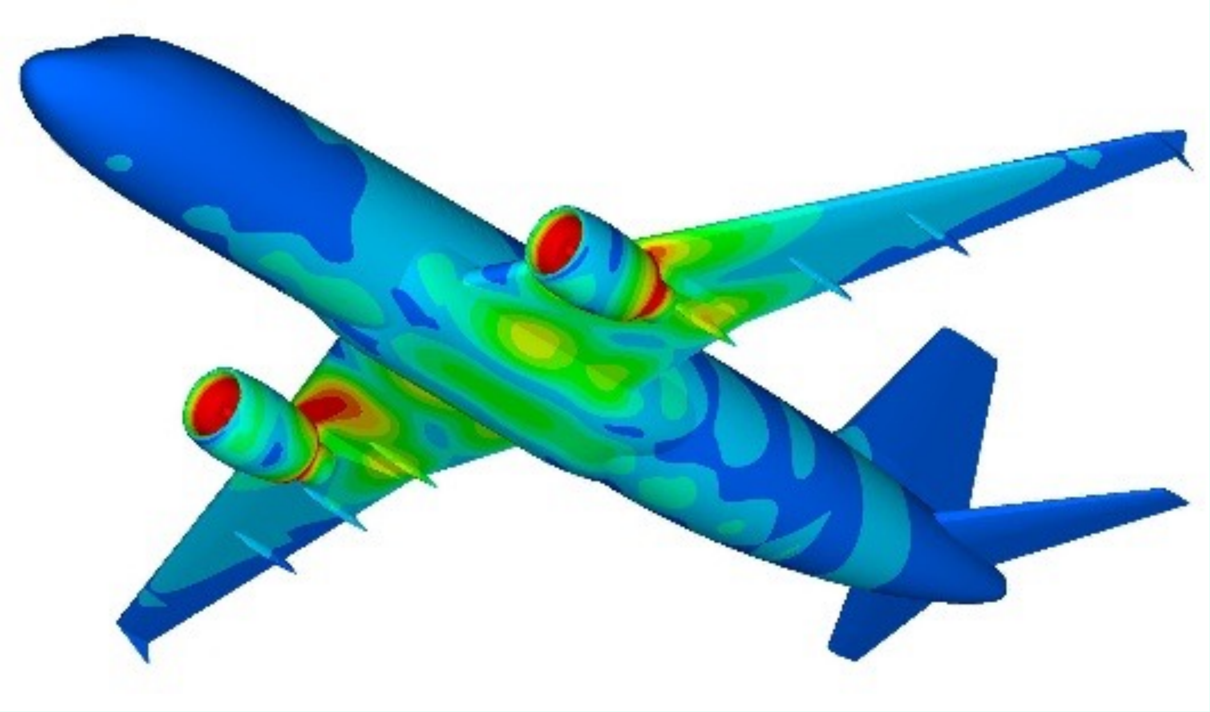
Tetrahedral Solid Elements





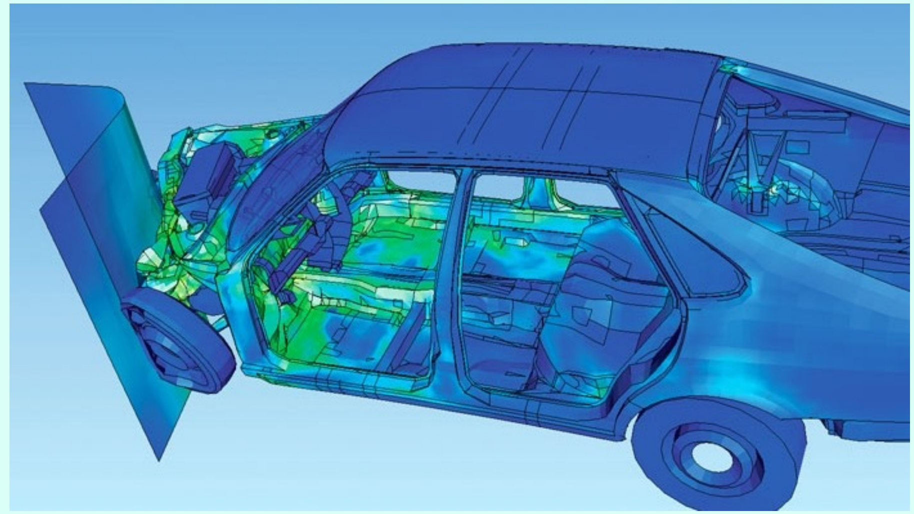
1a. Aerospace Engineering Applications

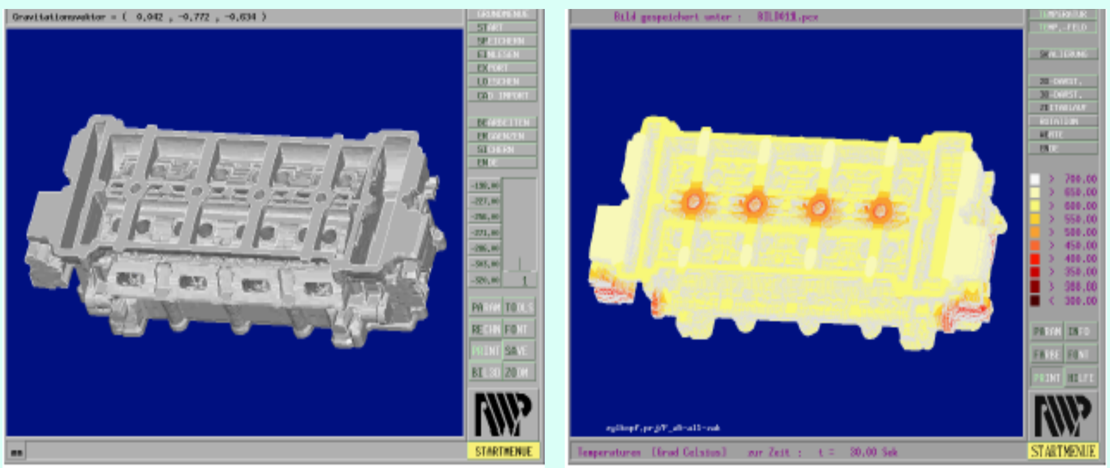
- Stress
- Fatigue
- Fracture



1a. Mechanical Engineering Applications

- Mechanical stresses and deformations
- Contact stresses
- Plasticity
- Thermal stresses



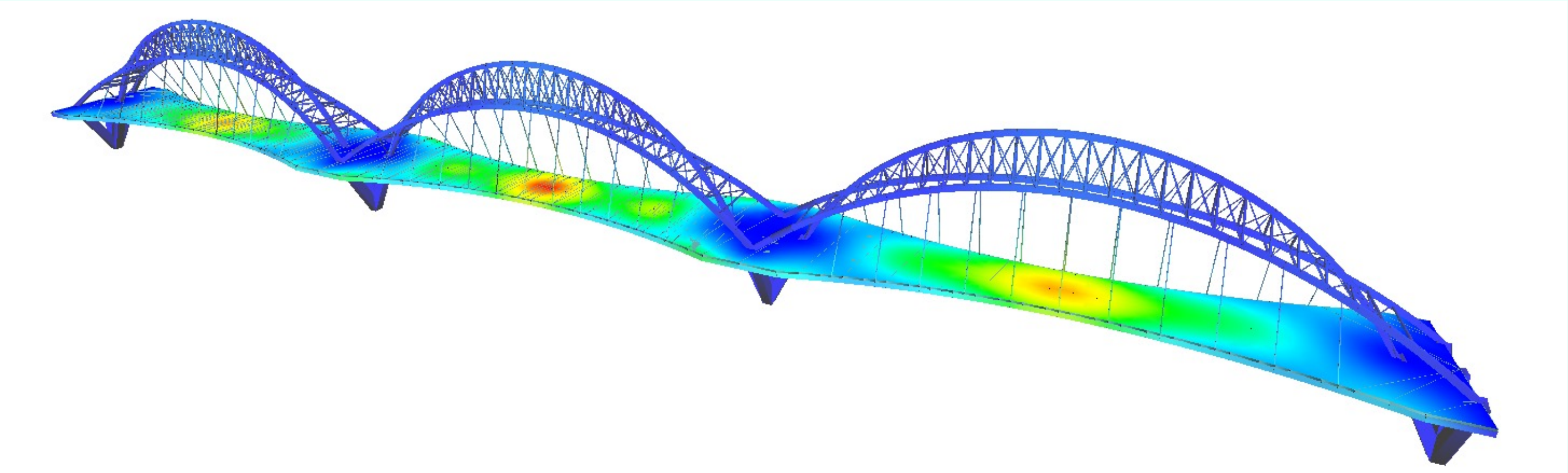


A FEM enmeshment has a good volume and surface approximation even with a small number of elements.

UNIVERSITY OF LEICESTER

1a. Civil Engineering Applications

- Steel and concrete
- Beams, columns, shells, plates
- Soil and rock (geotechnics)



UNIVERSITY OF LEICESTER

1a. Biomechanical Engineering Applications

- Soft tissues
- Prosthetics/implants
- Sports equipment
- Large deformations
- Interaction with fluids