G-L-7

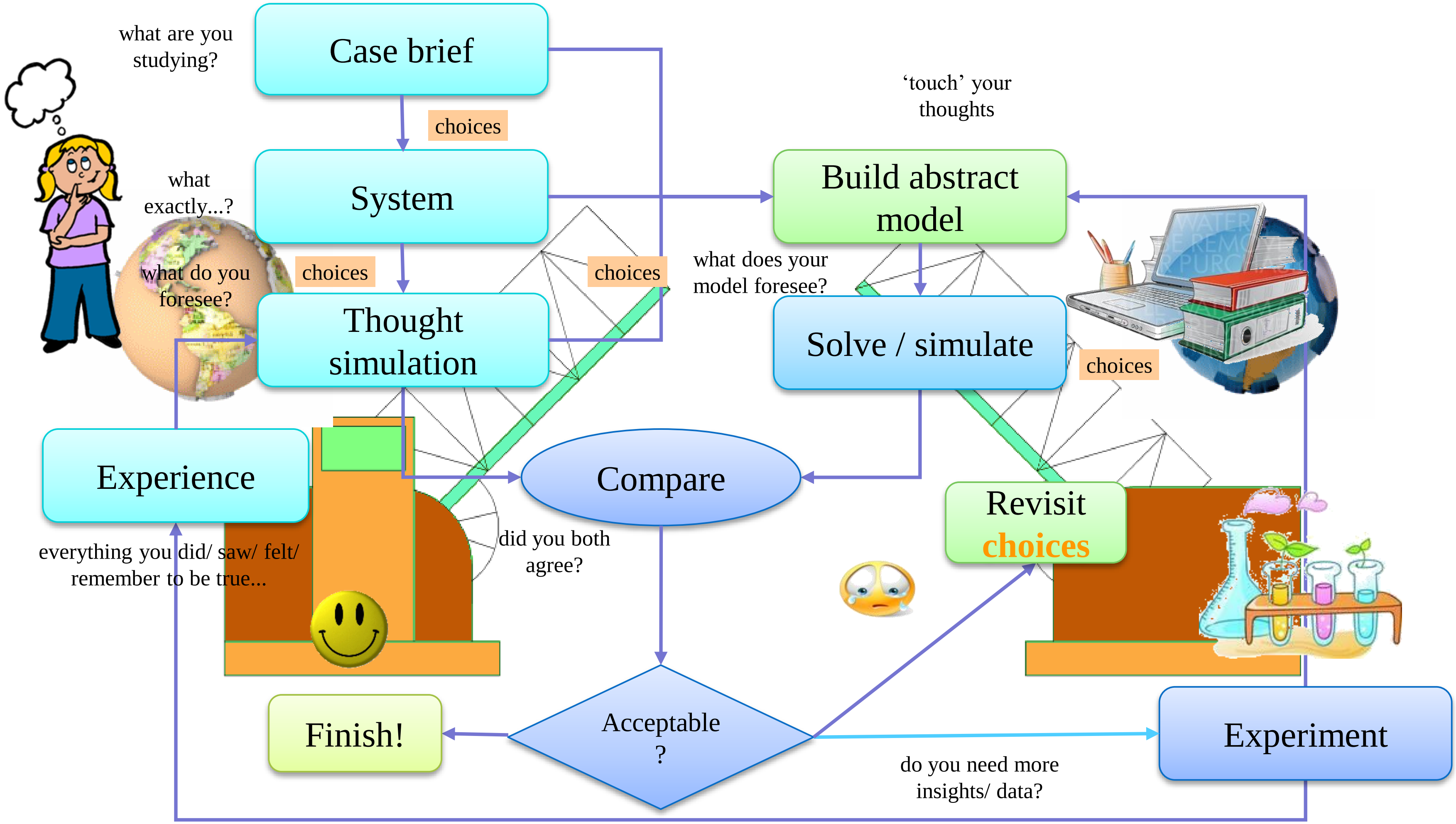
Advanced Simulation

Dr. Y. Song (Wolf)
Faculty of Industrial Design Engineering
Delft University of Technology

The real & virtual world

The real & virtual world

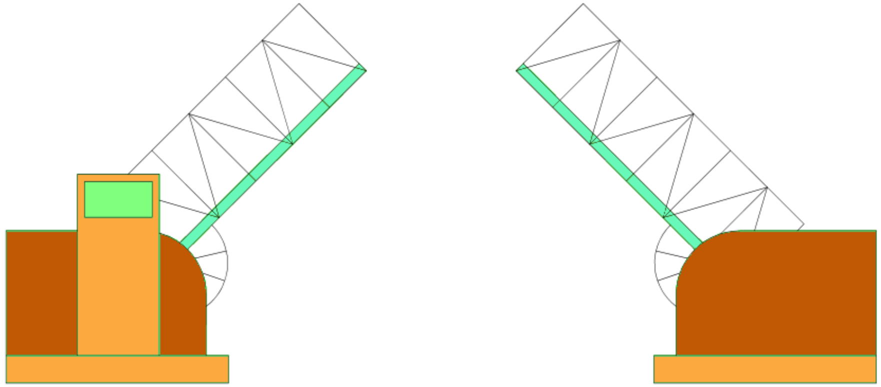
We need a bridge

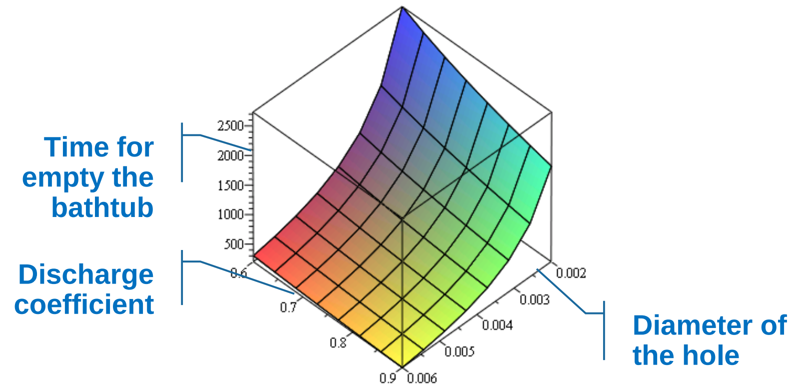


Courtesy of centech.com.pl and http://www.clipsahoy.com/webgraphics4/as5814.htm

For simple problems

$$-\rho_{water} \cdot Length_{bathtub} \cdot 2 \cdot \sqrt{R^2 - (R - h(t))^2} \cdot \frac{dh(t)}{dt} = n_{orifices} \cdot C_d \cdot \rho_{water} \cdot A_{orifices} \cdot \sqrt{2 \cdot g \cdot h(t)}$$





NCAP car crash test: VW Golf 6

VW Golf

Make and model	Overall rating	Adult	Child	Pedestrian	Safety assist	Comparison
VW Golf	2009 ★★★★★	97%	84%	61%	71%	+ Add | Comparable

Pre 2009 rating

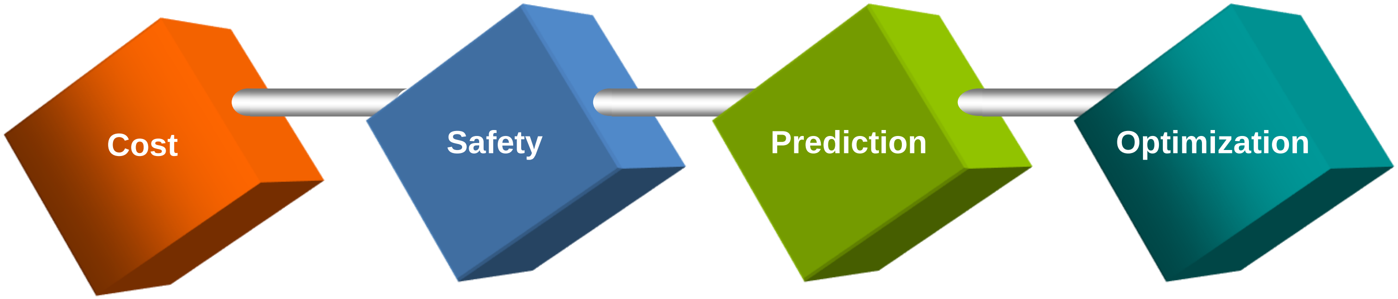
Make and model	Adult	Child	Pedestrian	Compare
VW Golf (1998)	★★★★☆		☆☆☆☆	+ Add | Comparable
VW Golf (2008)	★★★★★	★★★★☆	★★★☆	+ Add | Comparable
VW Golf (2004)	★★★★★	★★★★☆	★★★☆	+ Add | Comparable

The power of modelling

Case study: PAM Crash

ESI® PAM-CRASH®

FOR SAFER CARS EURO NCAP



Courtesy of http://www.esi-group.com/products/crash-impact-safety/pam-crash

Case study: The diving board

Case brief:
Design a jump-off diving board for the Olympic game.

Requirement:
When the athlete stands still at the tip of the board, the deformation should be between 7~15cm

Fiction

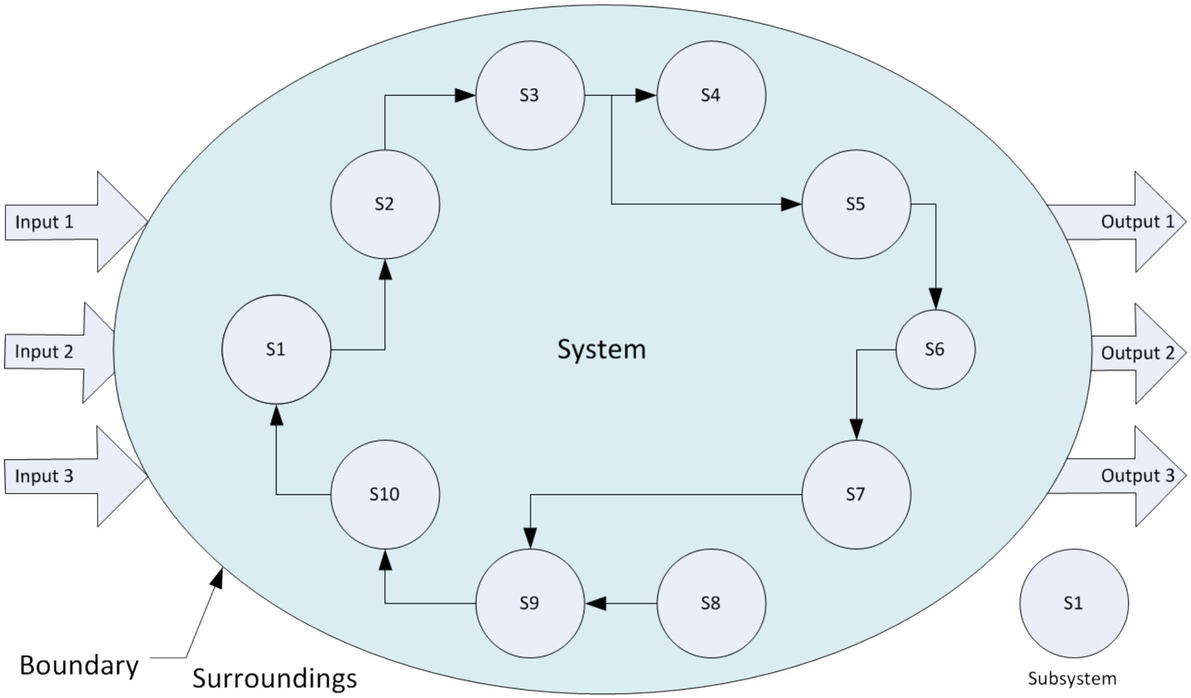
Analysis

System

System

System consists of a set of interacting or interdependent system components (or sub-systems)

- -Structure & interconnectivity
- -Boundary
- -Input & Output
- -Surroundings



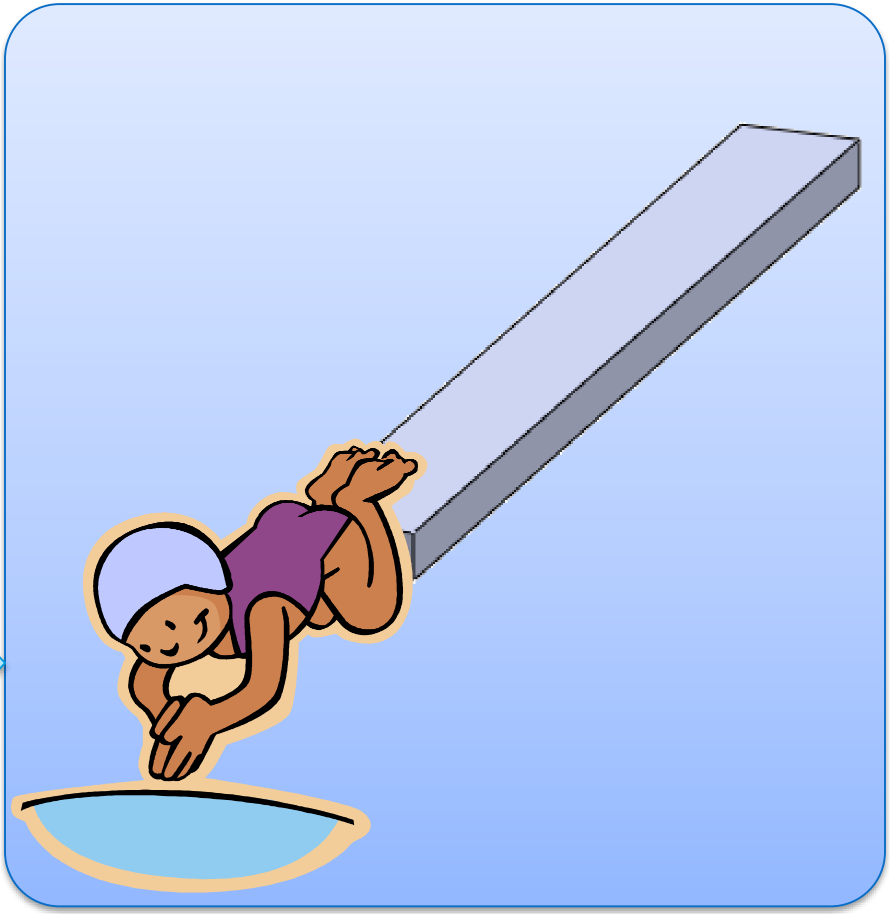
The design

System

- **Board**
- **Support**
- **Human**

Choices: to neglect

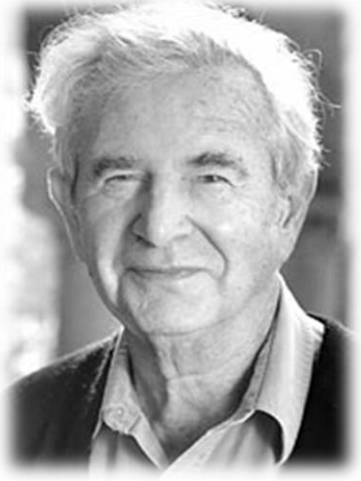
Temperature differences
Humidity
Position of standing
Non-uniform Material
Supporting Structure
…



Modelling

The purpose of models

The purpose of models is not to fit the data but to sharpen the questions.



Samuel Karlin

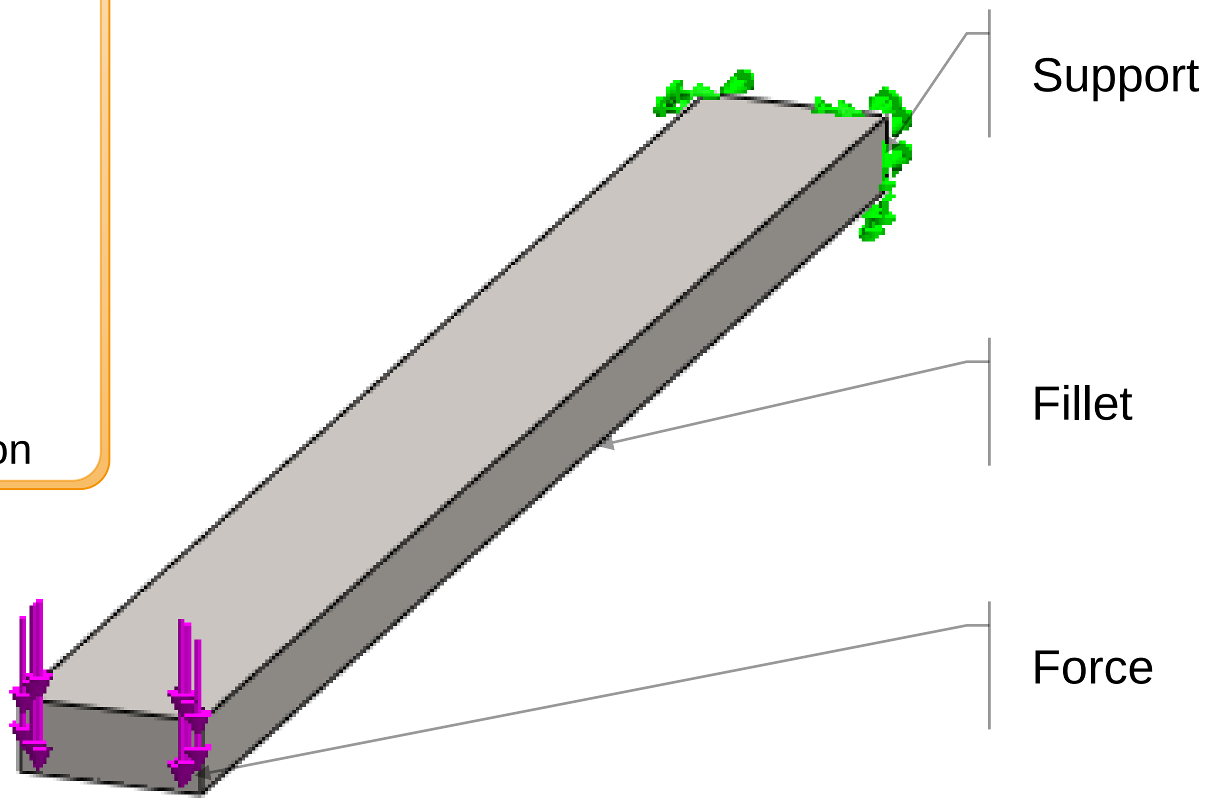
National medal of science

Our model: Choices

Phenomenon
Statics

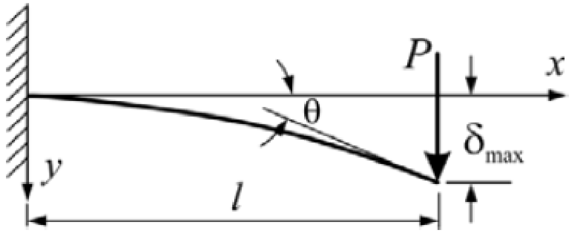
Model
Model simplification & adjustment

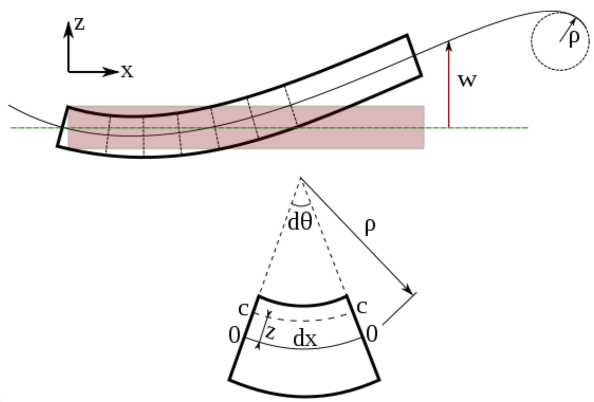
Boundary conditions
1. Materials
2. Fixture
3. Force
4. Component interaction



Simulation

Analytical solution of a beam





Force

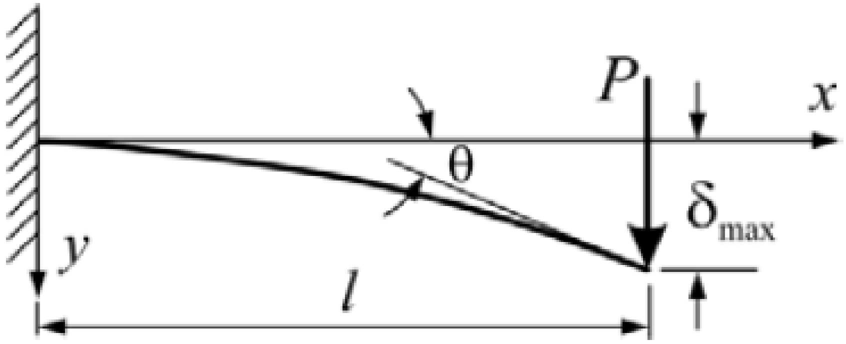
Length

$$\delta_{max} = \frac{Pl^3}{3EI}$$

Elastic modulus

Area momentum of inertia

Analytical solution of the beam



> restart;

> $deflection := -\frac{F \cdot L^3}{3 \cdot E \cdot II}$

$$deflection := -\frac{1}{3}\frac{F L^3}{E\, II}$$

> $E := 2.1 \cdot 10^{11}$

$$E := 2.100000000\ 10^{11}$$

> $F := 1;\ L := 0.1;$

$$F := 1$$

$$L := 0.1$$

> $II := \frac{B \cdot H^3}{12}$

$$II := \frac{1}{12} B H^3$$

> $B := 0.01;$

$$B := 0.01$$

> $H := 0.004;$

$$H := 0.004$$

> deflection

$$-0.00002976190476$$

Introducing numerical solutions

$$-\rho_{water} \cdot Length_{bathtub} \cdot 2 \cdot \sqrt{R^2 - (R - h(t))^2} \cdot \frac{dh(t)}{dt} = n_{orifices} \cdot C_d \cdot \rho_{water} \cdot A_{orifices} \cdot \sqrt{2 \cdot g \cdot h(t)}$$

```
> sol := dsolve({equ, ics}, theta(t));
```

$sol :=$

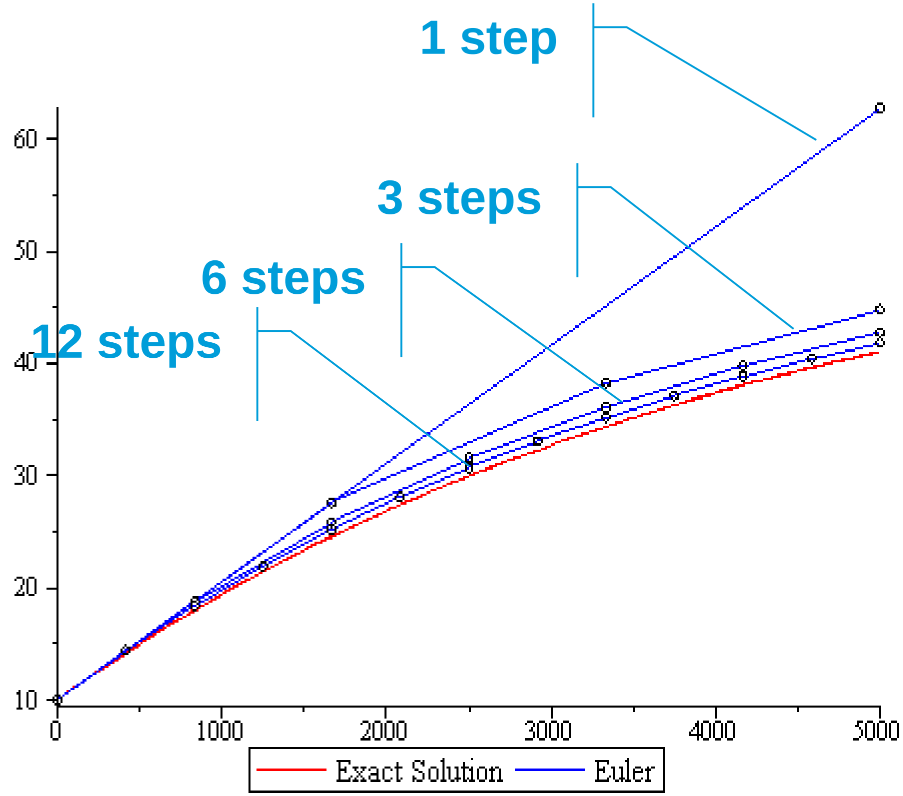
Solve it numerically

```
> sol := dsolve({equ, ics}, theta(t), type = numeric, output = listprocedure);
```

$sol := \left[t = \textbf{proc}(t) \ \ldots \ \textbf{end proc}, \theta(t) = \textbf{proc}(t) \ \ldots \ \textbf{end proc}, \frac{d}{dt}\theta(t) = \textbf{proc}(t) \ \ldots \ \textbf{end proc} \right]$

An example of numerical solution

Using Euler method to solve an ODE

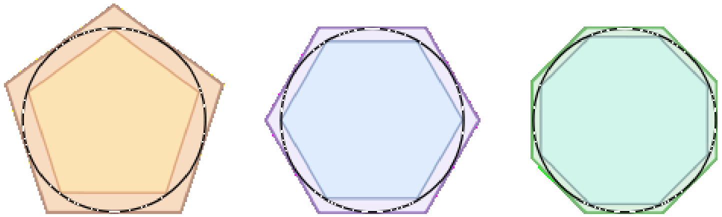


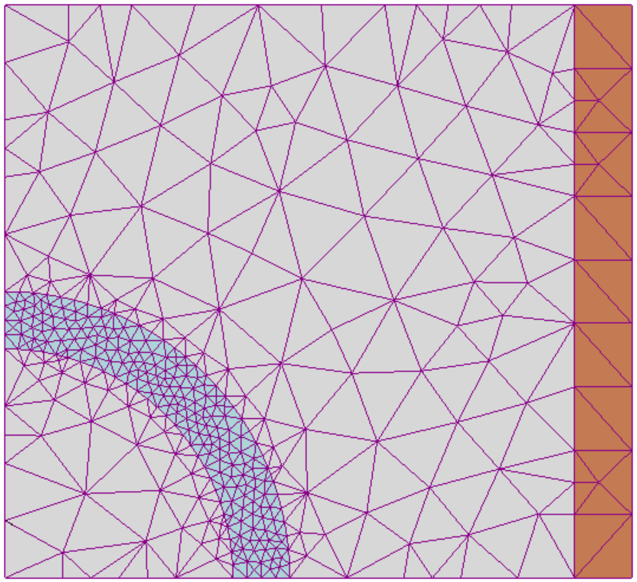
The Finite Element Method (FEM)

A numerical technique for finding approximate solutions of partial differential equations (PDE)

Eliminating the differential equation
or
rendering the PDE into an ODE

Widely adopted in **CAE** software
as
The *de facto* standard

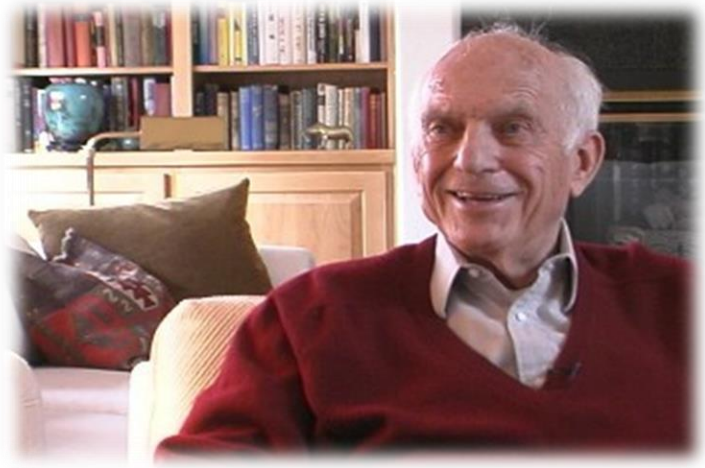




Ref. http://en.wikipedia.org/wiki/Finite_element_method

FEM

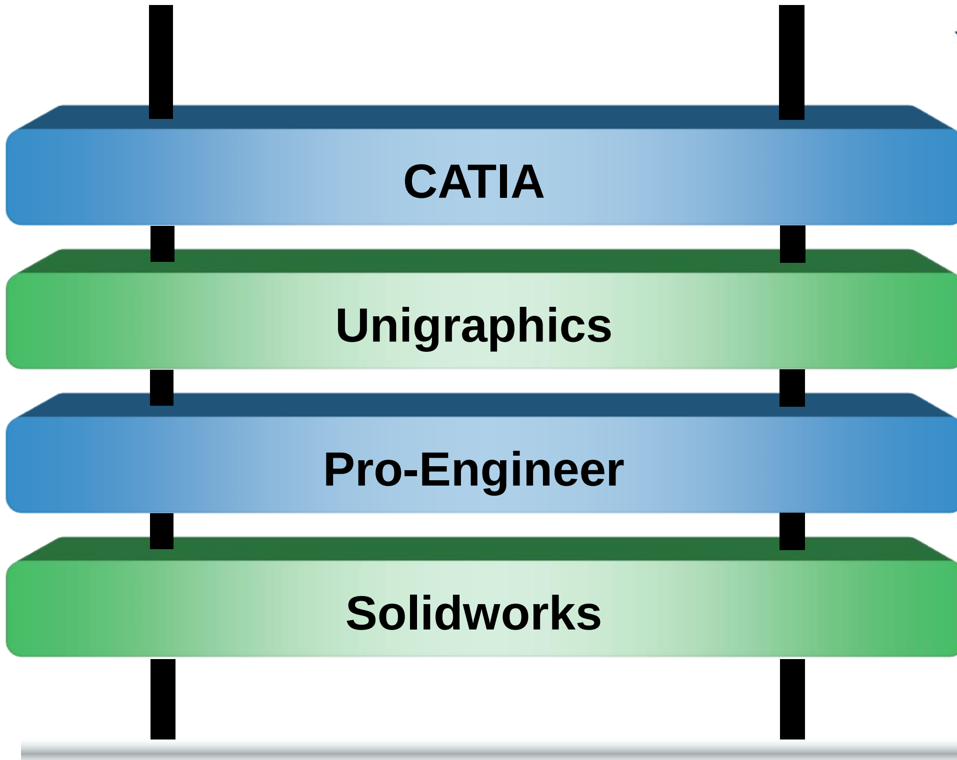
Depending on the validity of the assumptions made in reducing the physical problem to a numerical algorithm, the computer output may provide a detailed picture of the true physical behavior or it may not even remotely resemble it.



Ray W. Clough

Founder of FEM
National medal of science

CAD software



Computer Aided Engineering – Leading Companies

Siemens PLM Software

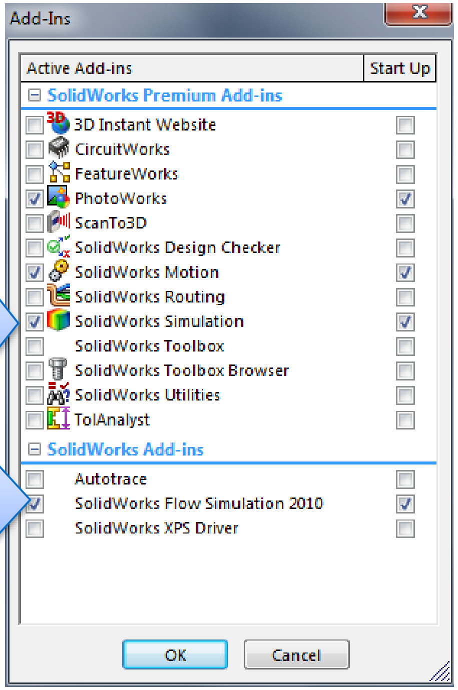
Courtesy of http://www.padtinc.com/blog/post/2011/08/26/CAE_Market_Size.aspx

Simulation @ Solidworks®

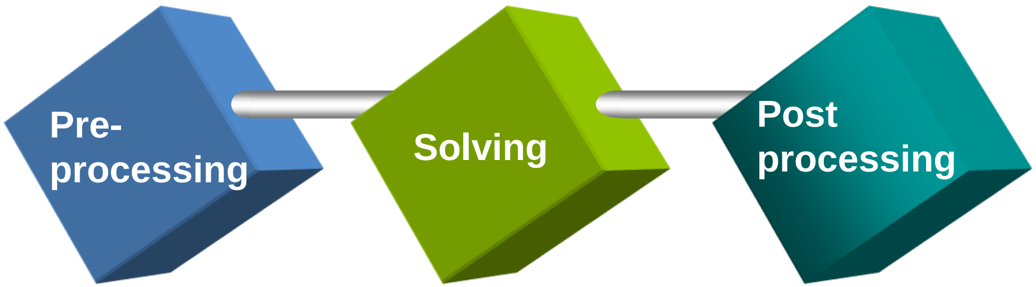
Solidworks — A

Add-ins: Simulation — B

Add-ins: Solidworks Flow Simulation 2012 — C



CAE software – The three phases



Defining the model and environmental factors to be applied to it.

It is usually performed on high powered computers

The results visualization tools

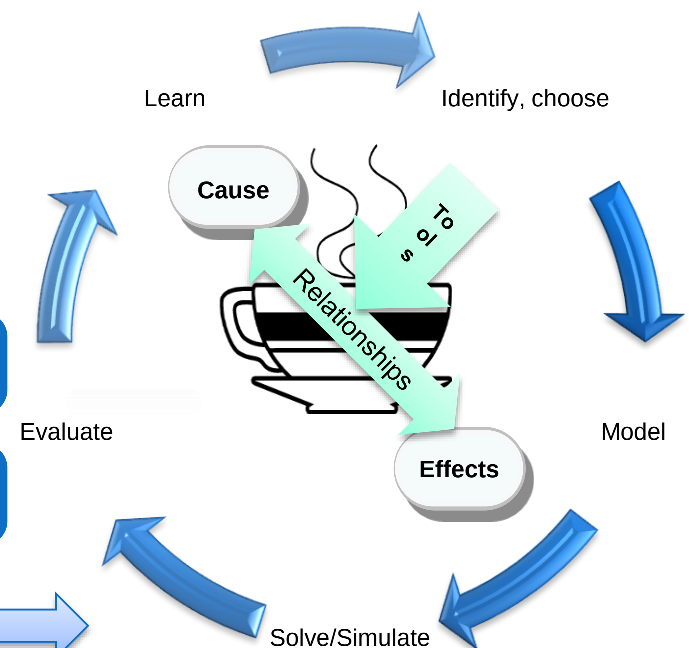
Identify, Choose

Evaluation

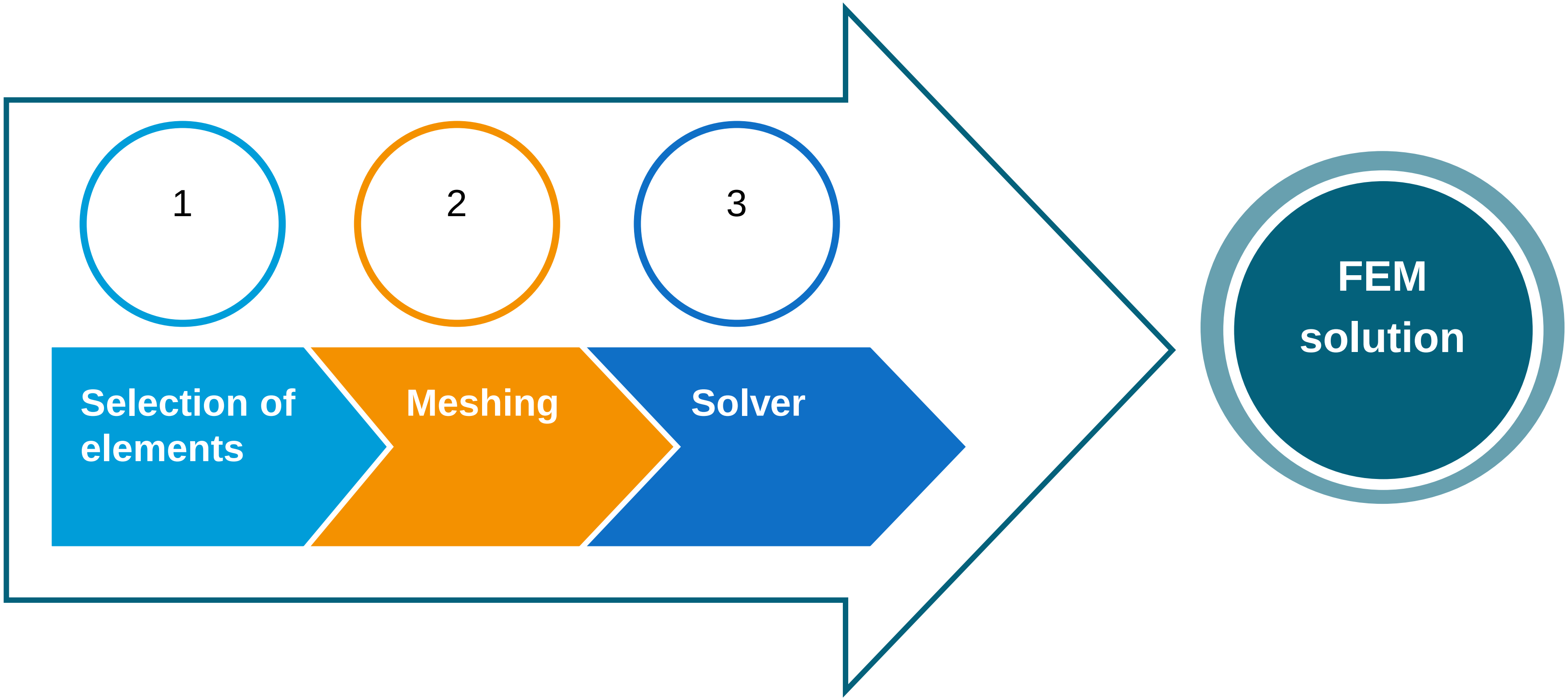
Model

Solve/Simulate

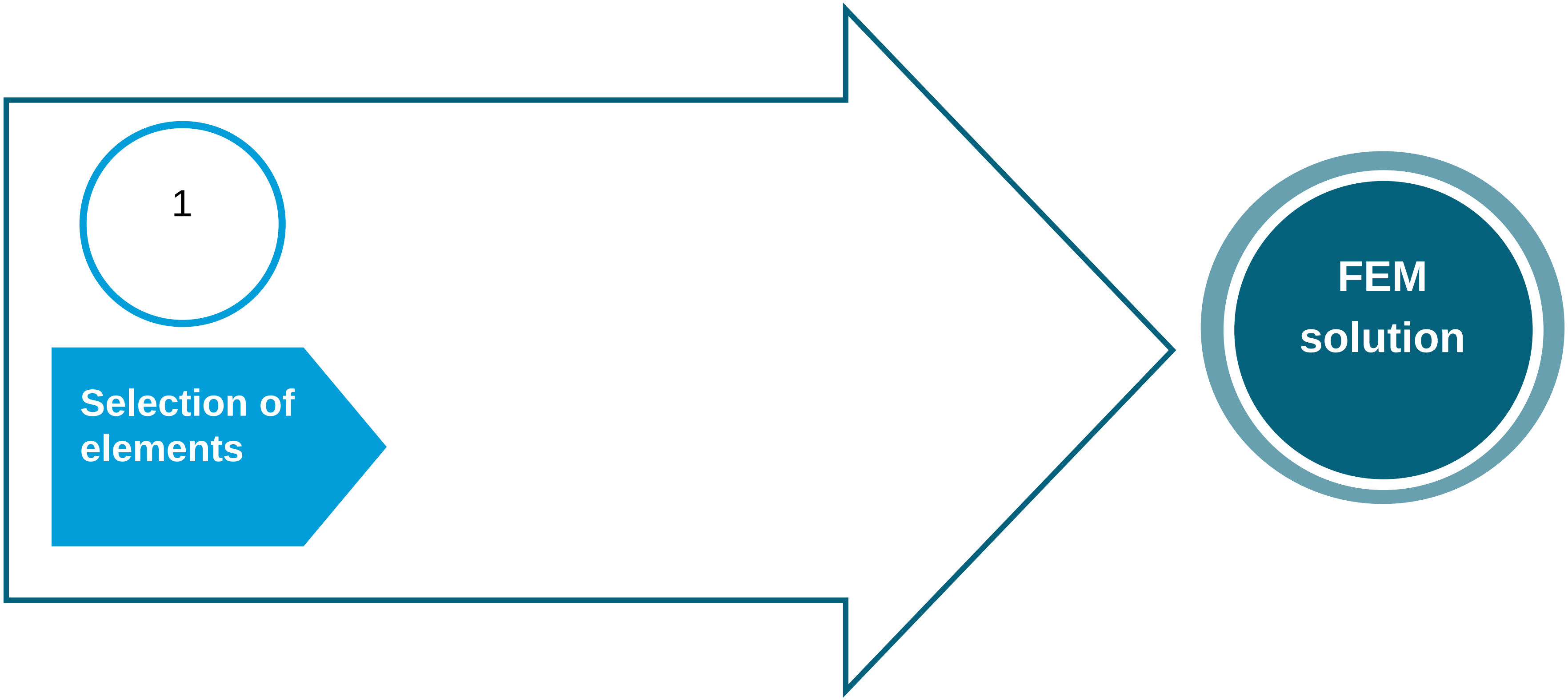
Learn



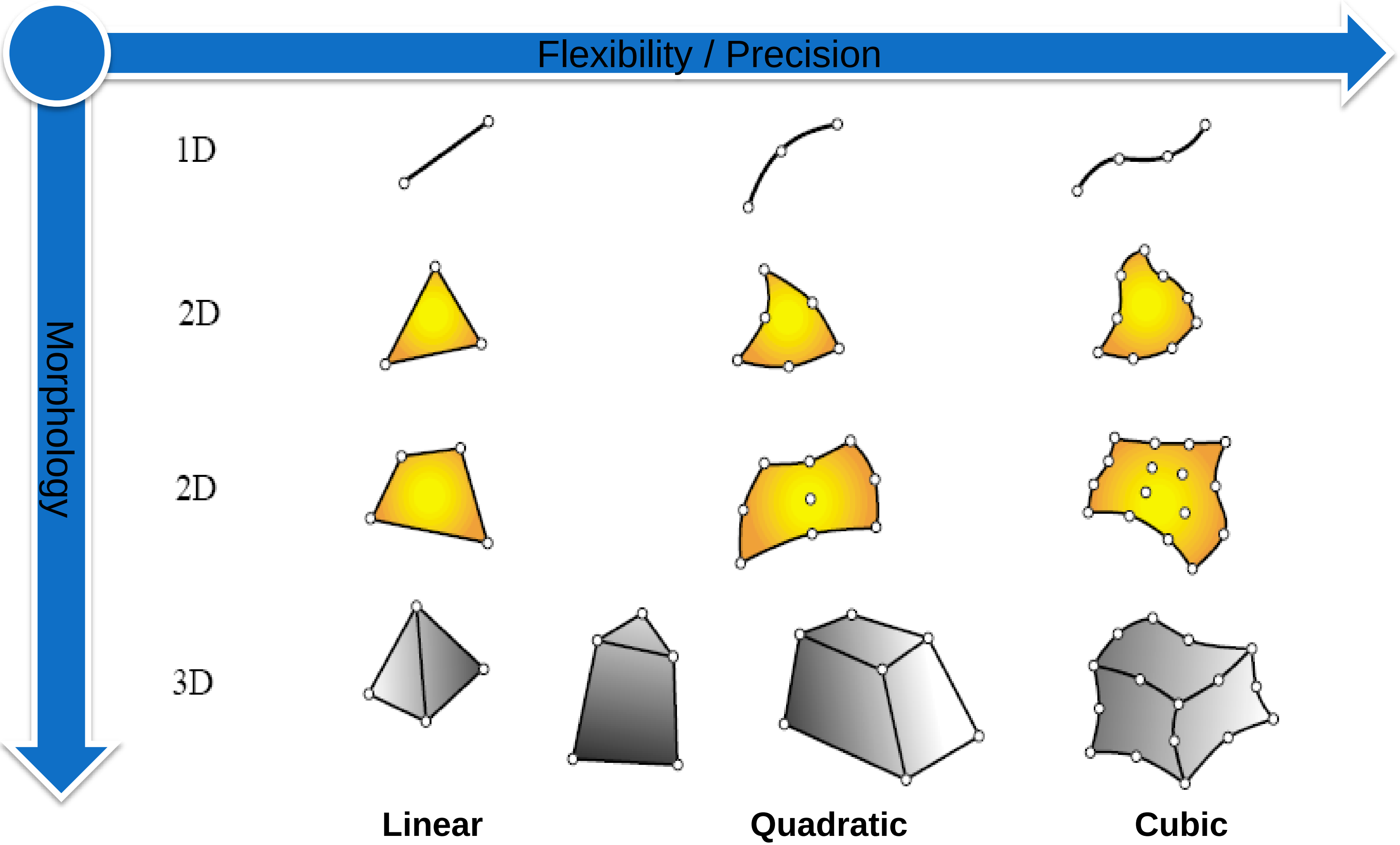
Elements & Solvers



Elements & Solvers

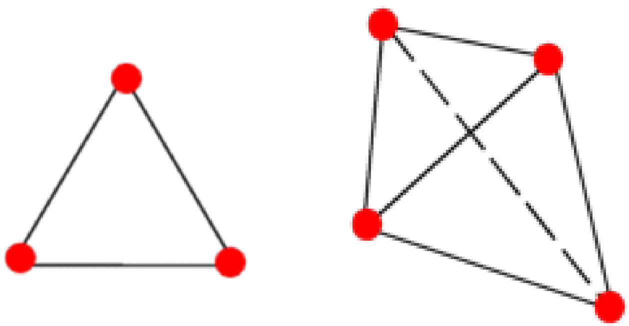


The types of elements



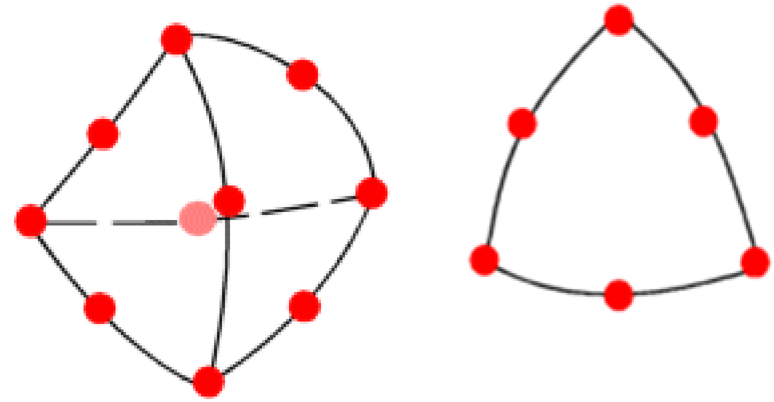
Implementation of nodes in Solidworks®

Draft quality



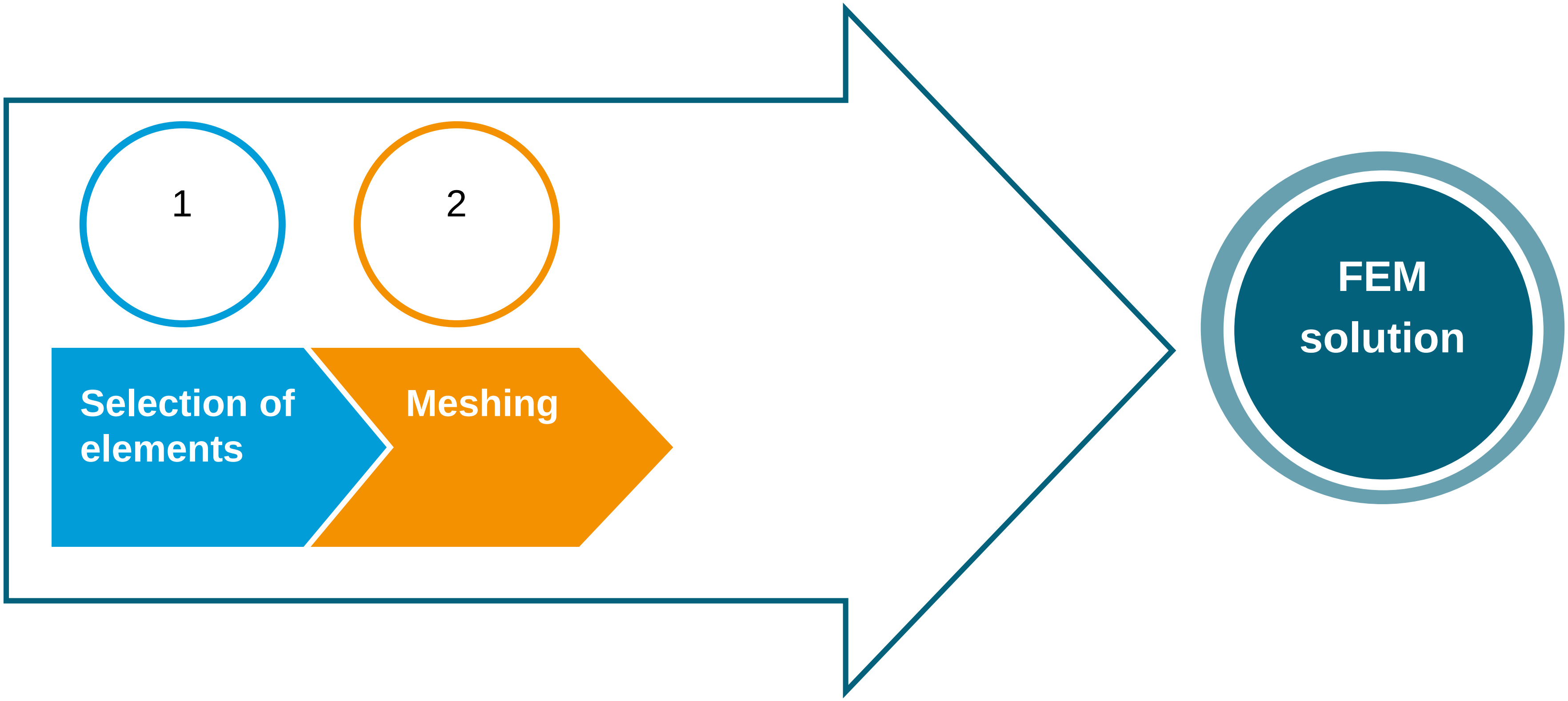
Linear triangular element   Linear solid element

High quality



Parabolic solid element   Parabolic triangular element

Elements & Solvers



Mesh generation

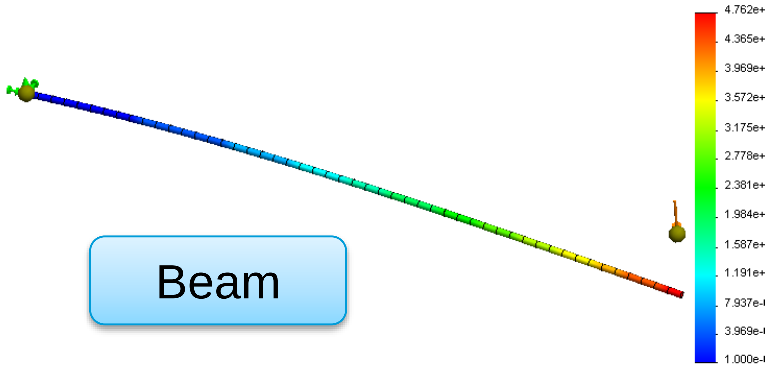
Mesh type

- Beam
- Shell
- Solid
- Mixed

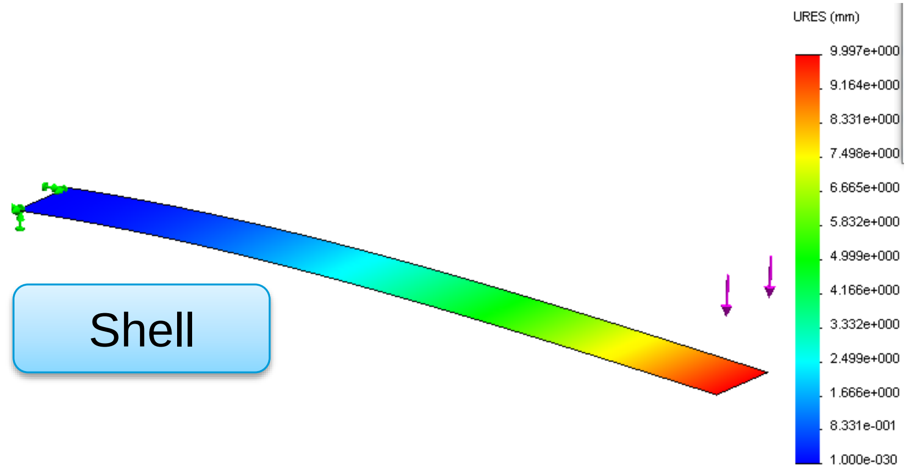
Mesh control

- Standard
- Curvature
- Transition
- Local mesh control

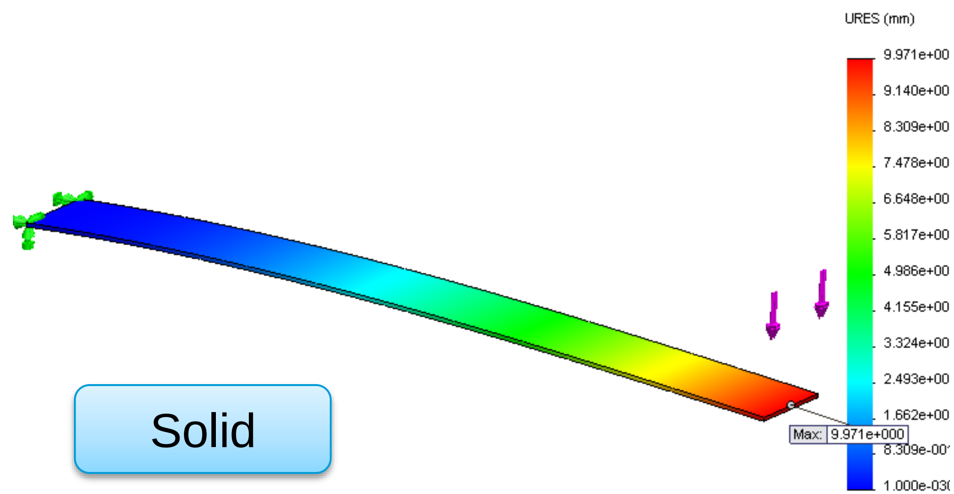
Typical implementation in Solidworks



Beam

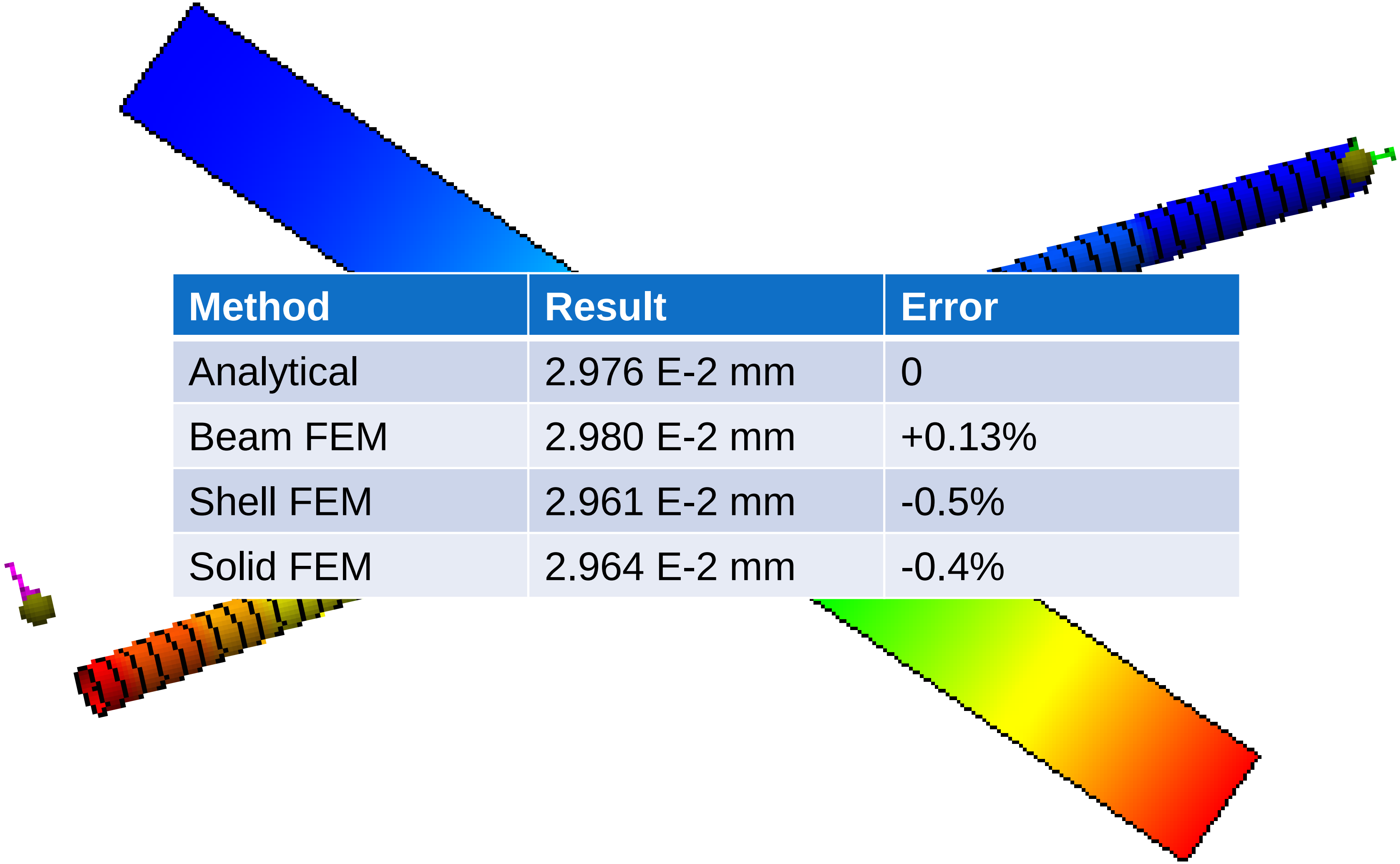


Shell



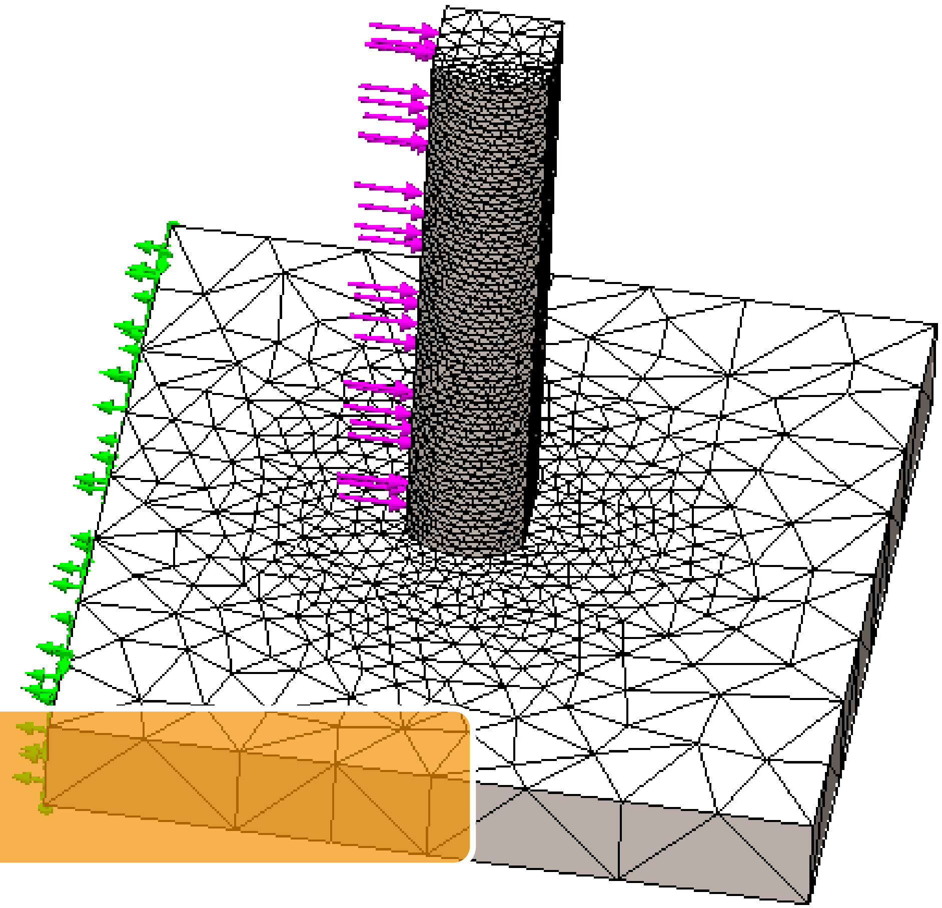
Solid

Solution of the “small” board



Method	Result	Error
Analytical	2.976 E-2 mm	0
Beam FEM	2.980 E-2 mm	+0.13%
Shell FEM	2.961 E-2 mm	-0.5%
Solid FEM	2.964 E-2 mm	-0.4%

Case study: Mesh control



Mesh generation

The quality of mesh

The quality of mesh

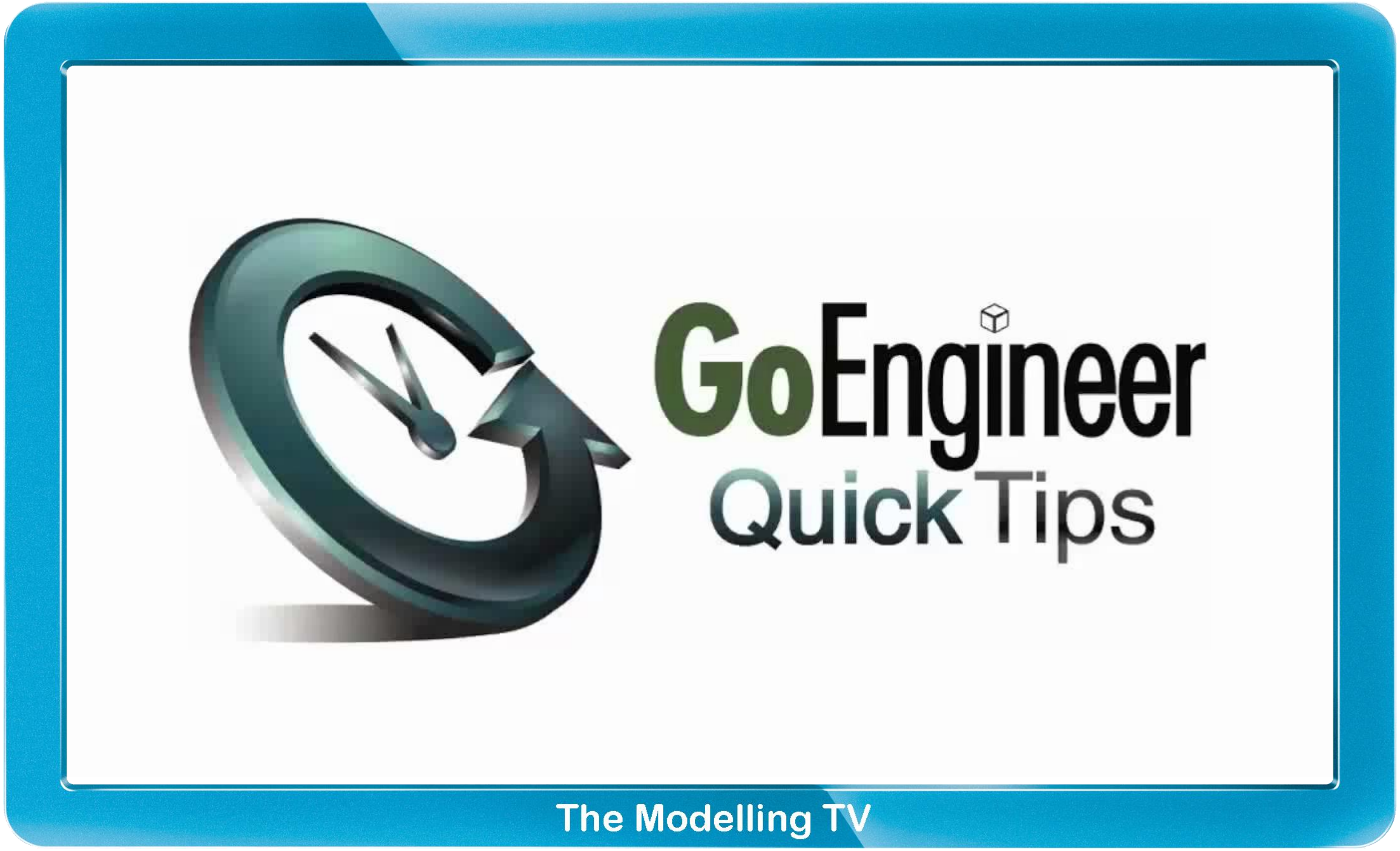
- Aspect ratio
- Taper
- Jacobian ratio
- Collapse
- Skew angle
- Warpage
- Twist
- …

Aspect ratio

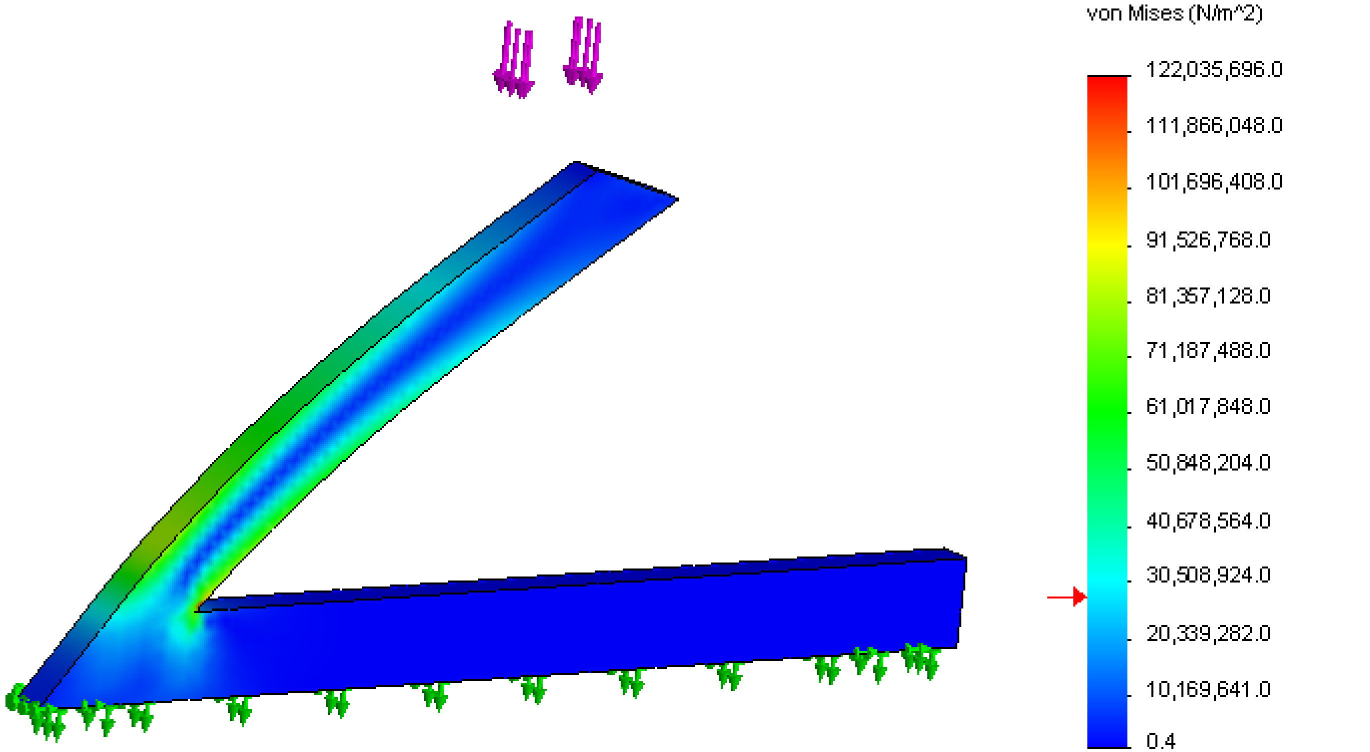
Jacobian ratio

SolidWorks

Aspect ratio – An illustration



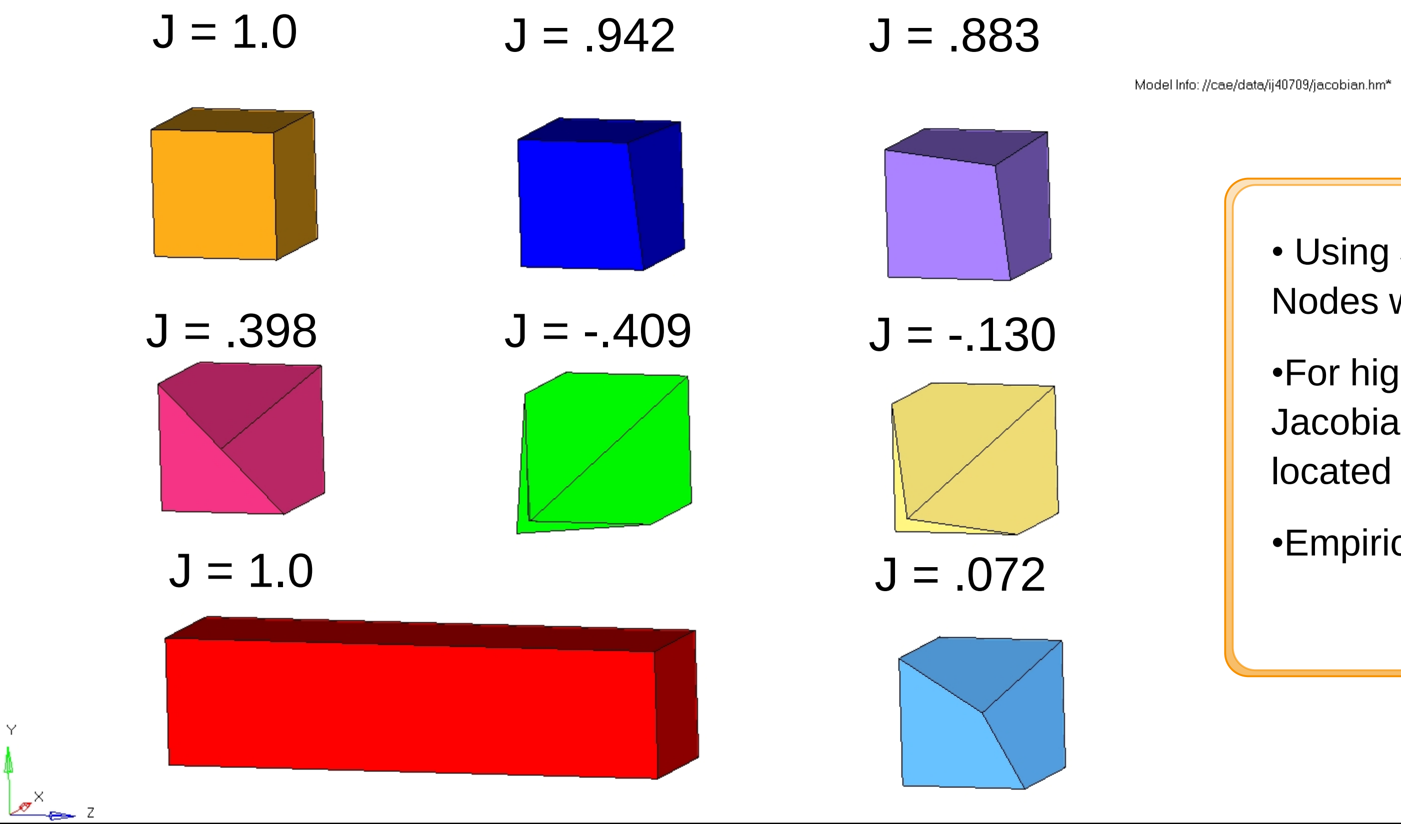
Case study: the support



It does matter

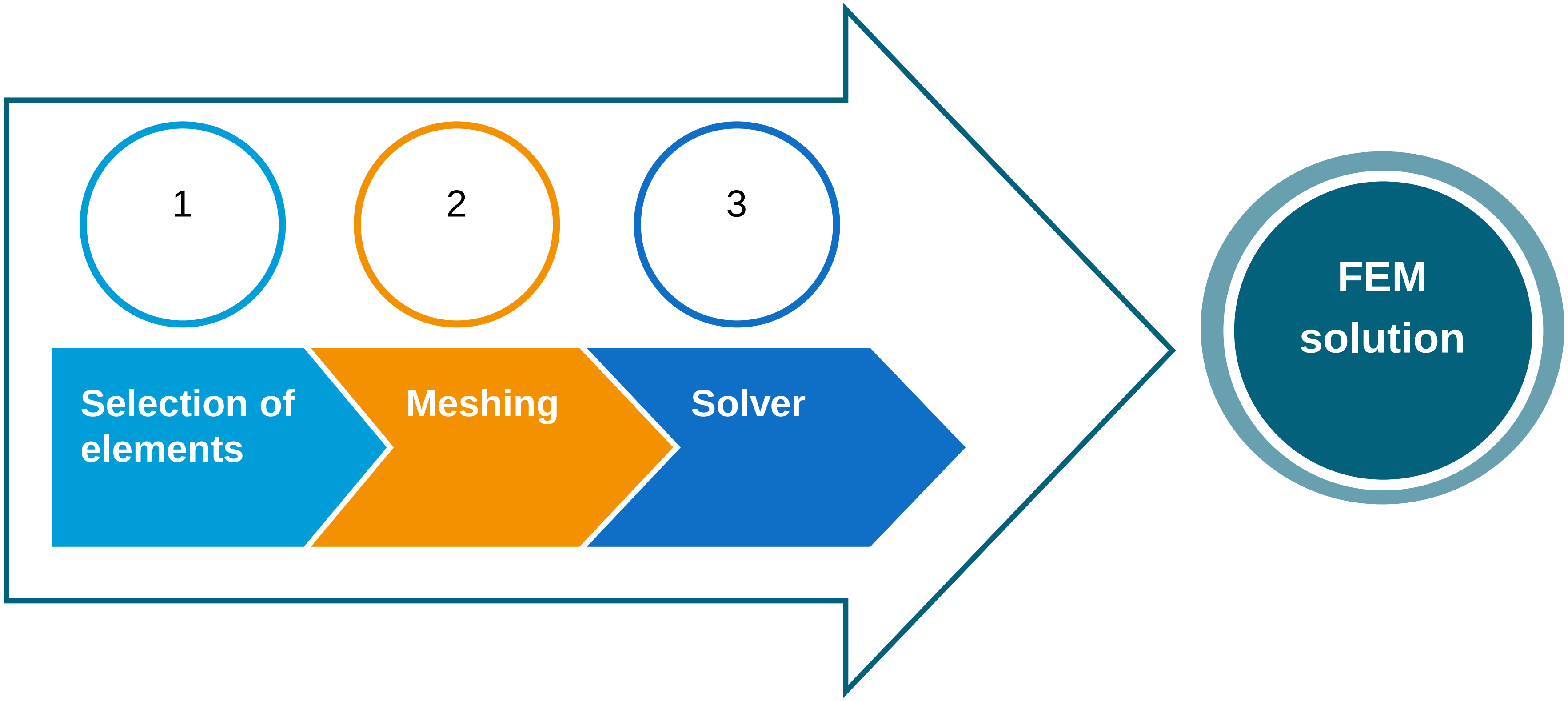
The Jacobian ratio

The Jacobian calculation is done at the integration points of elements commonly known as Gauss Point. At each integration point, Jacobian Determinant is calculated, and the Jacobian ratio is found by the ratio of the maximum and minimum determinant value.

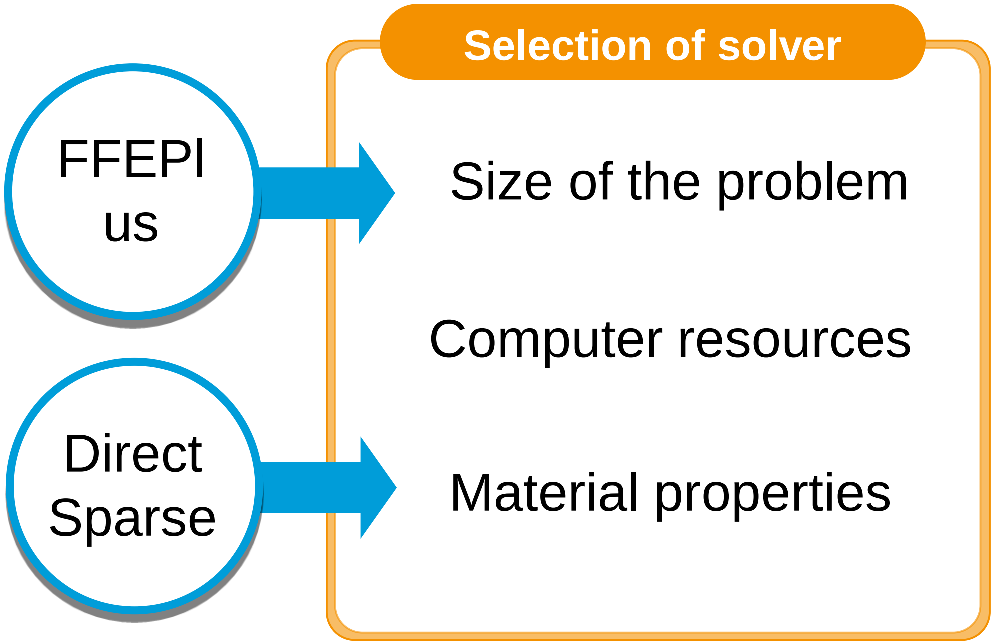


- Using Jacobian check at Nodes when using p-method
- For high order shells, the Jacobian check uses 6 points located at the nodes
- Empirical study indicates < 40

The solvers

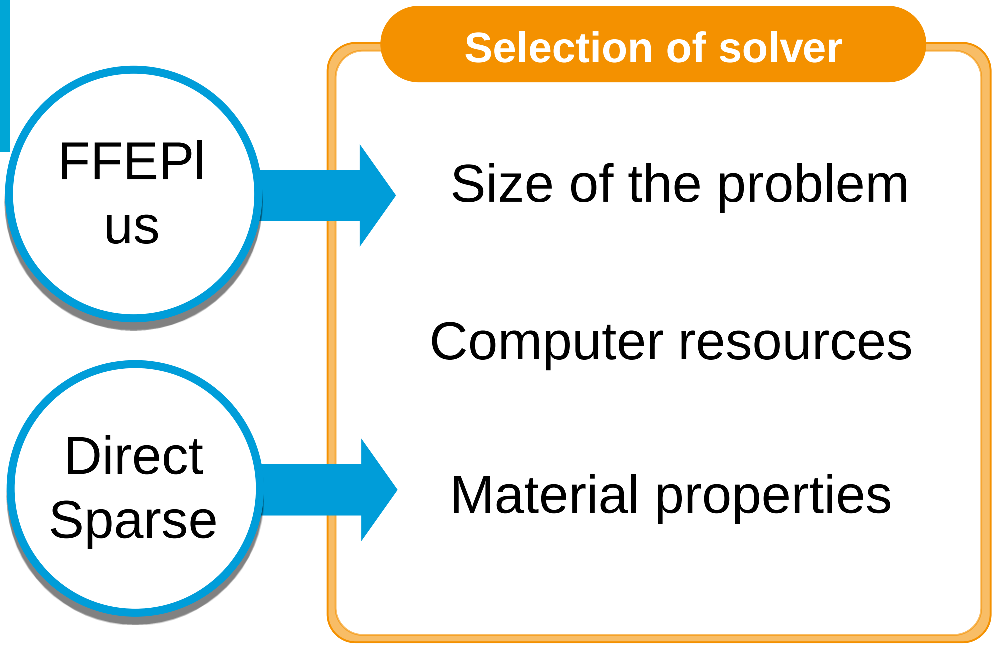


Solver selection



Size of the problem. In general, FFEPlus is faster in solving problems with degrees of freedom (DOF) over 100,000. It becomes more efficient as the problem gets larger.

Solver selection



Computer resources. The Direct Sparse solver in particular becomes faster with more memory available on your computer.

Solver selection

FFEPlus

Direct Sparse

Selection of solver

- Size of the problem
- Computer resources
- Material properties

Material properties. When the moduli of elasticity of the materials used in a model are very different (like Steel and Nylon), then iterative solvers are less accurate than direct methods.

The direct solver is recommended in such cases.

Evaluation

The complexity

Fools ignore complexity.

Pragmatists suffer it.

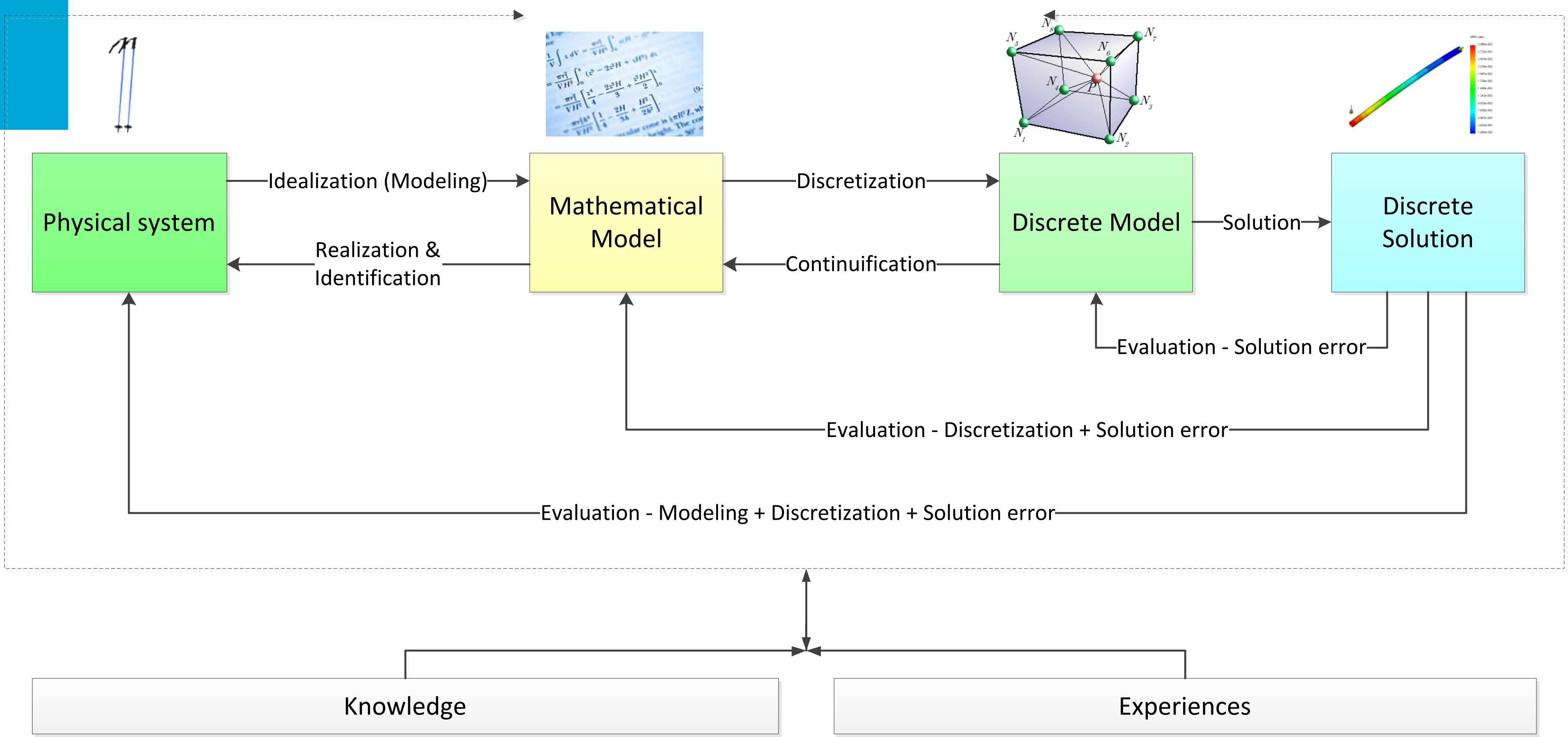
Some can avoid it.

Geniuses remove it.

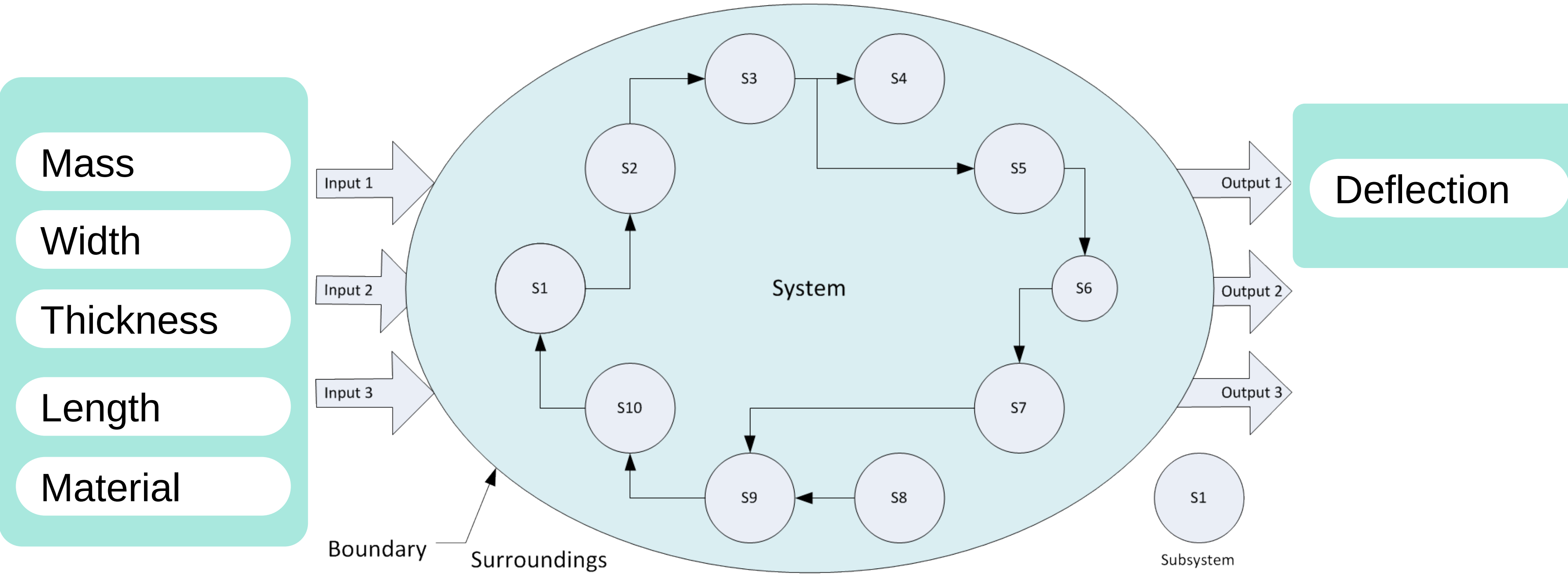
Alan Perlis

Computer scientist
1st ACM A.M. Turing Award (1966)

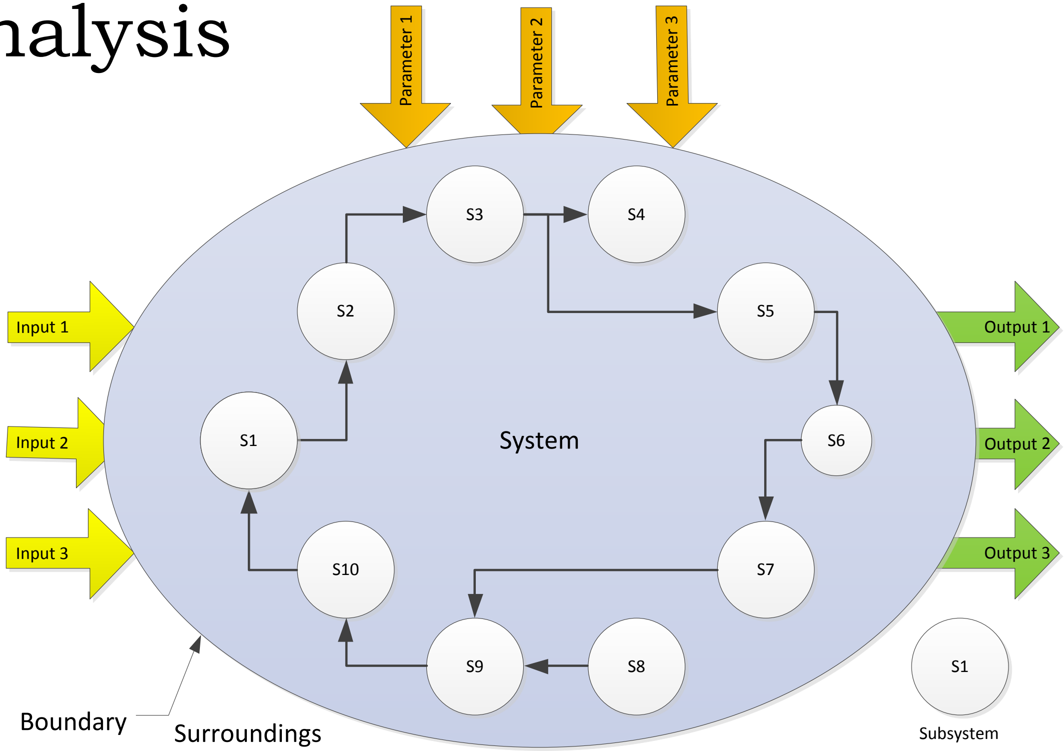
The influence of choice



Using sensitivity analysis to evaluate complicated problem



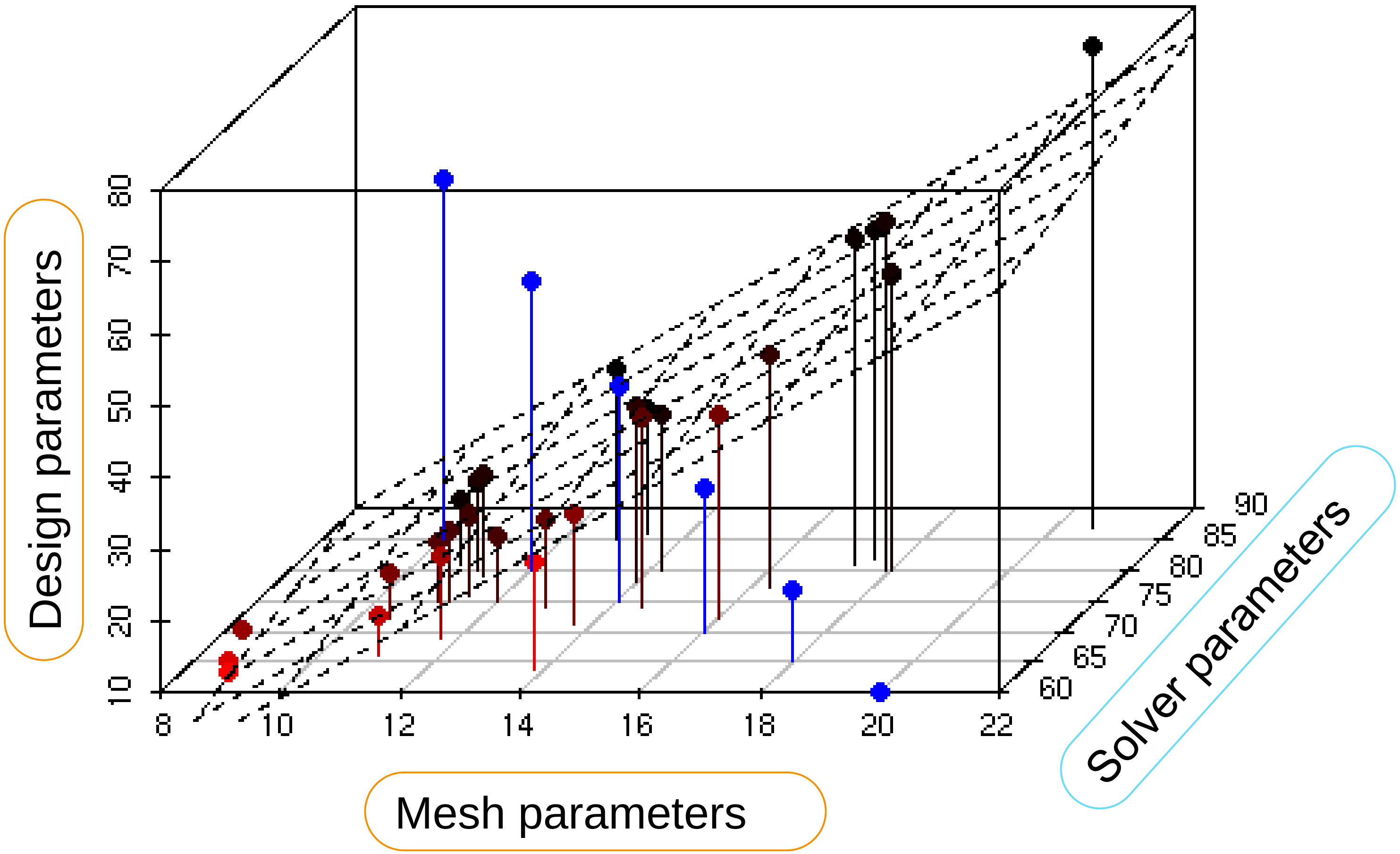
The mathematical meaning of Sensitivity analysis



Gradient of the metric (f) w.r.t. inputs / parameters (p_1,p_2...,p_n)

$$\nabla f = \left(\frac{\partial}{\partial p_1} f(p_1, p_2, \ldots p_n), \frac{\partial}{\partial p_2} f(p_1, p_2, \ldots p_n), \cdots, \frac{\partial}{\partial p_n} f(p_1, p_2, \ldots p_n)\right)$$

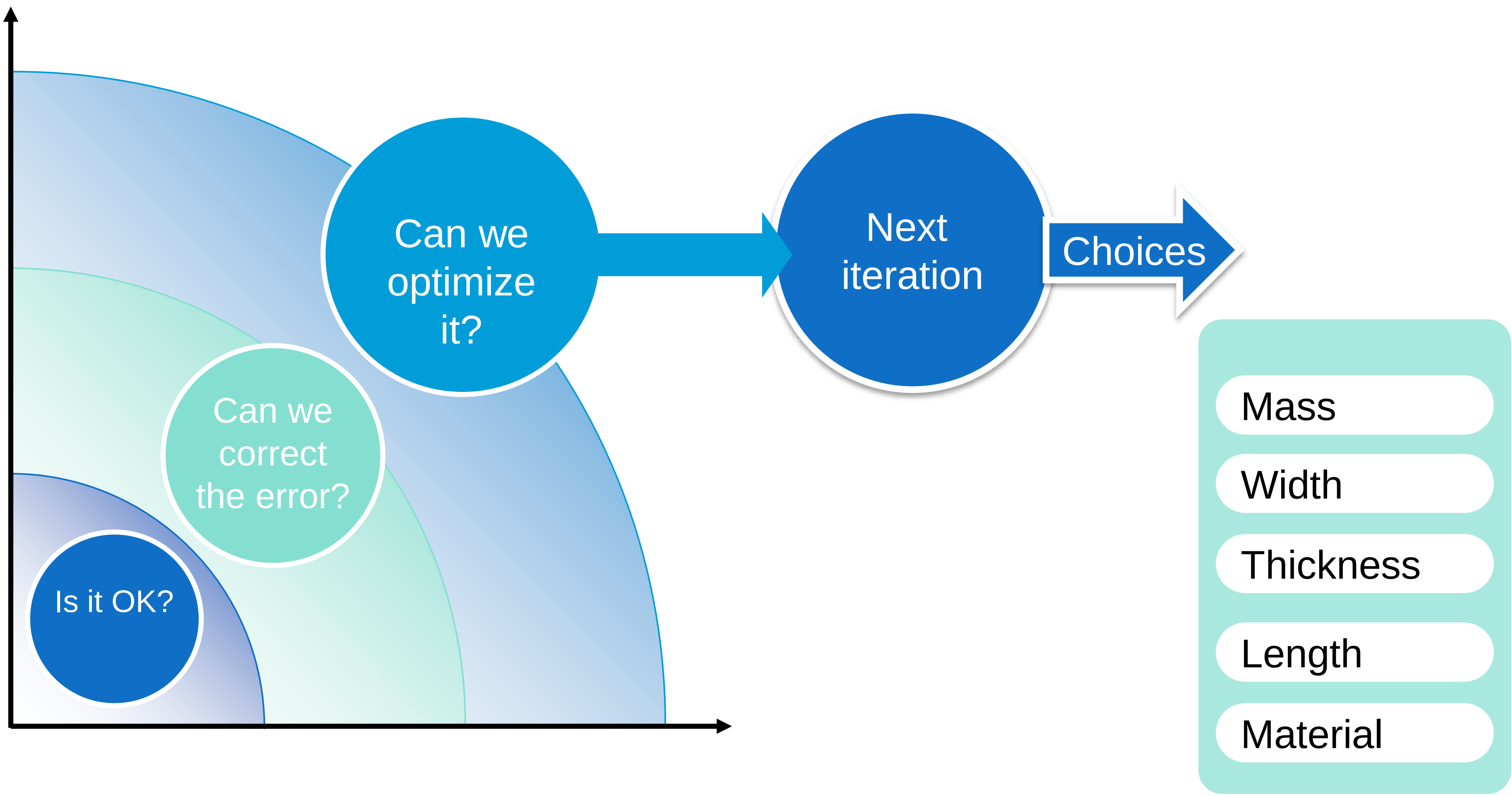
Evaluation



Design parameters
Mesh parameters
Solver parameters
80
70
60
50
40
30
20
10
8
10
12
14
16
18
20
22
60
65
70
75
80
85
90

Reflection

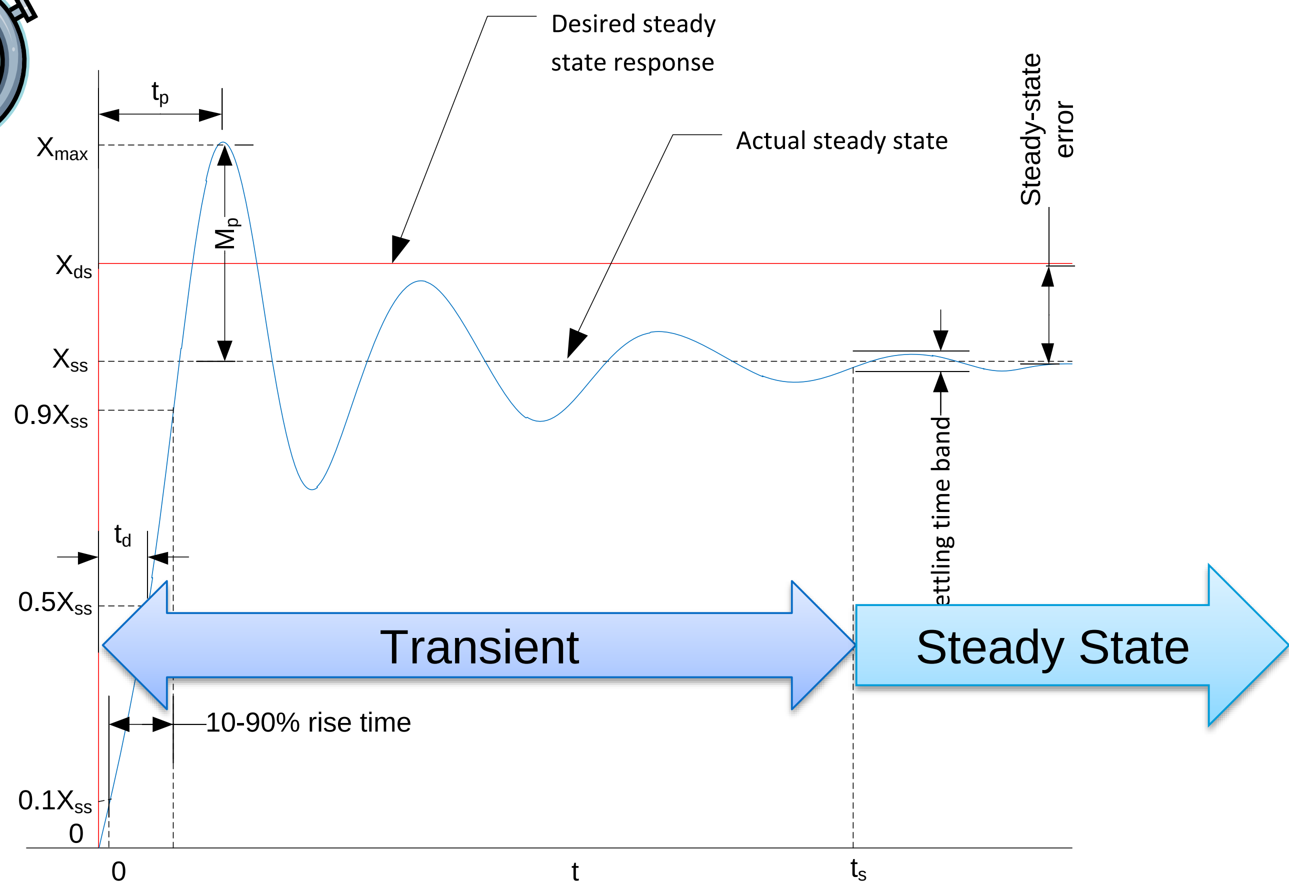
Reflection


Can we optimize it?
Can we correct the error?
Is it OK?
Next iteration
Choices
Mass
Width
Thickness
Length
Material

Linear Dynamics

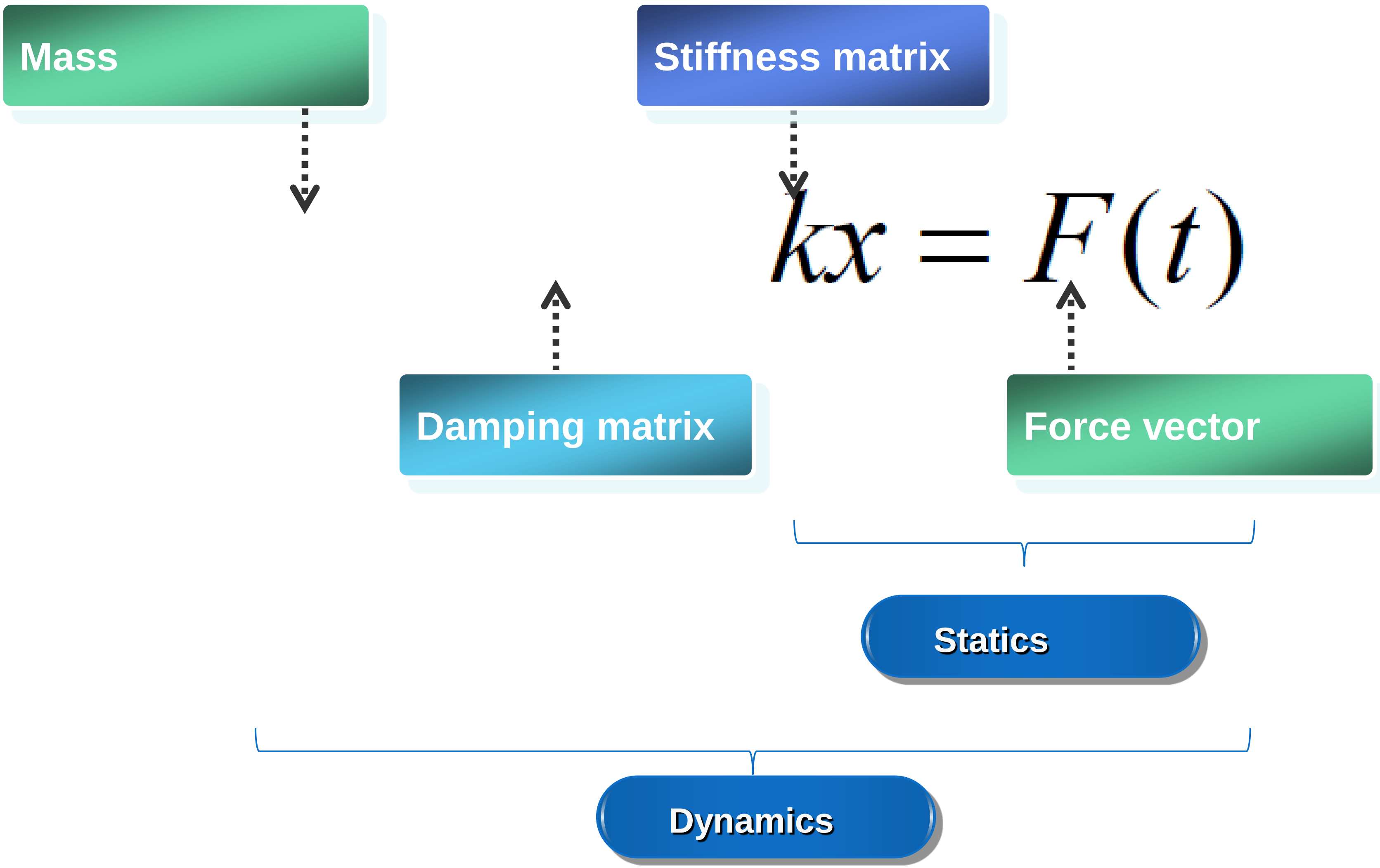
Transient and steady state

Time dependent



Ref. William Palm III, System Dynamics, McGraw-Hill Science/Engineering/Math; 2 edition, January 26, 2009

From Statics to Dynamics



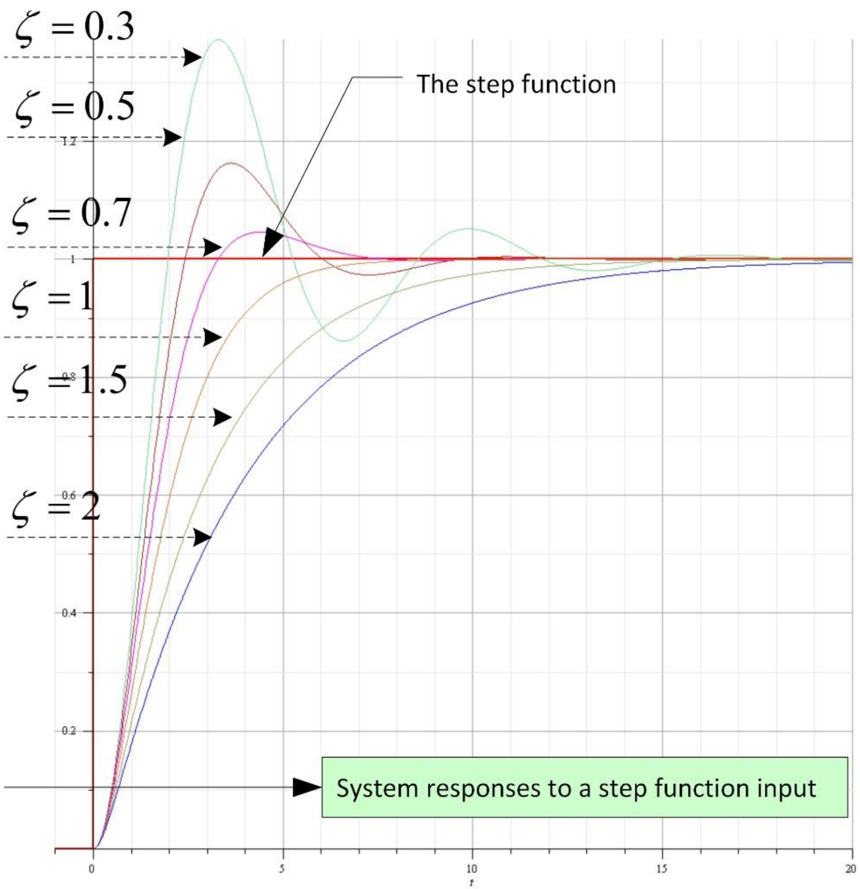
Damping – Modal damping

Modal Damping

Modal damping is

defined as a ratio of the

critical damping



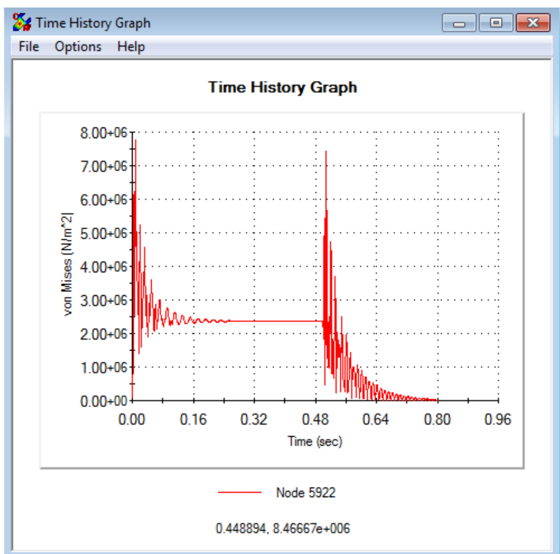
Modal damping ratio

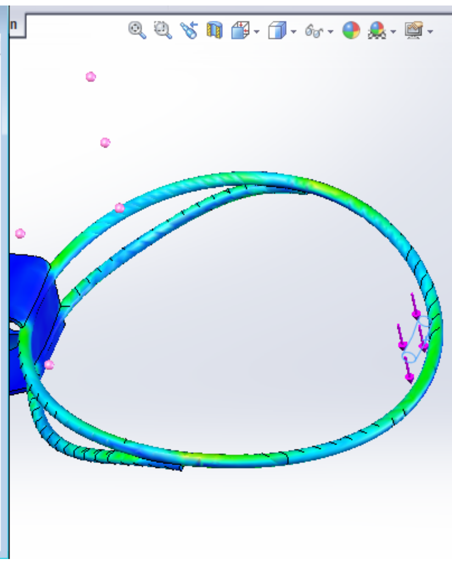
System	Viscous Damping Ratio
Metals (in elastic range)	less than 0.01
Continuous metal structures	0.02 - 0.04
Metal structures with joints	0.03 - 0.07
Aluminum / steel transmission lines	~ 0.04
Small diameter piping systems	0.01 - 0.02
Large diameter piping systems	0.02 -0.03
Auto shock absorbers	~ 0.30
Rubber	0.05
Large buildings during earthquake	0.01 - 0.05
Prestressed concrete structures	0.02 -0.05
Reinforced concrete structures	0.04 -0.07

Courtesy of Solidworks® simulation tutorial

Case study: Linear dynamics

A Slam dunk





Non-linear analysis

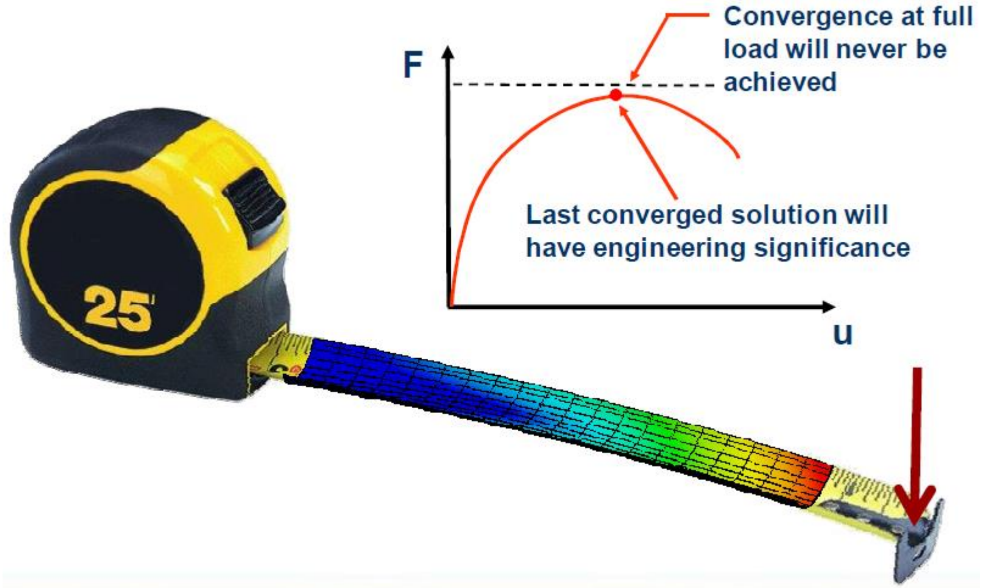
Structural nonlinearities

Courtesy of CAE associations: Snap through bulking

Geometric Nonlinearities

Contact Nonlinearities

Material Nonlinearities

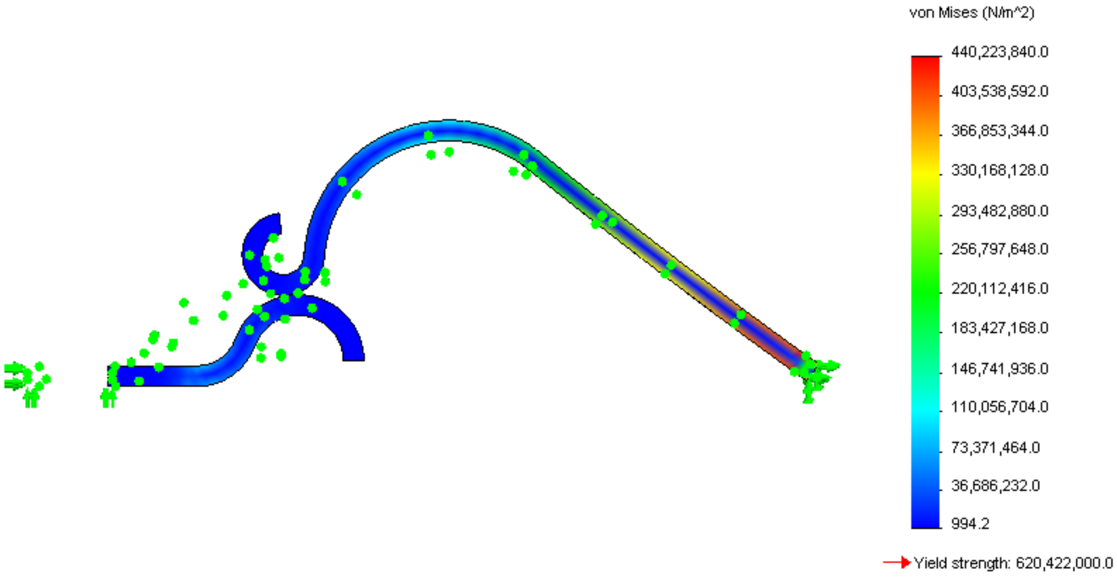


Snap through bulking

Structural nonlinearities

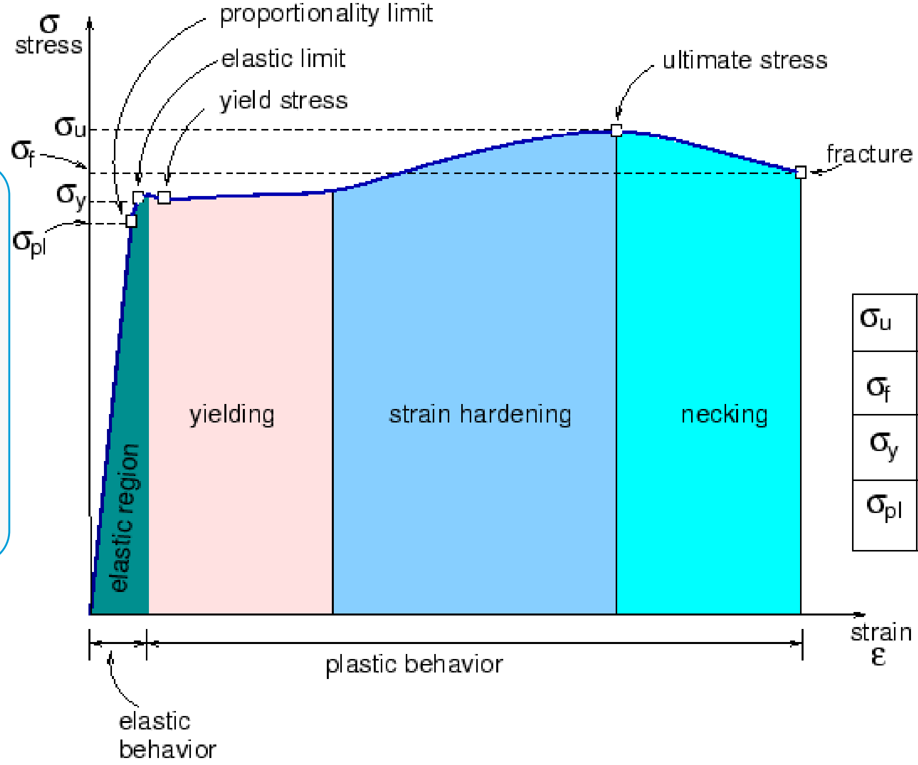
Courtesy of CAE associations: Snap through bulking

- Geometric Nonlinearities
- Contact Nonlinearities
- Material Nonlinearities



Material Nonlinearities

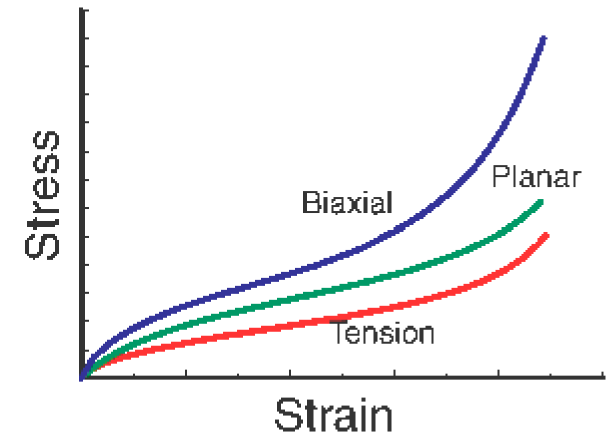
- Geometric Nonlinearities
- Contact Nonlinearities
- Material Nonlinearities



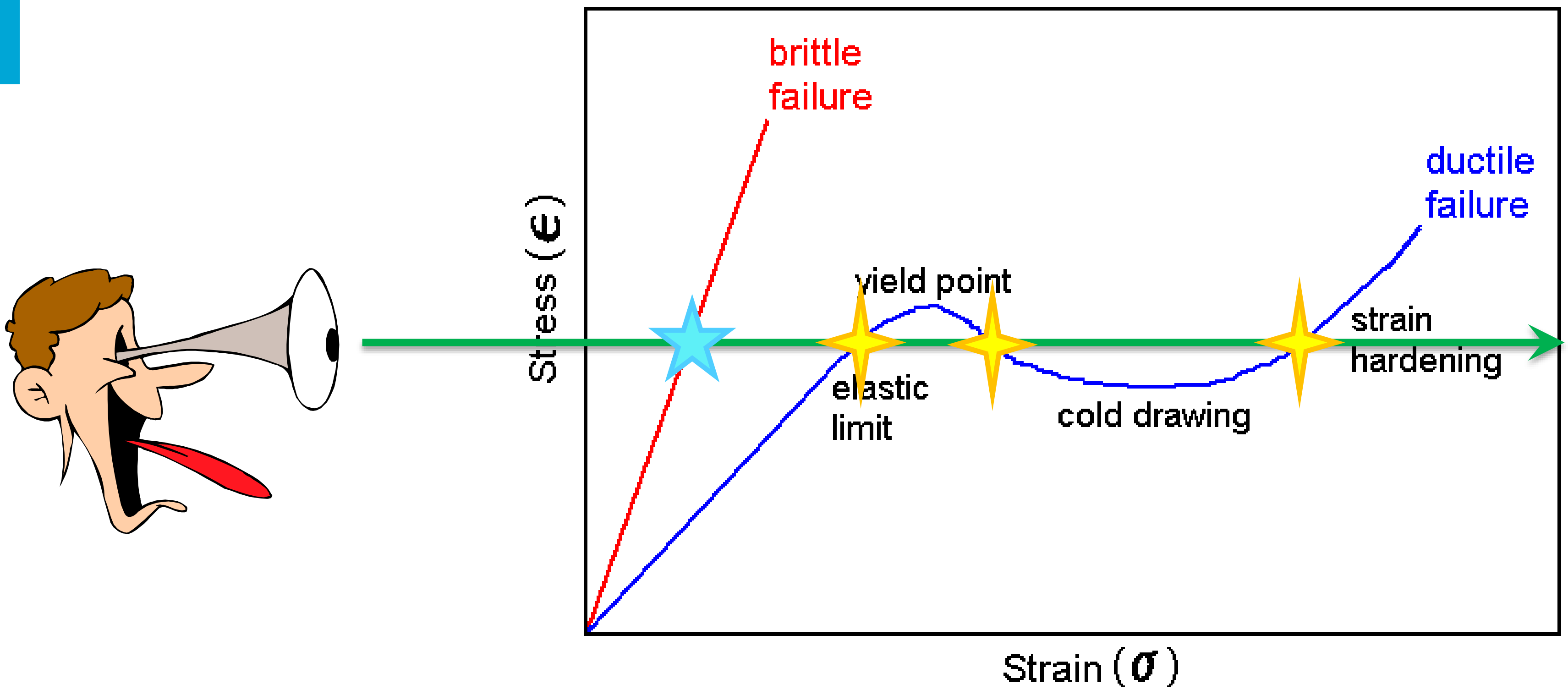
σ_u	Ultimate stress
σ_f	Fracture stress
σ_y	Yield stress
σ_{pl}	Proportionality limit

Material models

- Material model
  - Linear Elastic
    - Isotropic
    - Orthotropic
  - Nonlinear elastic
    - Plasticity
    - Hyperelasticity
    - Viscoelasticity
    - Creep
    - Nitinol
    - ...



Time dependent solution

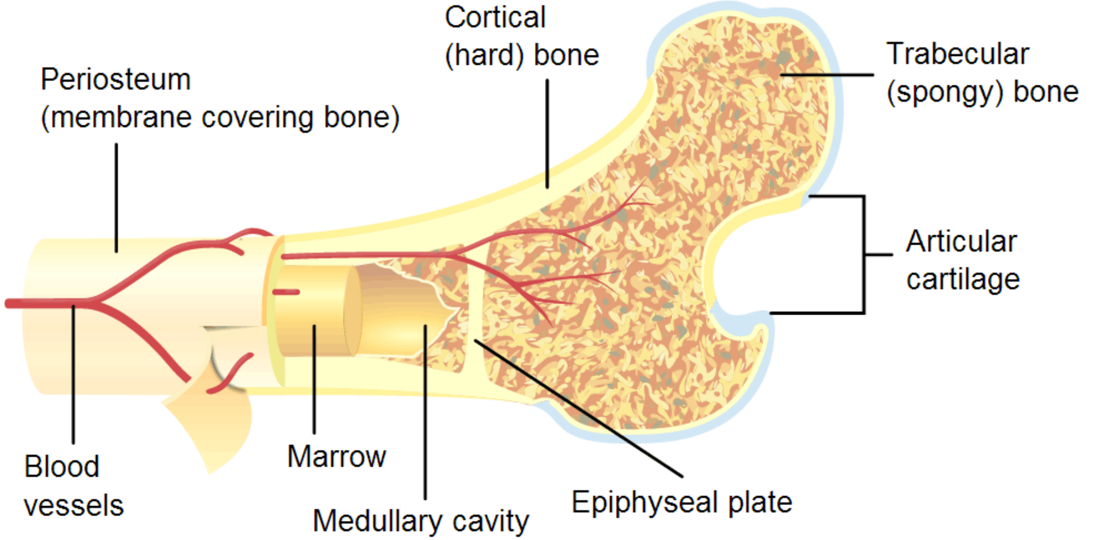


Biomechanics

Approach from MoM

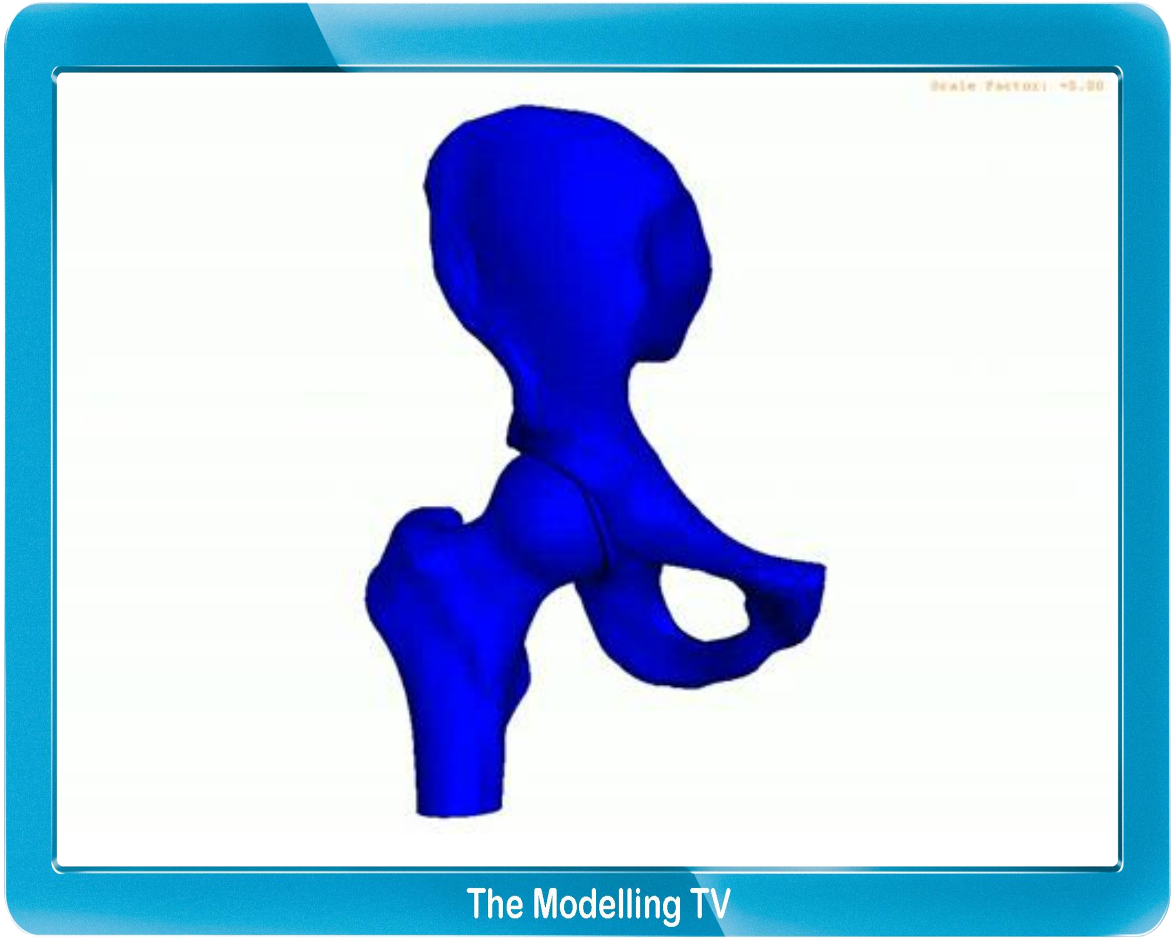
Complex Beam Theory

- Straight Beam
- Curved Beam
- Composite Beam



Courtesy of Daviddarling.info

Case study: Human Joint analysis

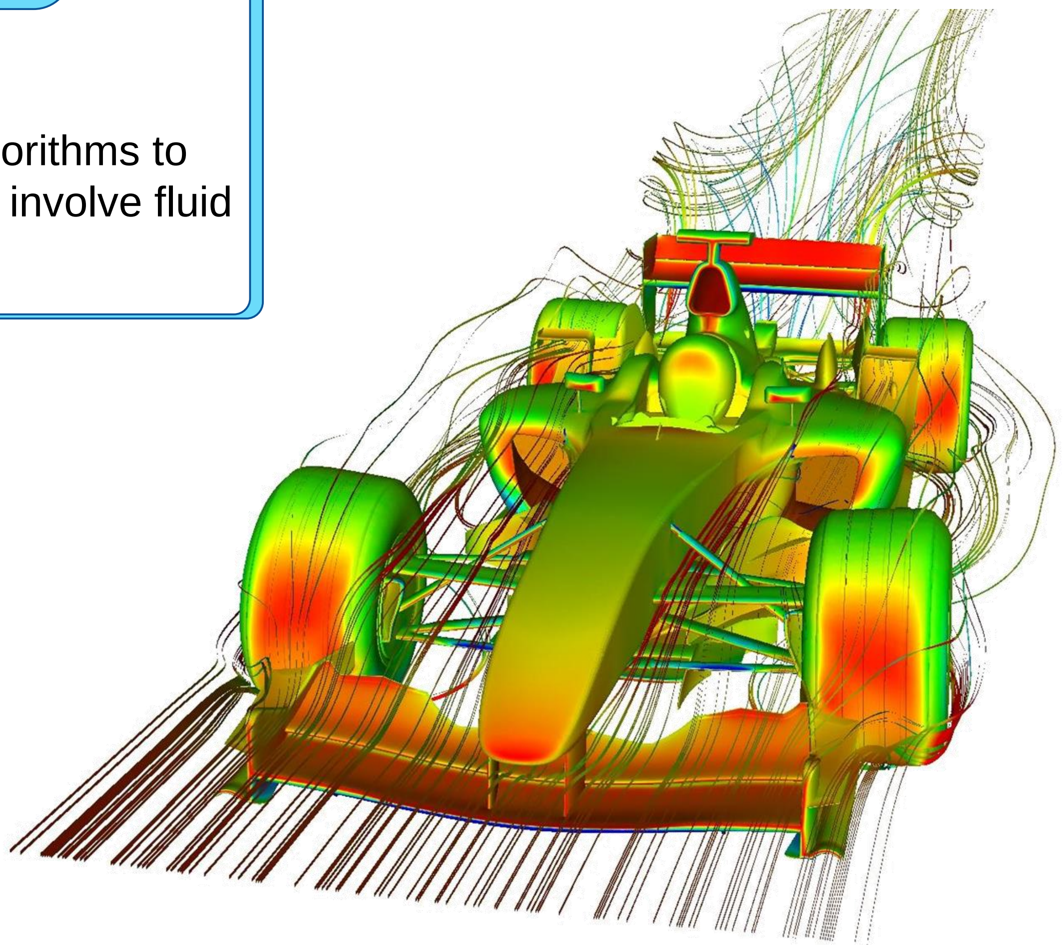


Computing Fluid Dynamics

Computing Fluid Dynamics

CFD

A branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.



Courtesy of http://www.autoracing.com.br/forum/index.php?showtopic=64512

Case study: Air drag

Drag coefficient

http://en.wikipedia.org/wiki/Automobile_drag_coefficient

$$F = \frac{1}{2} \cdot \rho \cdot A \cdot C_d \cdot v^2$$

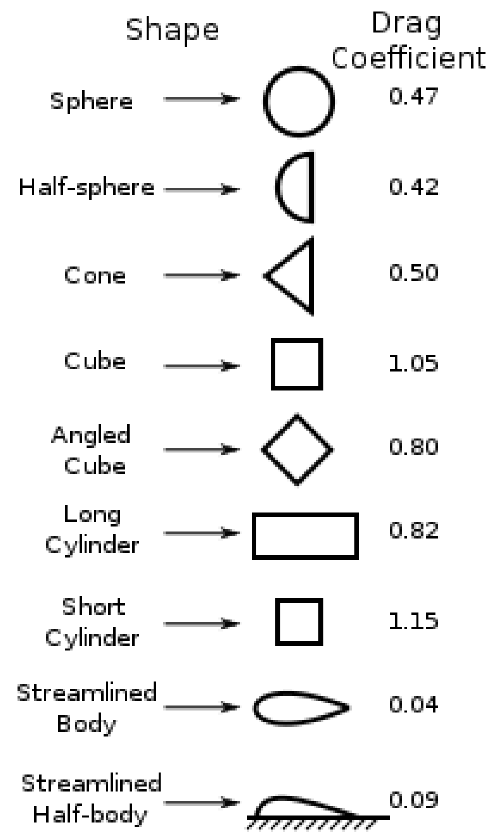
Drag [N]

Density [kg/m³]

Area [m²]

Drag Coefficient

Velocity [m/s]



Measured Drag Coefficients

Drag coefficient

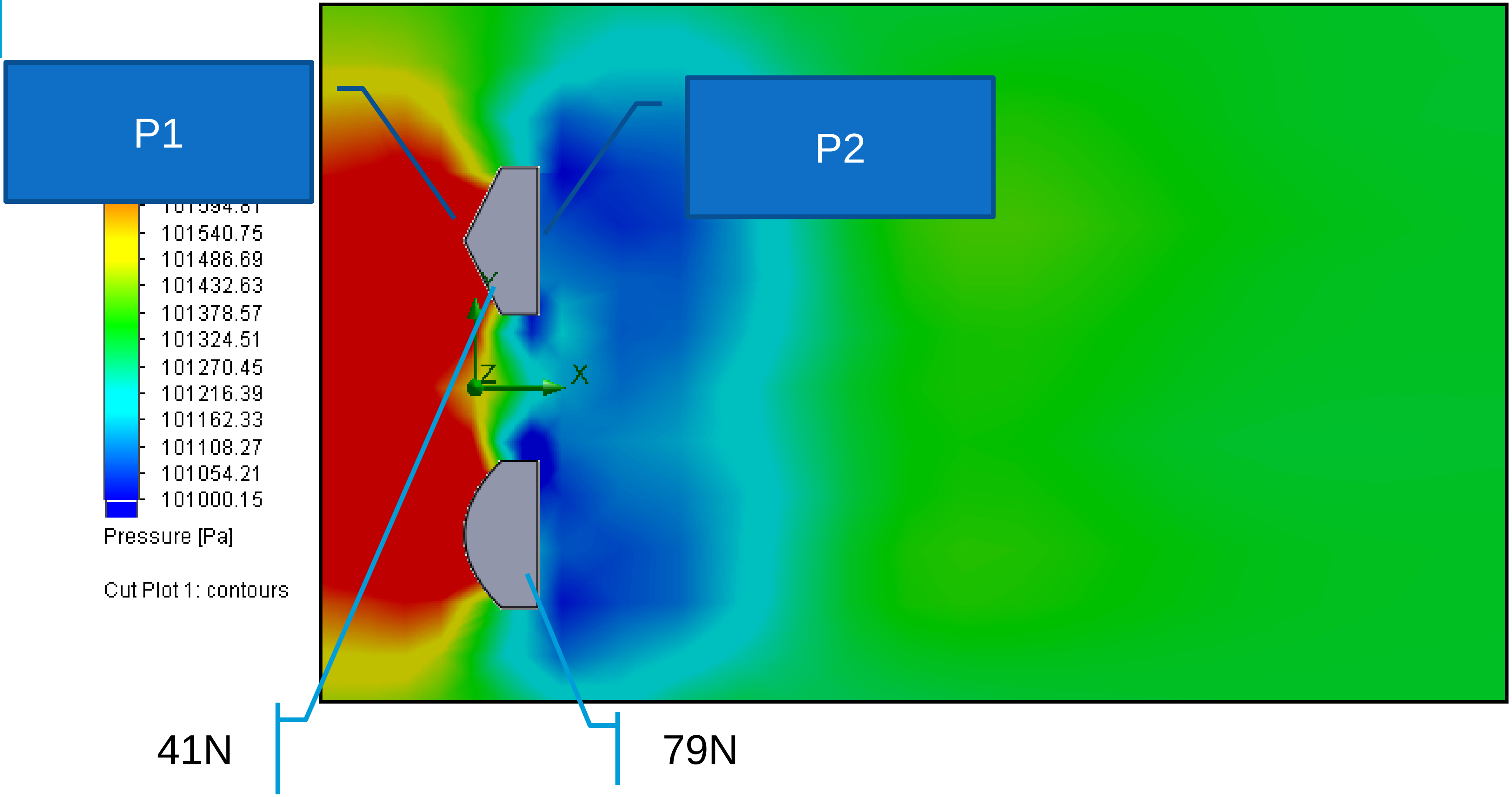
http://en.wikipedia.org/wiki/Automobile_drag_coefficient

0.31	Audi A4 B5	1995
0.31	BMW 7-series	2009
0.31	Honda Civic (Sedan)	2006
0.31	Peugeot 307	2001
0.31	Porsche 997 Turbo/GT3	2006
0.31	Volkswagen GTI Mk IV	1997
0.30	Nissan 370Z Coupe (0.29 with sport package)	2009 [16]

$C_d = 0.26$

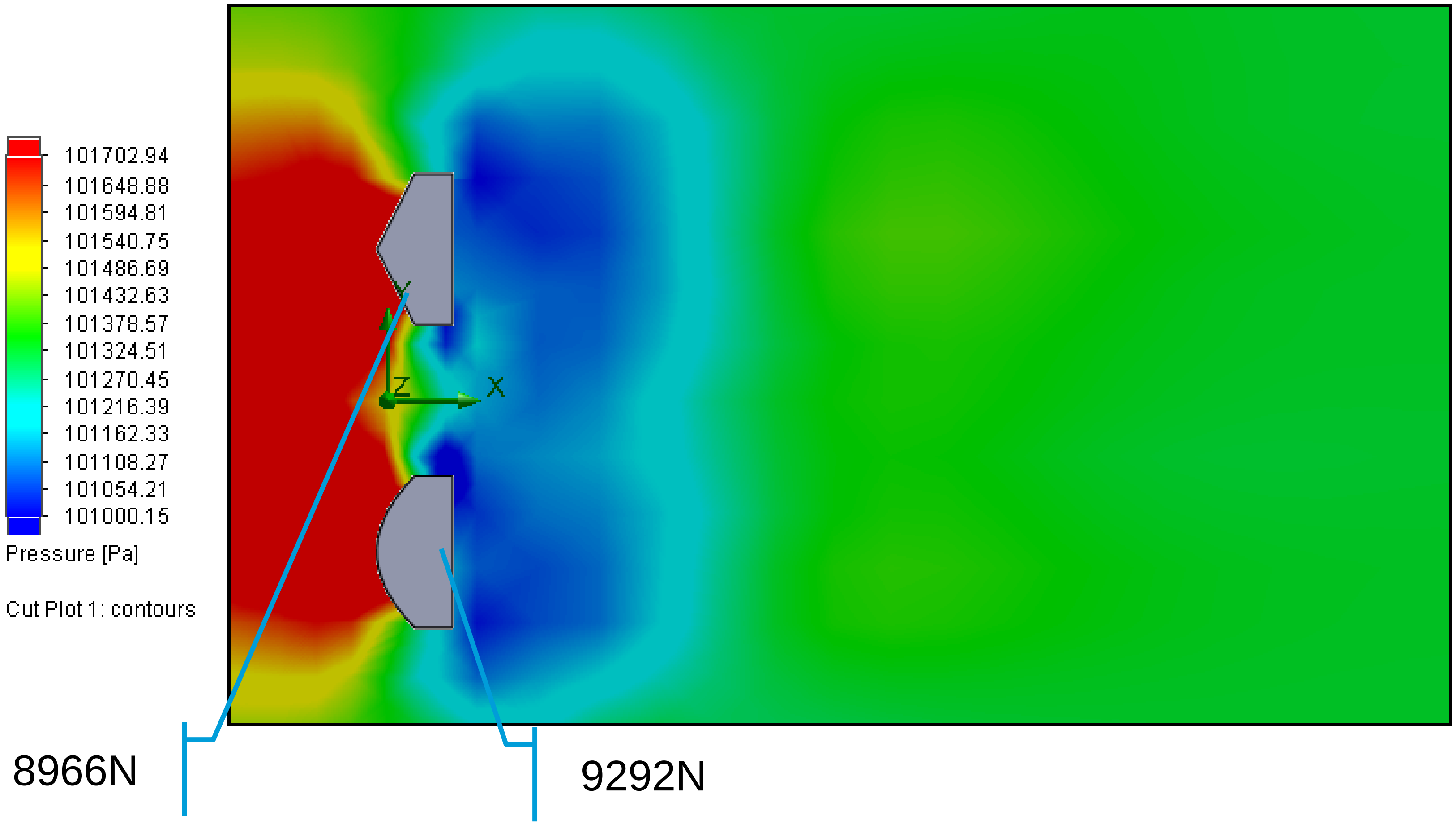
Case study: Air drag – Low speed

At 120 km/hour, which design is faster?



Case study: Air drag – Supersonic

At 350 m/s, which design is faster?



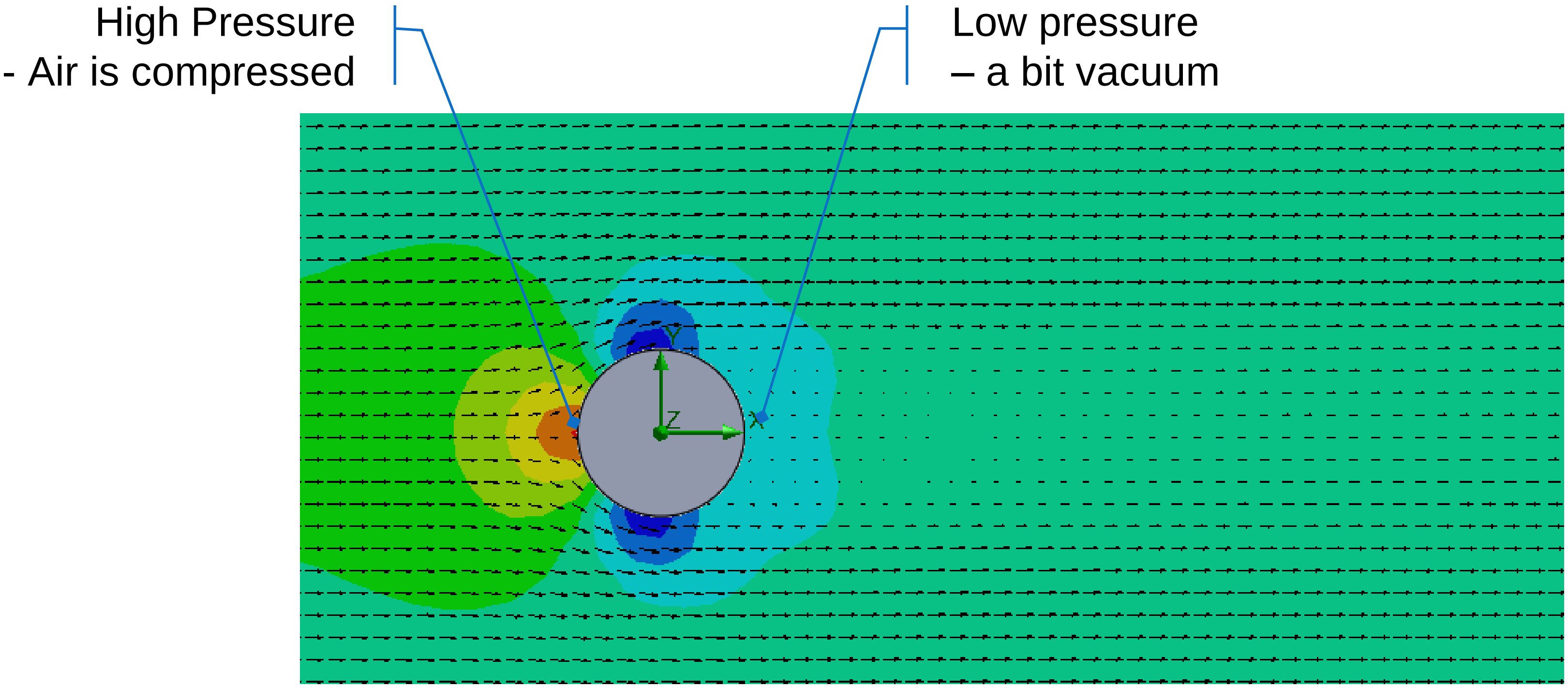
Case study: Drafting

What is drafting?

Drafting

Drafting or slipstreaming is a technique where two vehicles or other moving objects are caused to align in a close group reducing the overall effect
of drag due to exploiting the lead object's slipstream.

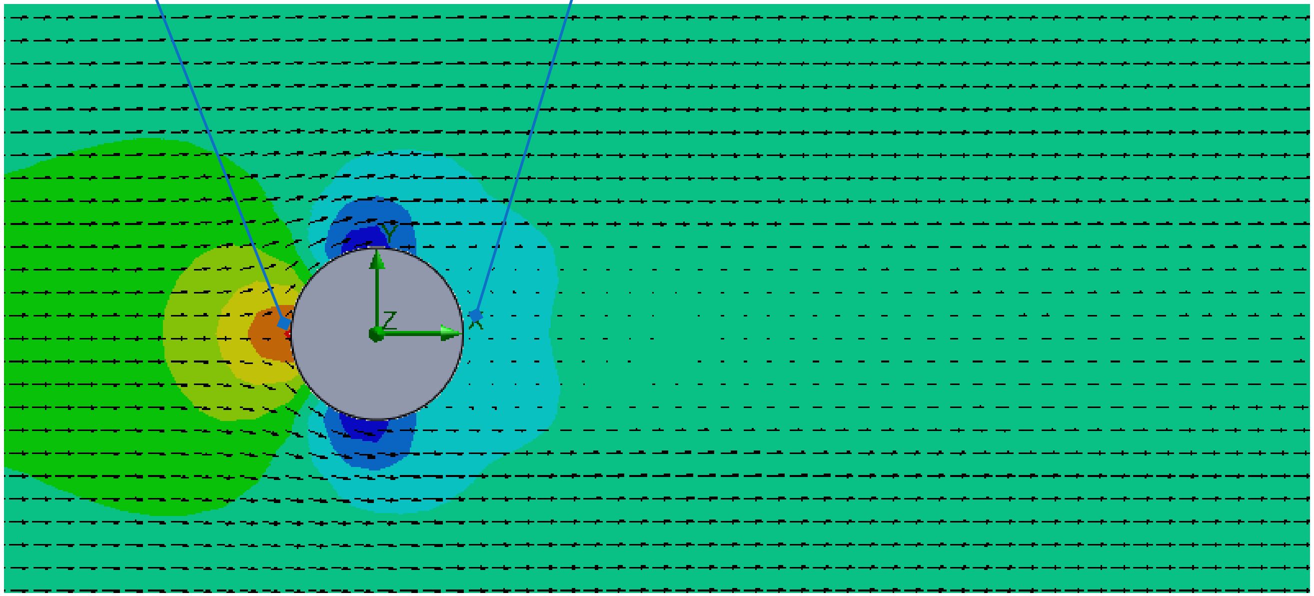
Air drag


High Pressure
- Air is compressed
Low pressure
– a bit vacuum
Y
Z
X

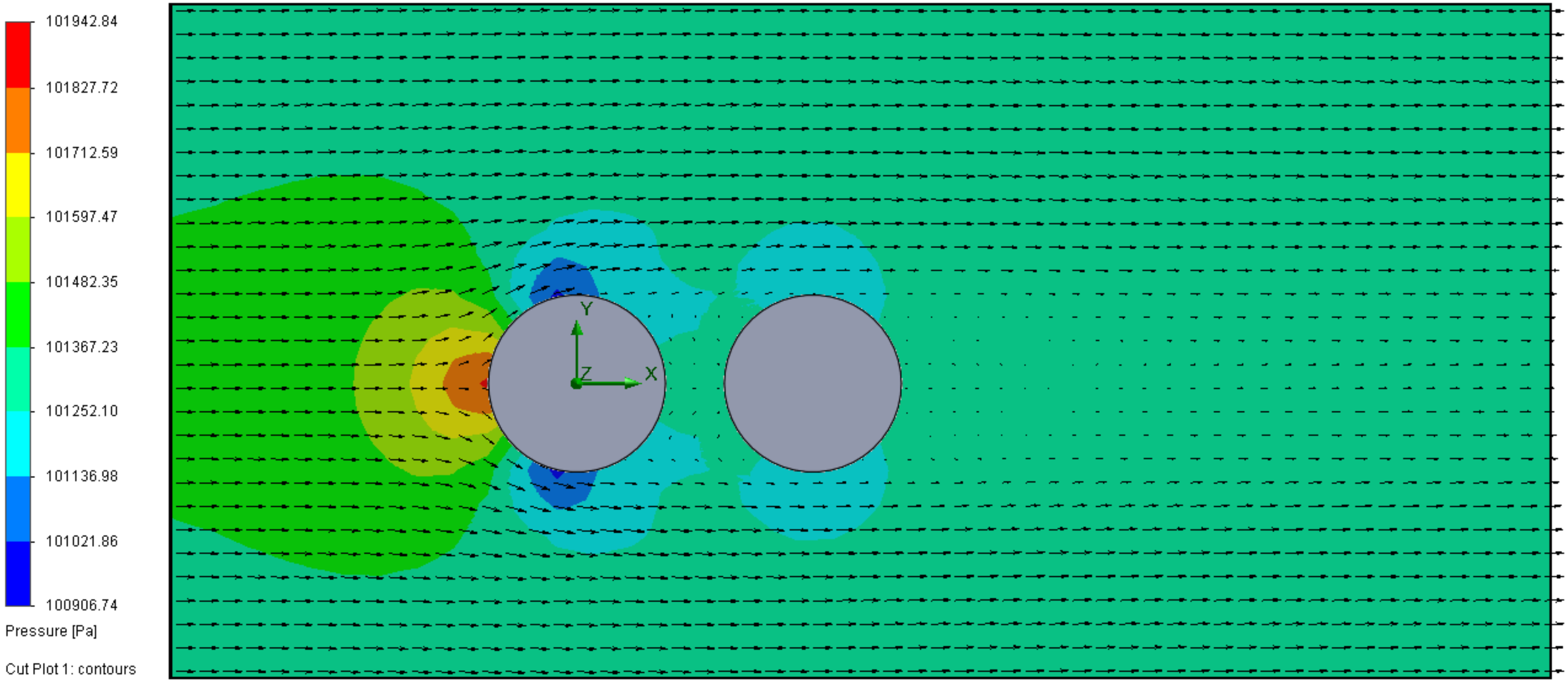
To reduce air drag

Reduce the pressure here

Increase the pressure here



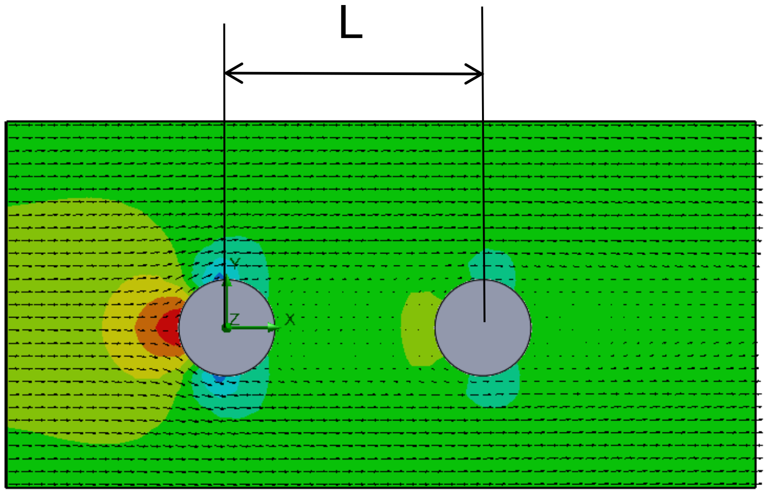
Drafting

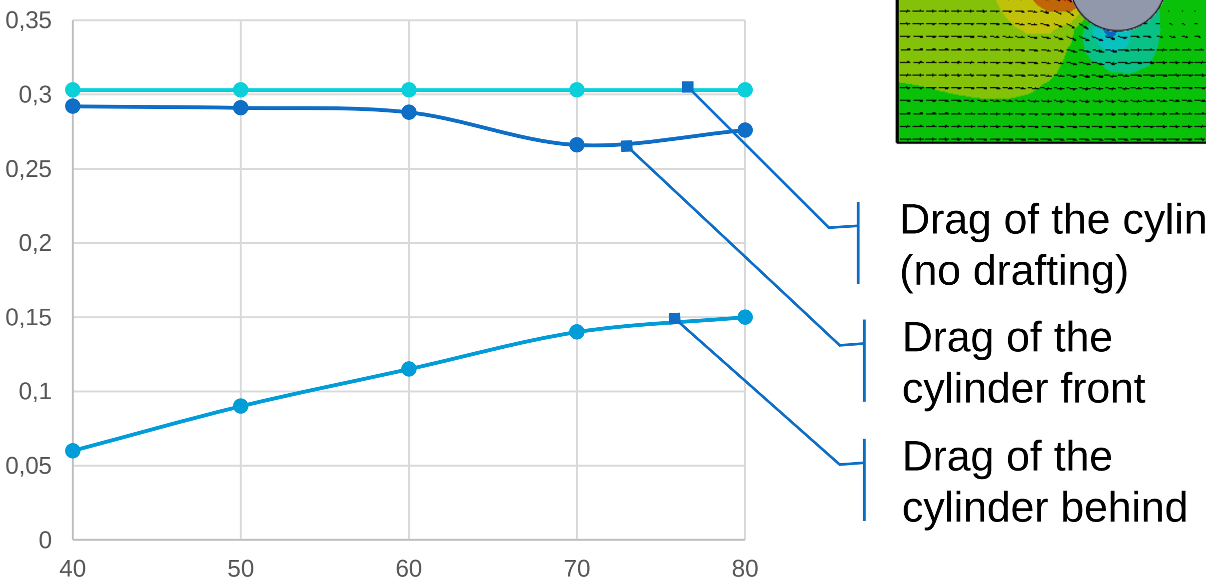


101942.84
101827.72
101712.59
101597.47
101482.35
101367.23
101252.10
101136.98
101021.86
100906.74
Pressure [Pa]
Cut Plot 1: contours
Y
Z
X

Relations with in-between distance

L (mm)	Air Drag Cylinder 1 (N)	Air Drag Cylinder 2 (N)
40	0.292	0.06
50	0.291	0.09
60	0.288	0.115
70	0.266	0.141
80	0.276	0.15



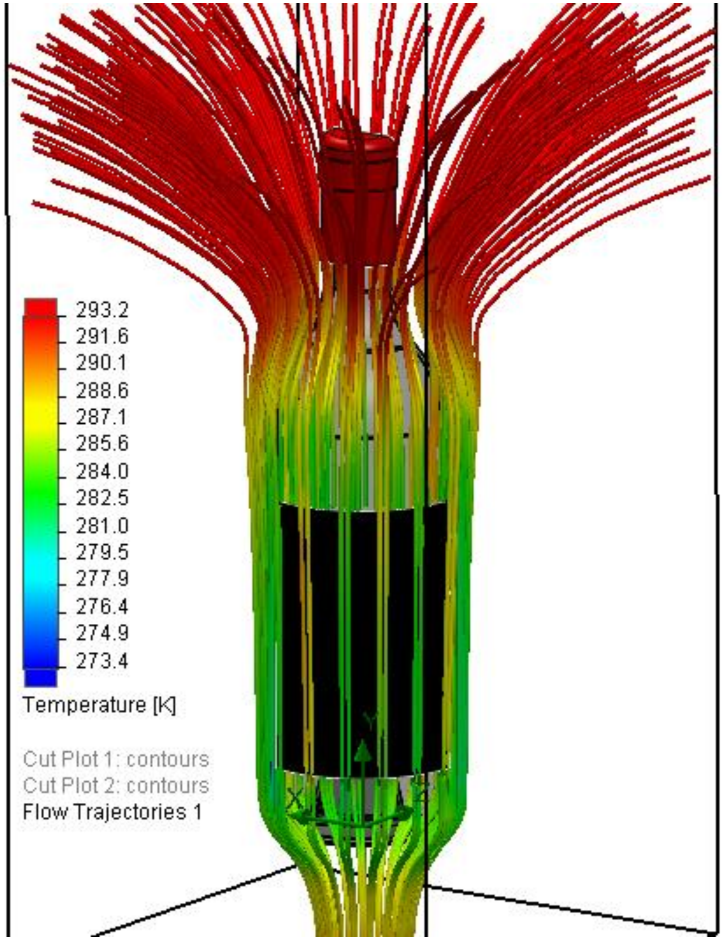


Who taught swan goose aerodynamics?

Natural convection

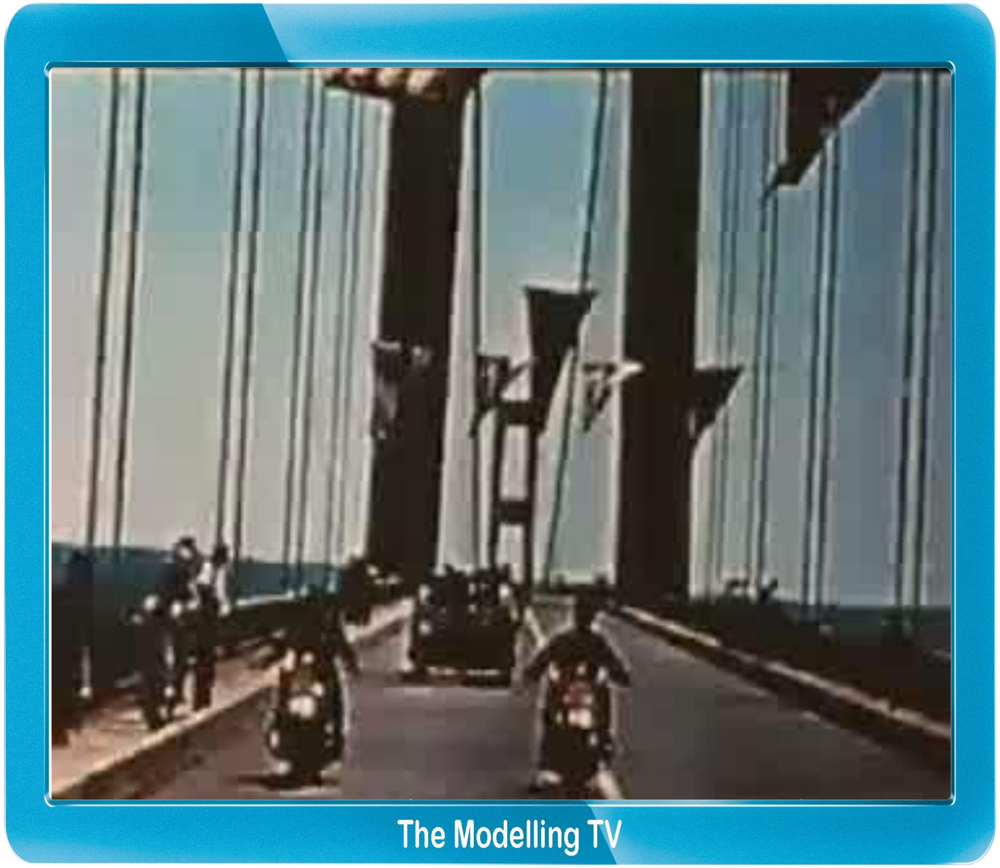
Natural convection

Heat wine by natural convection



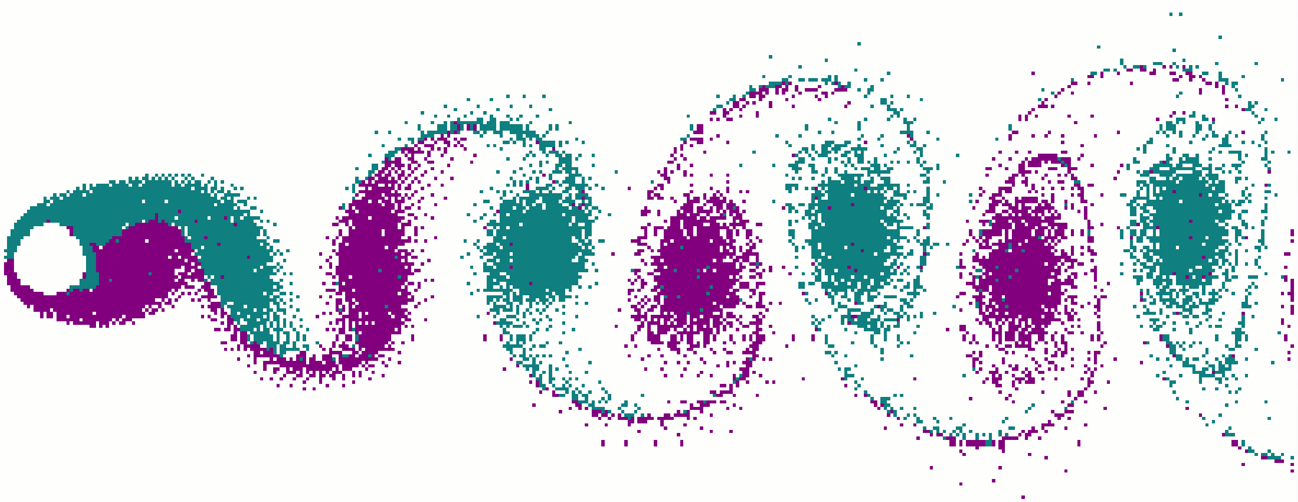
Case study: Karman Vortex Street

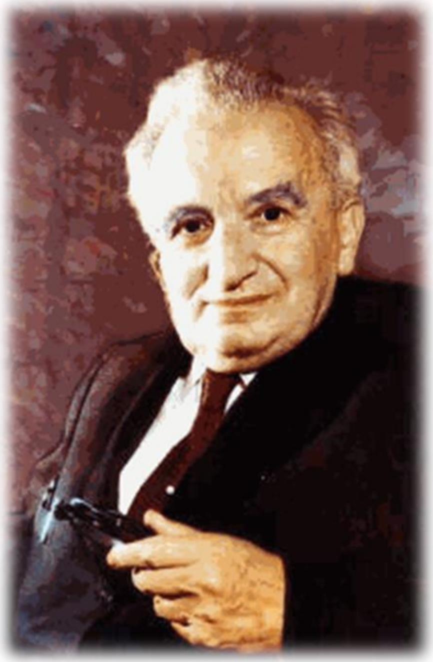
Tacoma narrow bridge 1940



Case study: Karman Vortex Street

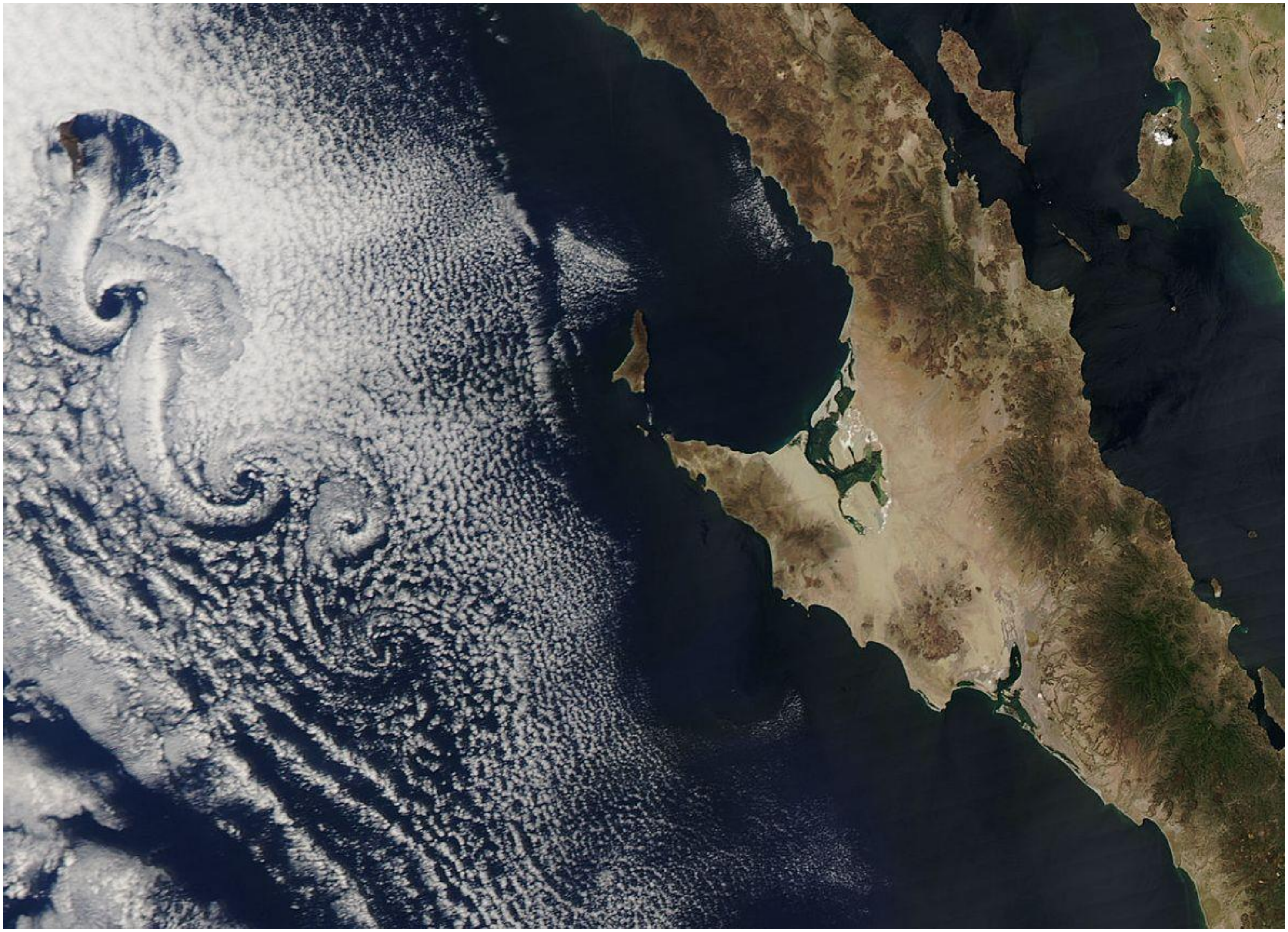
A repeating pattern of swirling vortices caused by the unsteady separation of flow of a fluid around blunt bodies



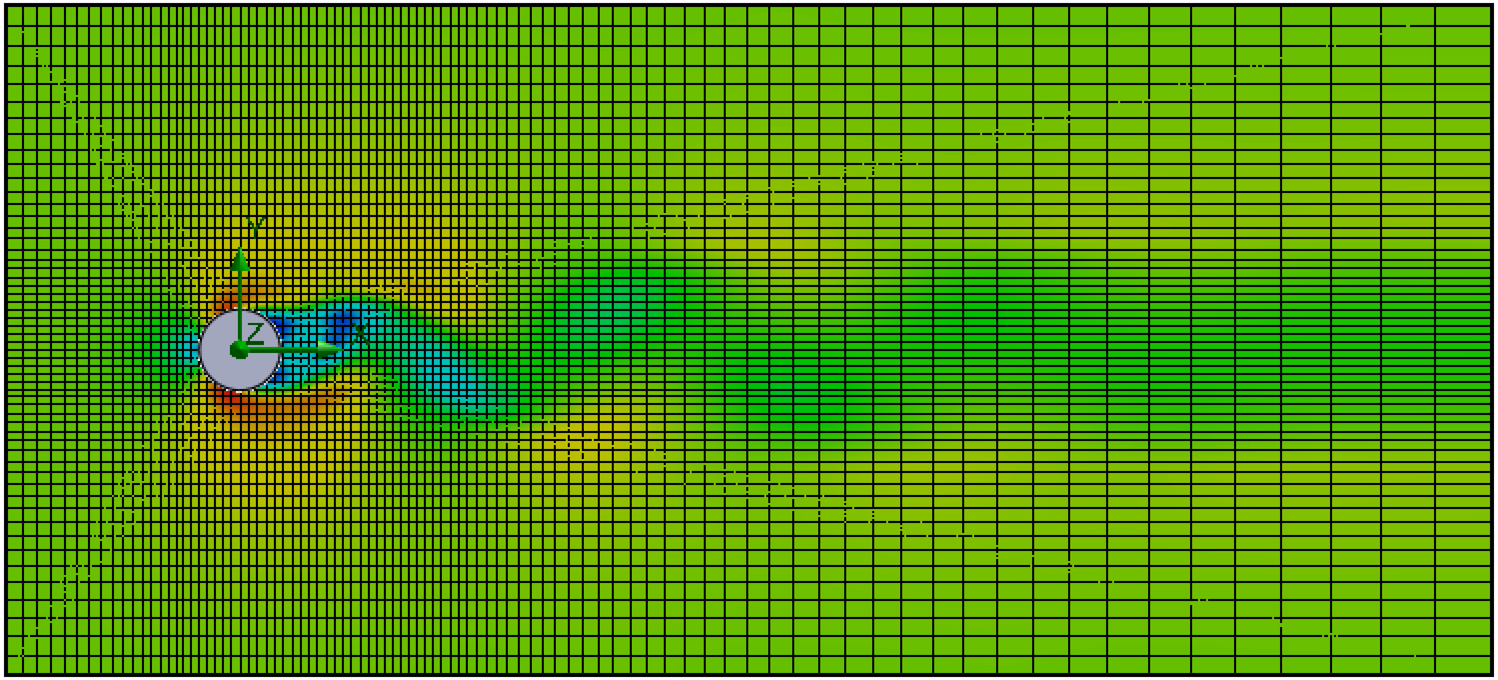


Theodore von Karman

Case study: Karman Vortex Street



Cell mesh in Flow Works



Rotation

Parrot AR Drone

Courtesy of http://www.24-7pressrelease.com/press-release/parrot-ar-drone-helicopters-now-available-for-preorder-169459.php

Simulation

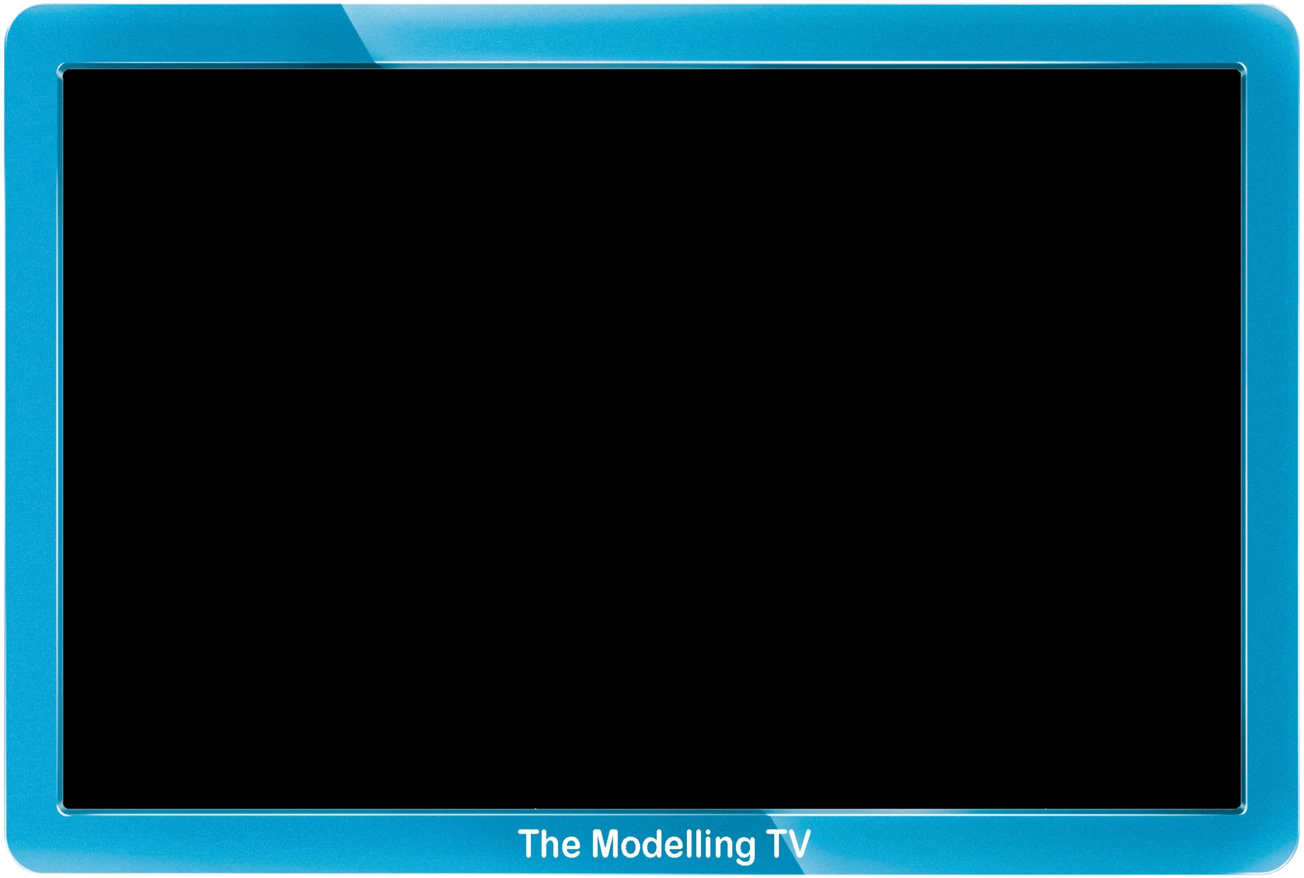
Courtesy of ADE, Alec Momont, Simon Desnerck

Case study: Fluid structure interactions (FSI)

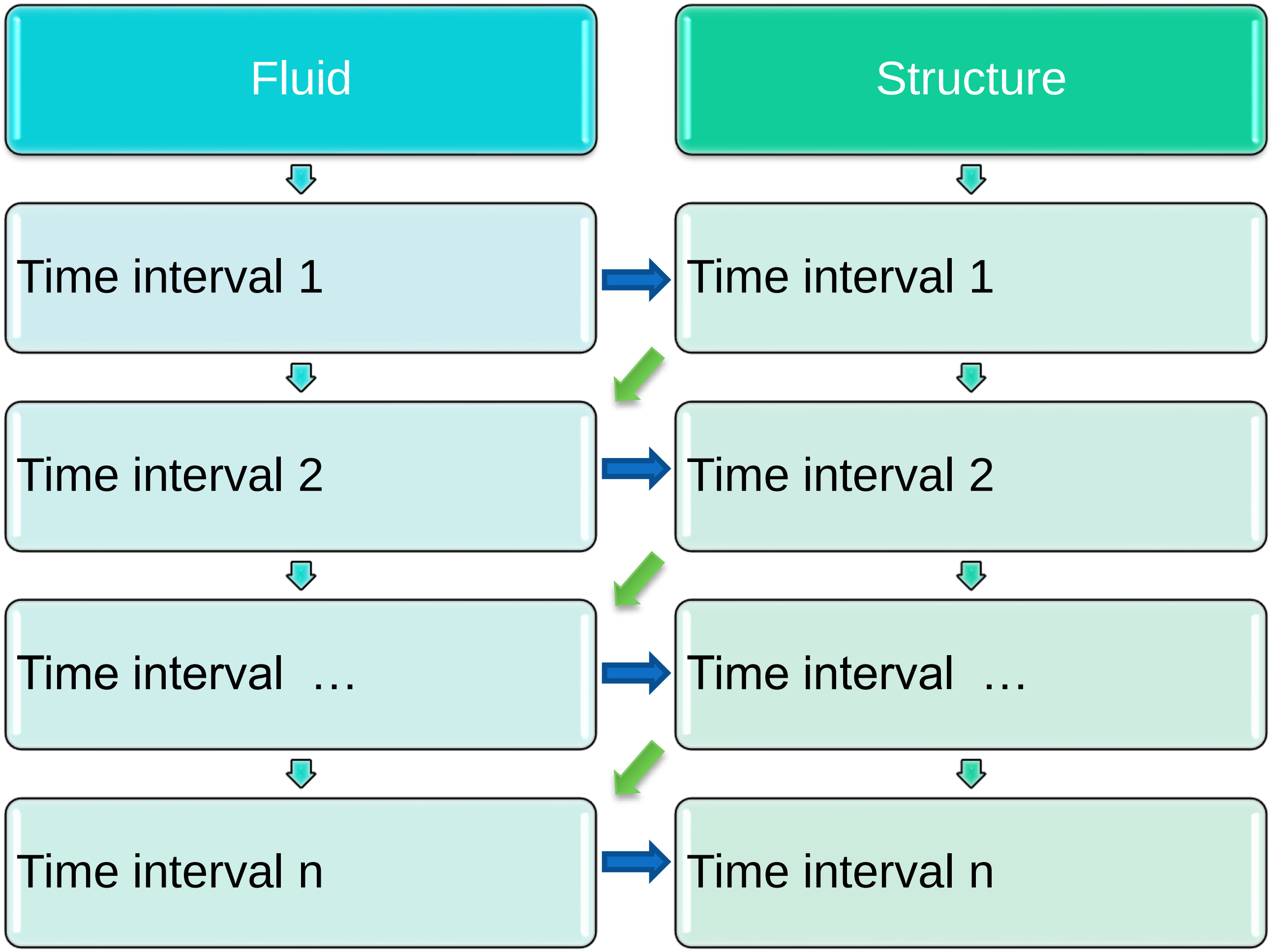
The Senz Mini model

Courtesy of http://design-milk.com/senz-umbrella/

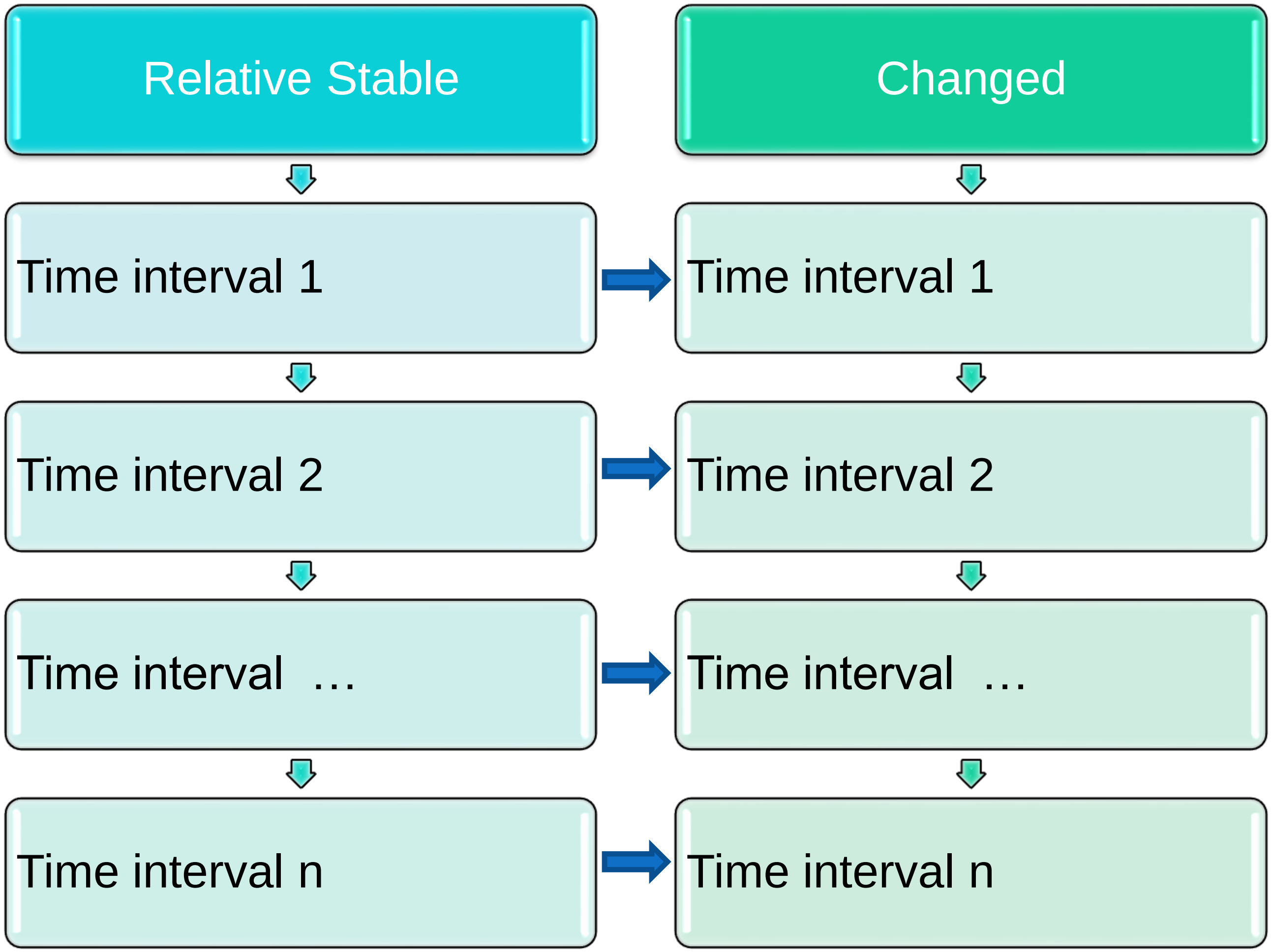
The Senz Mini flow simulation



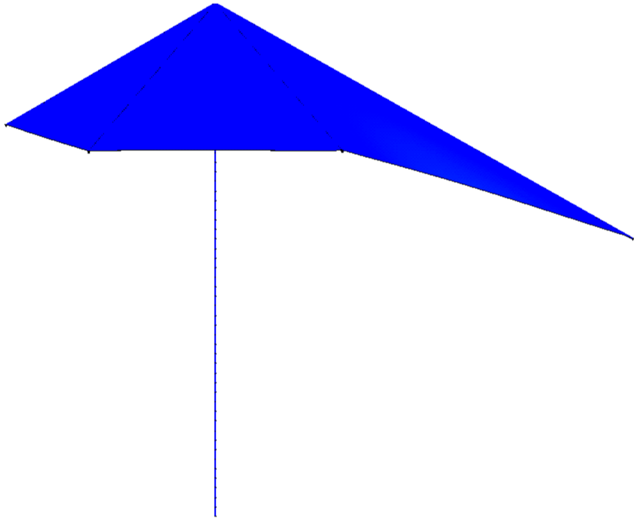
FSI in different ways

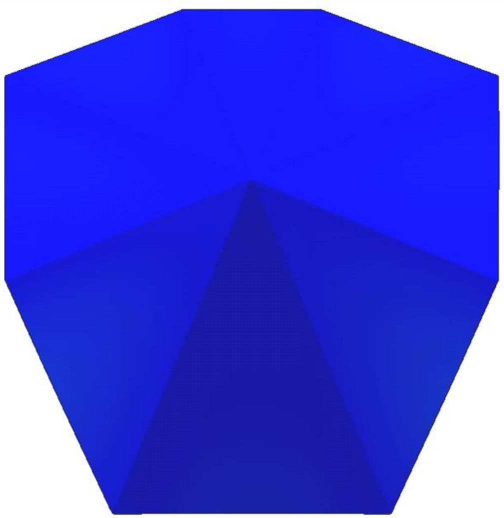


SW - Think before we start



Non-linear: Results





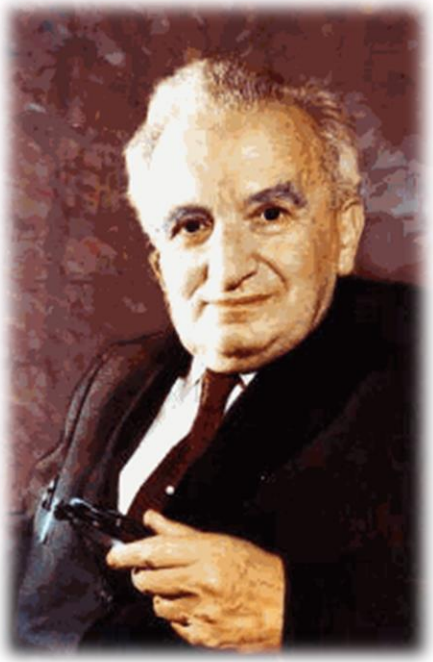
Real Test

Theodore von Karman

Scientists study the world as it is,

Engineers create the world that

never has been.



Theodore von Karman

National medal of science

At least we can

If you can't make it good, at least make it look good.

Bill Gates

Thank You!

Dr. Y. Song (Wolf)
Faculty of Industrial Design Engineering
Delft University of Technology