UNIVERZITET U ZENICI
Mašinski fakultet

katedra za Automatizaciju i Metrologiju

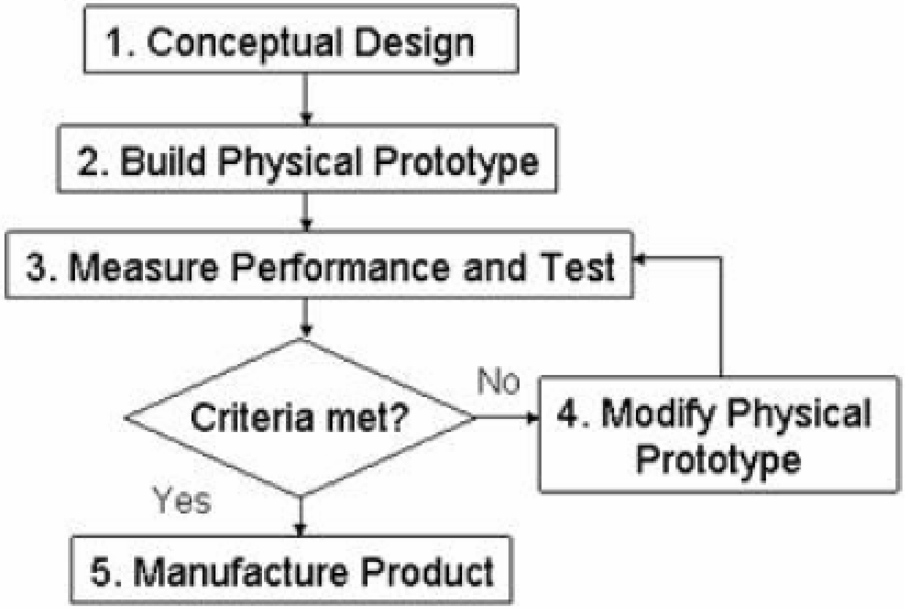
PART I:

Numerical methods in testing product characteristics (Virtual prototyping)

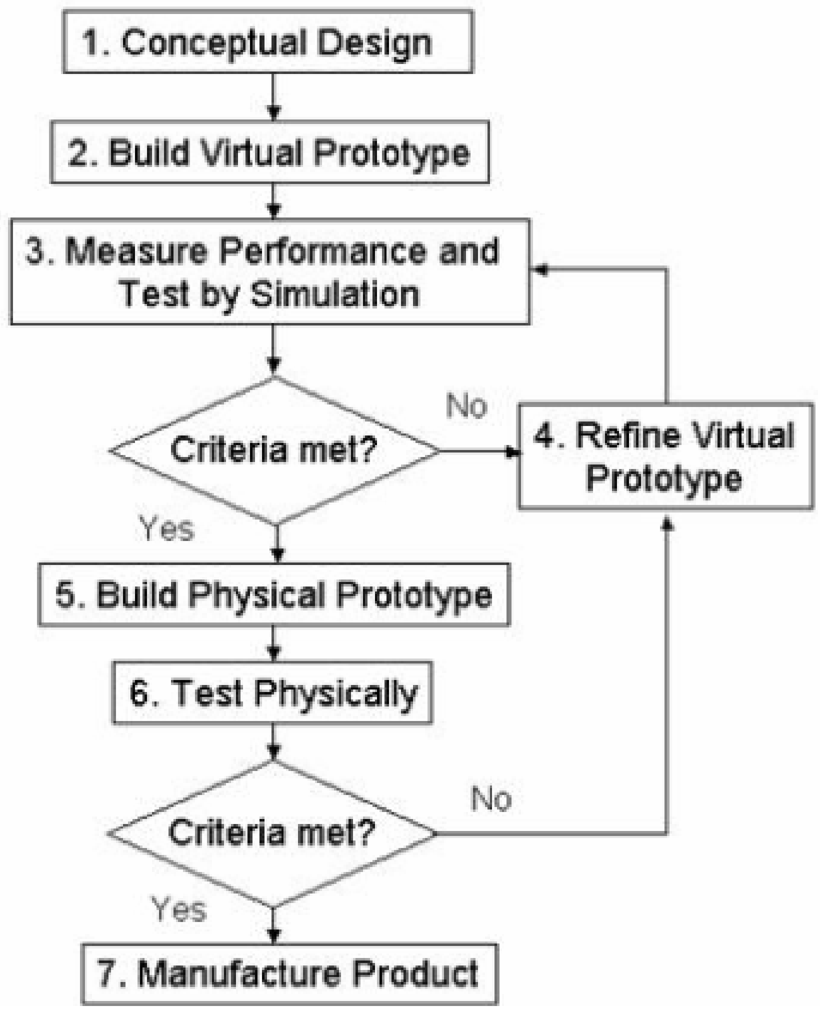
Aleksandar Karač
MFZE, room 1111
Tel: 449 120, ext. 140
Email: akarac@mf.unze.ba

TESTING PRODUCT CHARACTERISTICS

Traditional approach in product development



Virtual Prototyping (VP) approach in product development



Virtual prototyping

- simulation-based-design
- iterative design refinement of a designed product using a computer-based functional physical simulation (CAD/CAE)
- CAD – Computer Aided Design
- CAE – Computer Aided Engineering
- CAM – Computer Aided Manufacturing

VP - benefits

- Decreasing slow and expensive hardware’s cycles produce-test-modify
- Increasing quality
- Vast application usage: automotive, aero, metal, electro industry, …
- Treating the system as a whole
- Covering wider area of analyses: ergonomics, noise, safety tolerances, …
- Decreases number of actual prototypes for the same functionality

BUT ….

- Cannot overcome the need for a physical model (prototype)
- Give the best results with physical prototype

CAD – computer aided design

- 2D drafting
- 3D modelling – contemporary approach
- Global team work
- Geometrical modelling: primitives, Boolean operations, lines, arcs, …
- Parametric modelling
- Feature-based parametric modelling
- Interactive freeform surfacing
- Reversed engineering (3D scanning of physical models)
- Digital sketching
- Applications for 3D model formations from sketch

CAD – computer aided design

- 3D to 2D views
- 3D components can be easily assembled into complex virtual models
- The major benefit: reusability
- Different CAD formats
- Model calculations (mass, centre of gravity, moment of inertia)
- Visualisation (rendering, semi-transparency, perspectives, hidden lines, …)
- Programming codes for model control and establishing relations between parts

CAE – computer aided engineering

- Simulations based on numerical methods (DM, FEM, FVM, BEM, MM, PM, MoC, …)

- Stress and strain analysis
- Computational fluid dynamics (CFD)
- Kinematics analysis
- Analysis and sintesis of mechanisms
- Production process simulations (casting, forging, …)
- Tolerance analysis

CAE – computer aided engineering

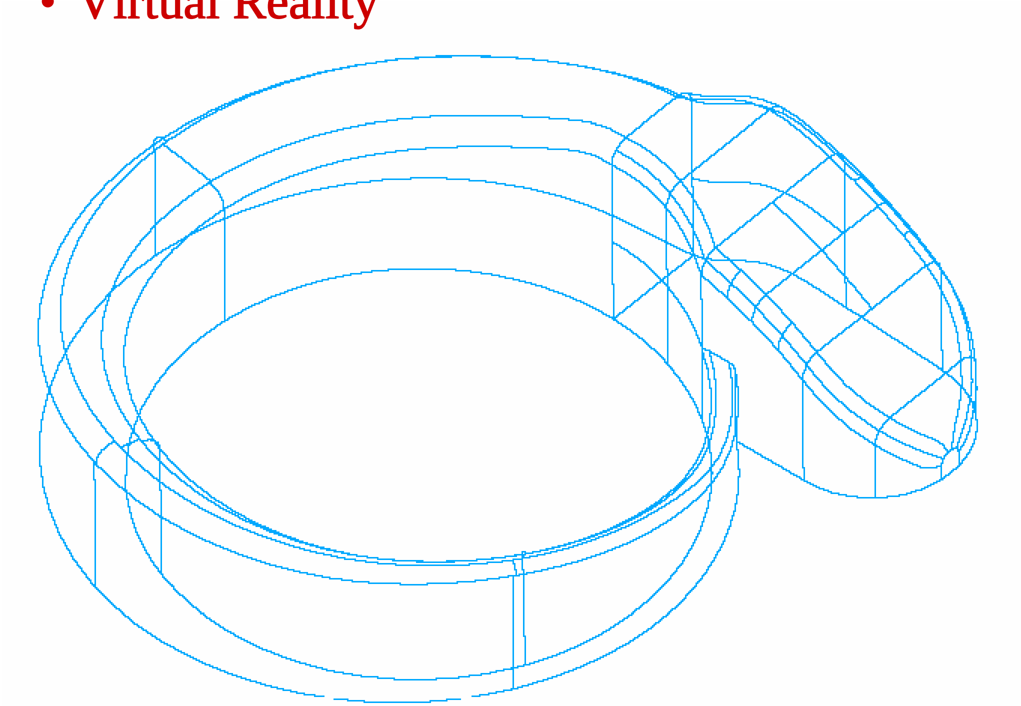
- Product or process optimisation
- Variable parameters
- Calculations for different parametric variants
- Optimal solution from iterative process, and model correction

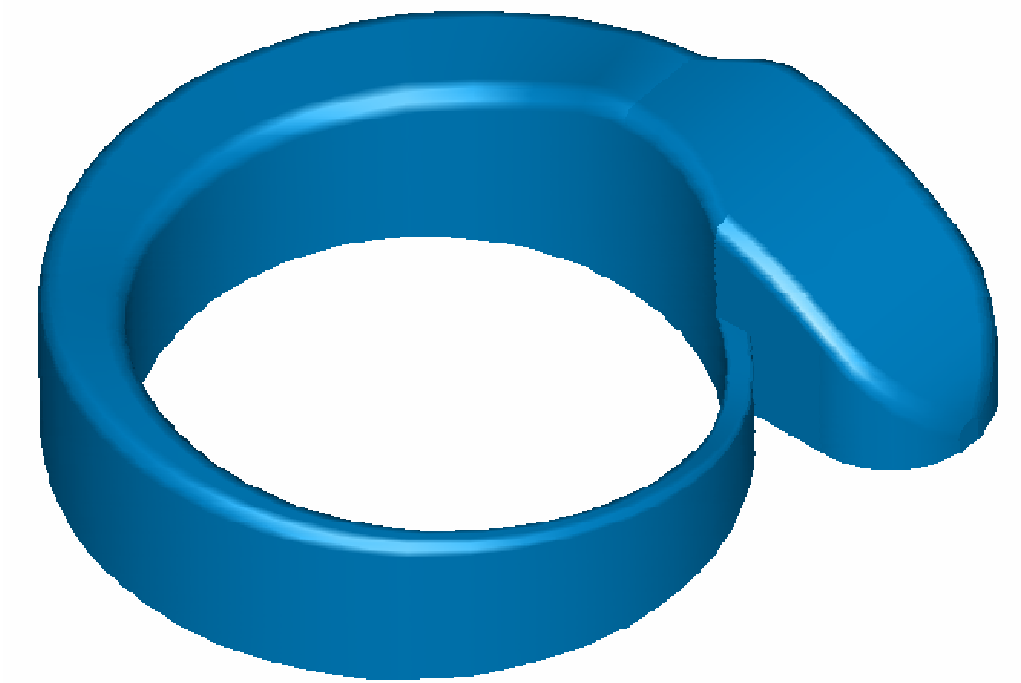
CAM – computer aided manufacturing

- CAD model is used for (semi-)automatic generation of CNC program for machining centres
- Metal, wood industry, rapid prototyping, art, …

Visualisation

- VP visualisation
- 3D model manipulation
- Virtual Reality

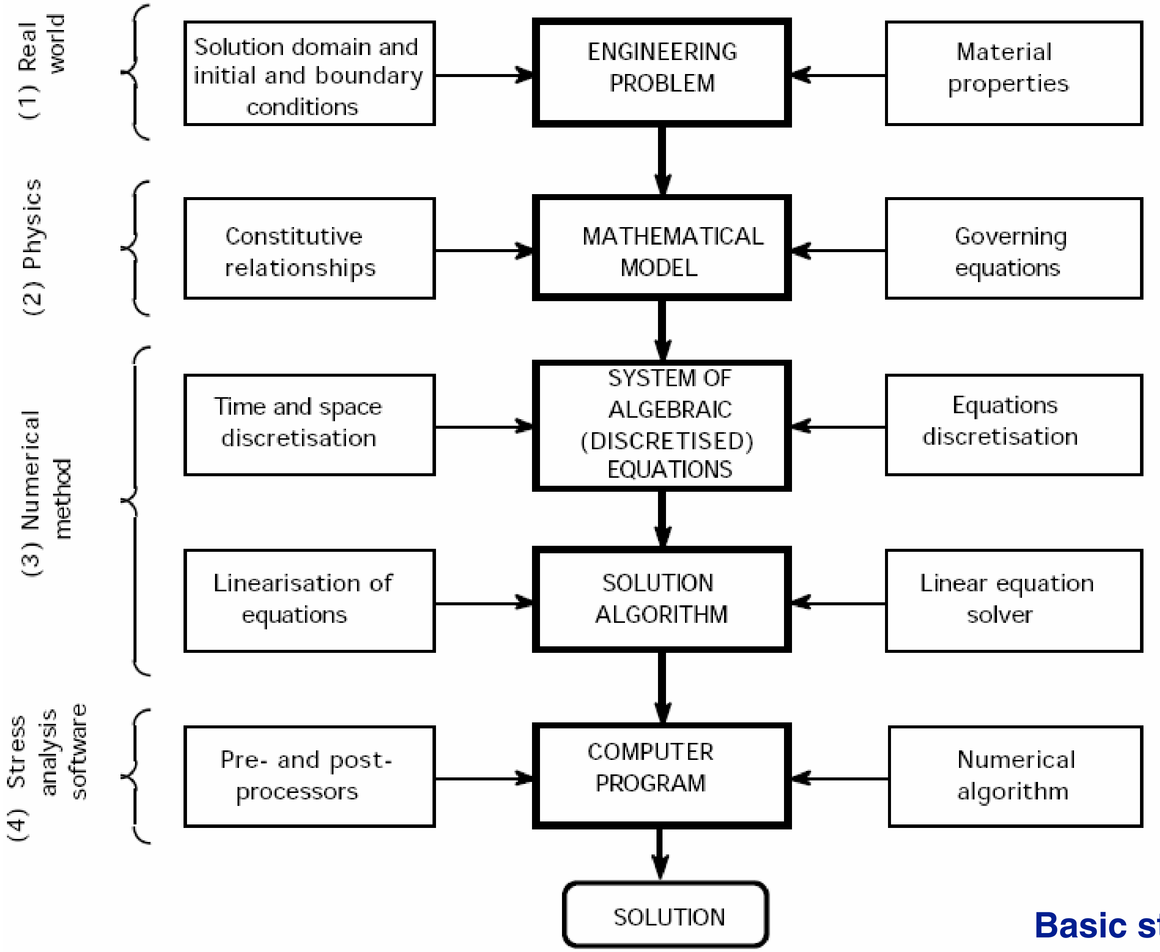




- Balić S., Numerička analiza procesa strujanja i naponskog stanja centrifugalnih pumpi u sistemima za hlađenje automobilskih motora, PhD, 2002

CAE – computer aided engineering

- Simulations based on numerical methods (DM, FEM, FVM, BEM, MM, PM, MoC, …)



Basic steps of numerical simulation of an engineering problem

CAE – computer aided engineering

- **Concept of continuum**
- **Continuity, homogeneity and isotropy**
- **Fundamental laws of continuum mechanics and other concepts**

1. Mass conservation
2. Reynold's theorem
3. Conservation of linear momentum (1st Euler's law, 2nd Newton's law)
4. Conservation of angular momentum
5. Energy conservation law (1st law of thermodynamics)
6. Law of entropy production (2nd law of thermodynamics)
7. Equations for large deformations, …

- **Constitutive relationships and equation of state**

1. Hooke's law of elasticity,
2. Pascal's law of hydrostatic pressure,
3. Newton's law of viscosity,
4. Fourier's law of heat conduction.

CAE – computer aided engineering

- **Mathematical model**

$$\frac{\partial}{\partial t}\int_V \rho B_\phi \mathrm{d}V + \int_S \rho B_\phi \mathbf{v}\cdot\mathbf{n}\mathrm{d}S = \int_S \Gamma_\phi \operatorname{grad}\phi\cdot\mathbf{n}\mathrm{d}S + \int_S \mathbf{q}_{\phi S}\cdot\mathbf{n}\mathrm{d}S + \int_V \mathbf{q}_{\phi V}\mathrm{d}V,$$

ϕ- transported property (displacement u, velocity v or temperature *T*) B_ϕ and G_ϕ are given in Table

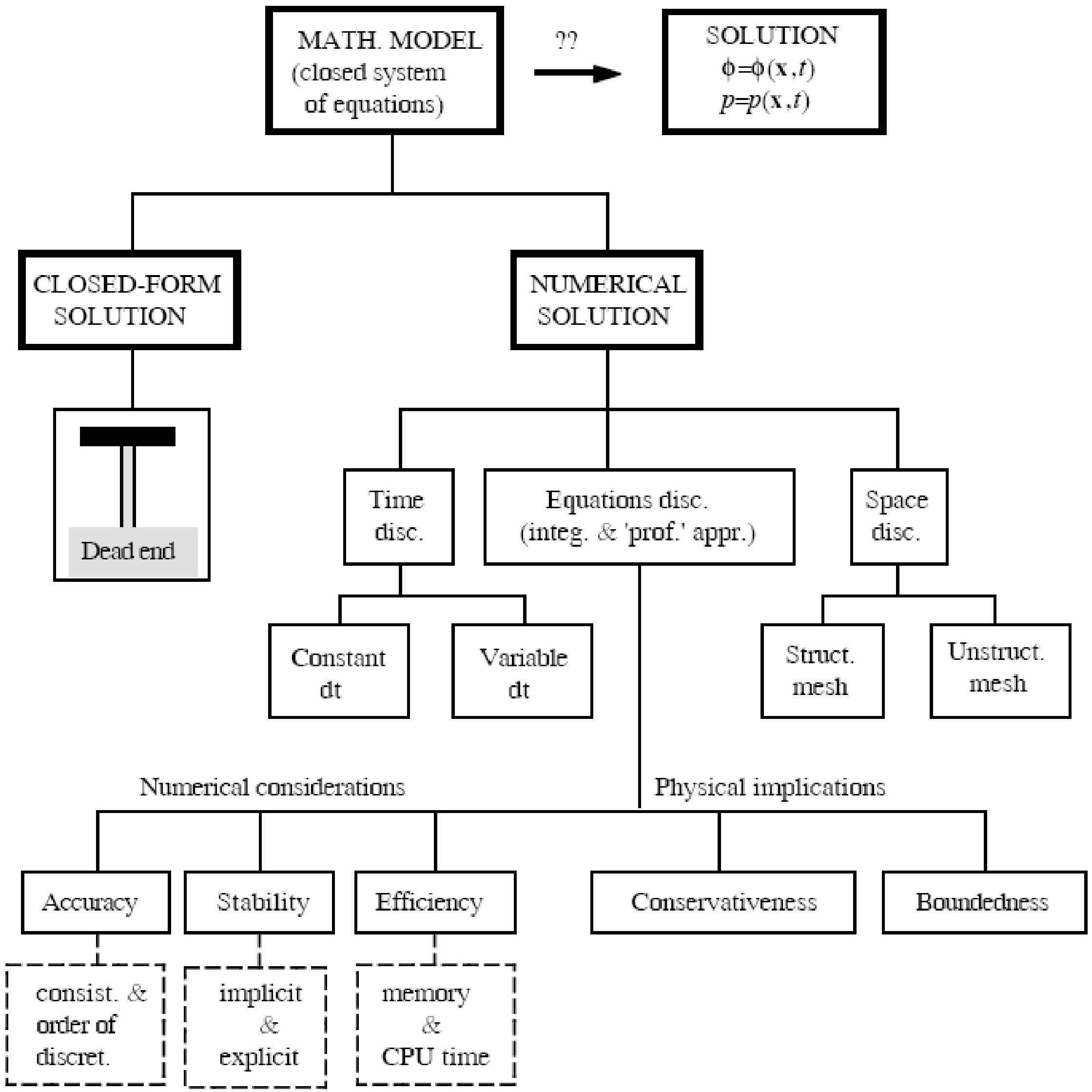
$q_{\phi S}$ contains parts of the mass or heat flux vector or the stress tensor, which are not included in $\Gamma_\phi \operatorname{grad}\phi$

$q_{\phi S}$ contains the volumetric source terms.

ϕ	B_ϕ	Γ_ϕ	$q_{\phi V}$	$\mathbf{q}_{\phi S}$
T	cT	k	$\sigma : \operatorname{grad}\mathbf{v} + h$	0
$\mathbf{u}$	$\frac{\partial \mathbf{u}}{\partial t}$	μ	$\rho \mathbf{f}_b$	$\mu(\operatorname{grad}\mathbf{u})^T + \operatorname{grad}\left[\lambda \operatorname{div}\mathbf{u} - (3\lambda + 2\mu)\alpha(T - T_0)\right]\mathbf{I}$
$\mathbf{v}$	$\mathbf{v}$	μ	$\rho \mathbf{f}_b$	$-p\mathbf{I} + \mu(\operatorname{grad}\mathbf{v})^T$

CAE – computer aided engineering

- Finite Volume discretisation

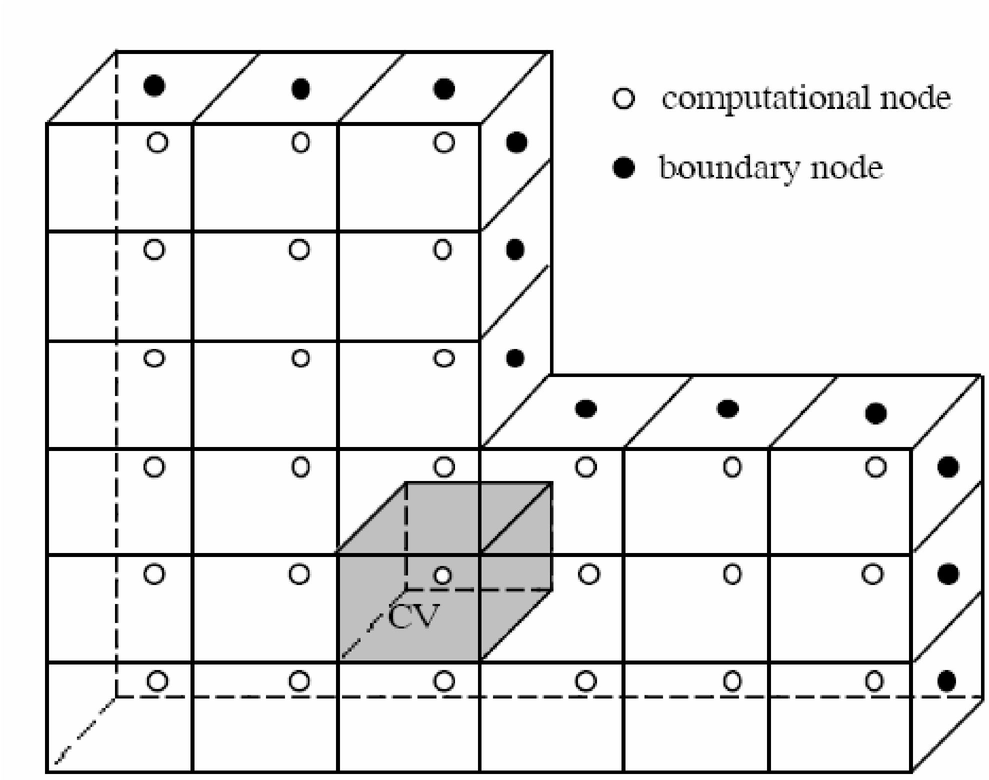


Main concepts and ideas of numerical analysis

CAE – computer aided engineering

- **Finite Volume discretisation**

Time and space discretisation



CAE – computer aided engineering

- **Finite Volume discretisation**

Equation discretisation

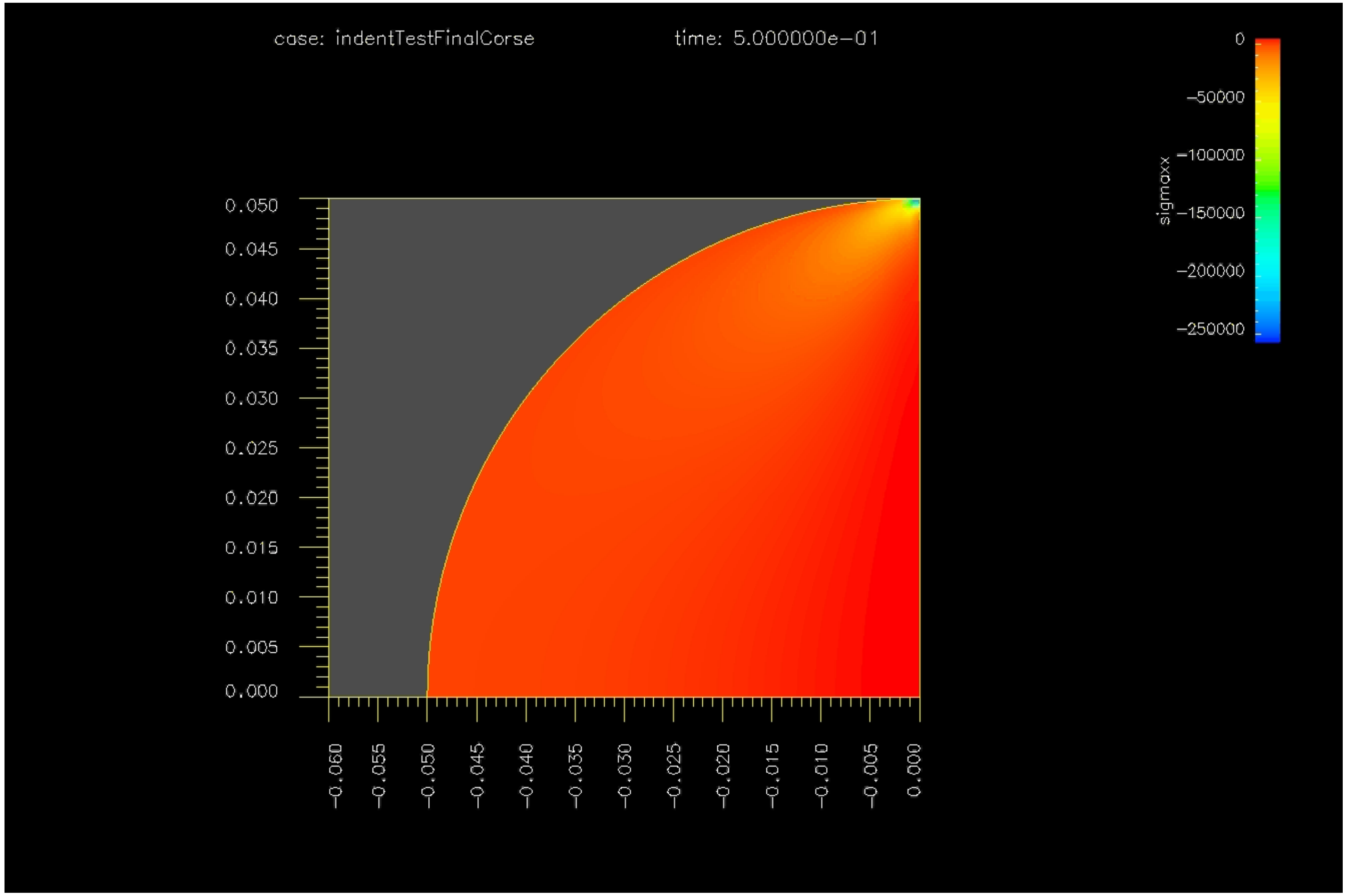
$$\frac{\partial}{\partial t}\int_V \rho B_\phi \, dV + \int_S \rho B_\phi \mathbf{v}\cdot\mathbf{n}\, dS = \int_S \Gamma_\phi \operatorname{grad}\phi \cdot \mathbf{n}\, dS + \int_S \mathbf{q}_{\phi S}\cdot\mathbf{n}\, dS + \int_V q_{\phi V}\, dV,$$

$$\Downarrow$$

$$\mathbf{A}_\phi \cdot \phi = \mathbf{b}_\phi$$

Initial and boundary conditions

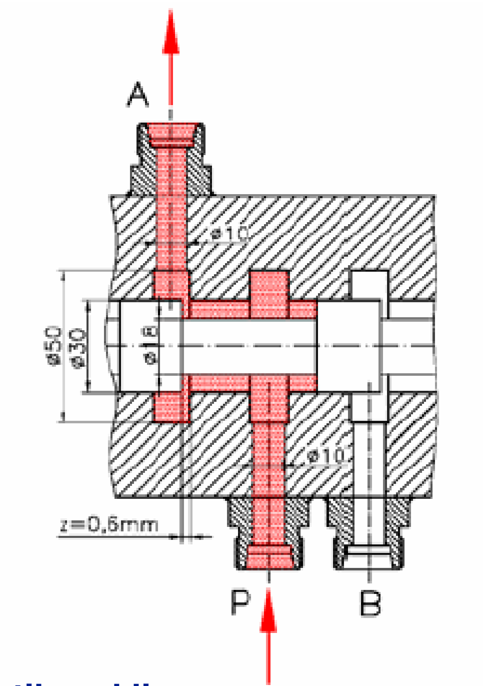
CAE – computer aided engineering



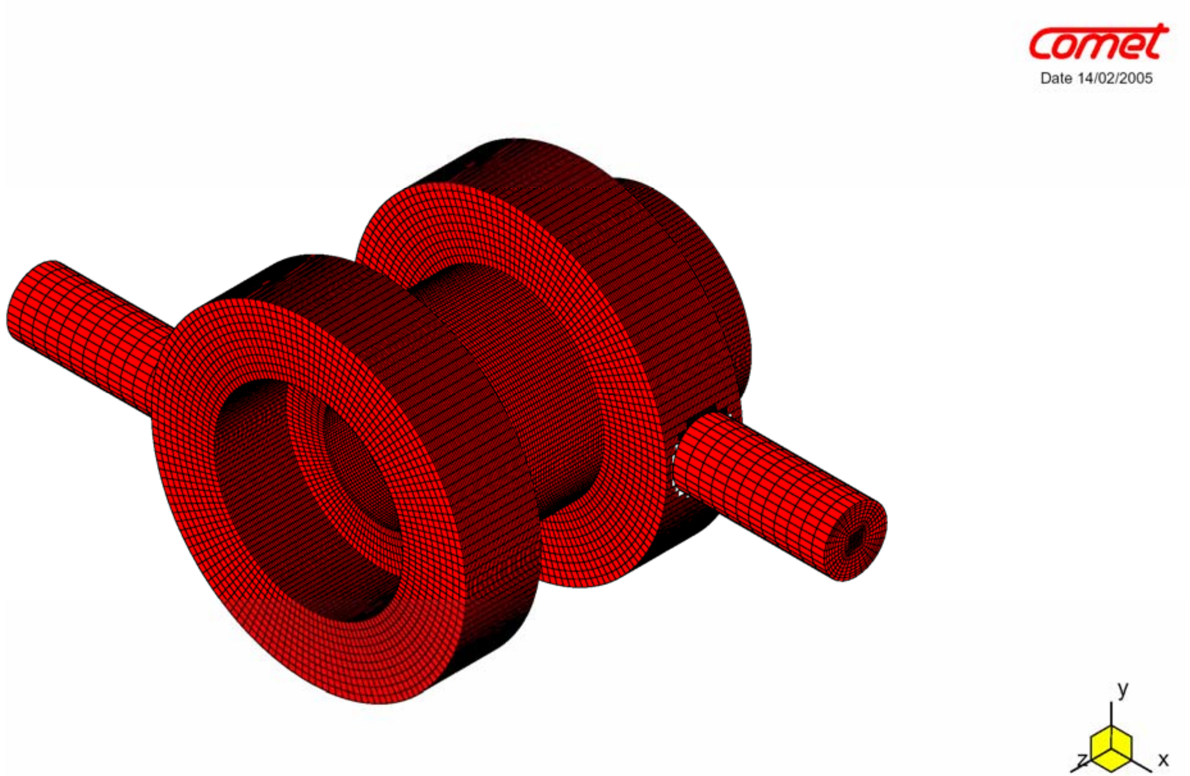
ITT test – asphalt, UCD, 2007

CAE - examples of application

Fluid flow through hydrulic components*



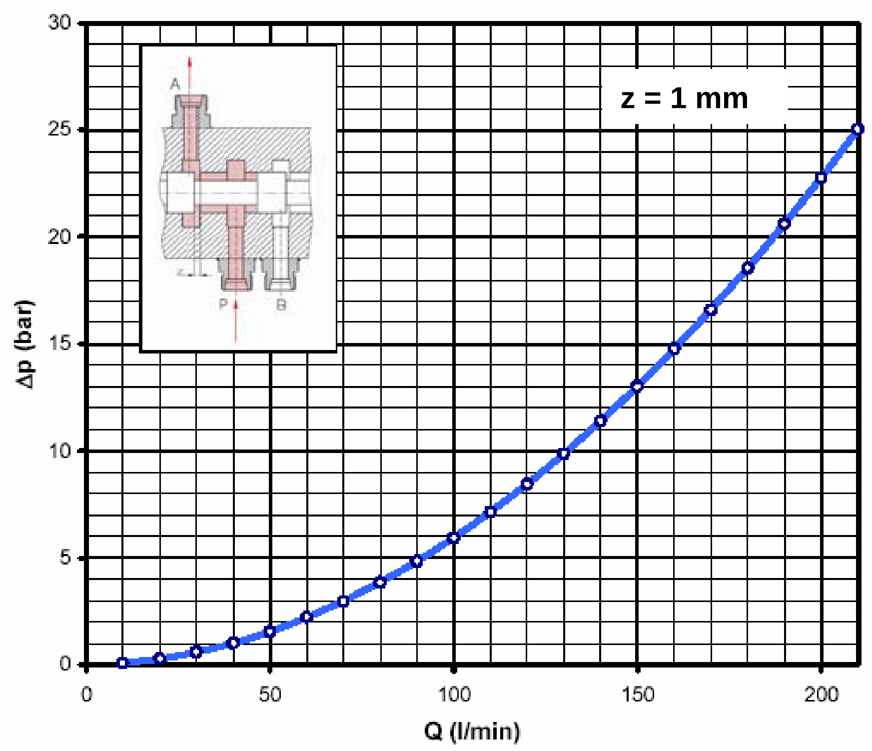
razvodni ventil sa klipom

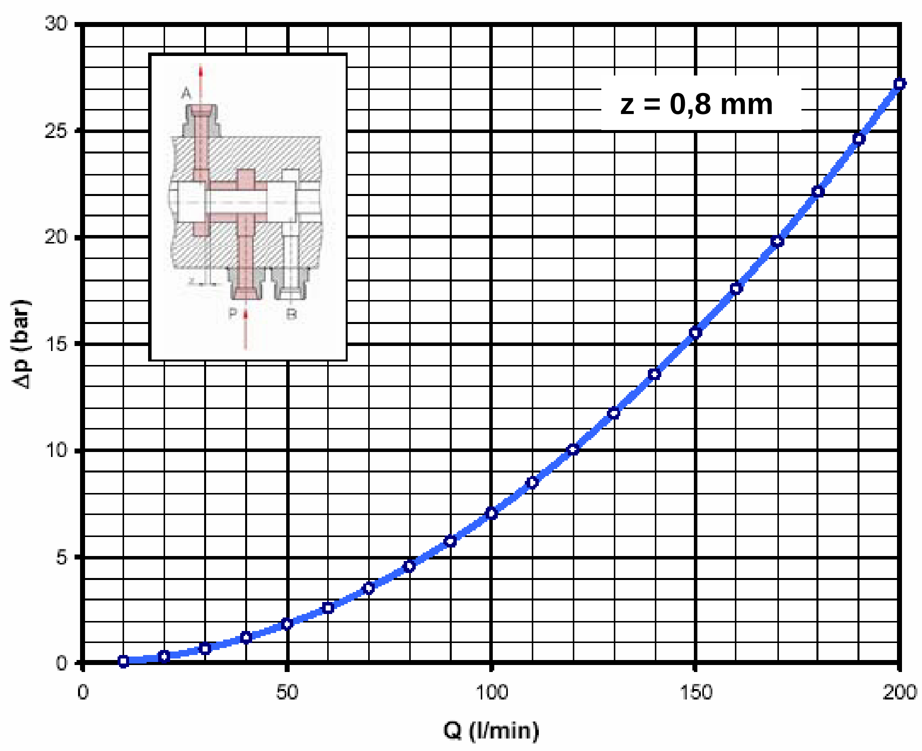


* Hodžić N., Numerička analiza strujanja ulja kroz razvodne elemente hidrauličnih sistema, PhD, 2005
http://www.unze.ba/doktorati/index.htm

CAE - examples of application

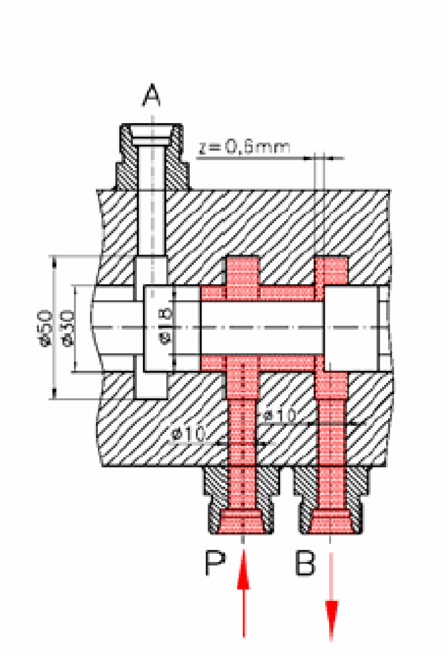
Fluid flow through hydrulic components

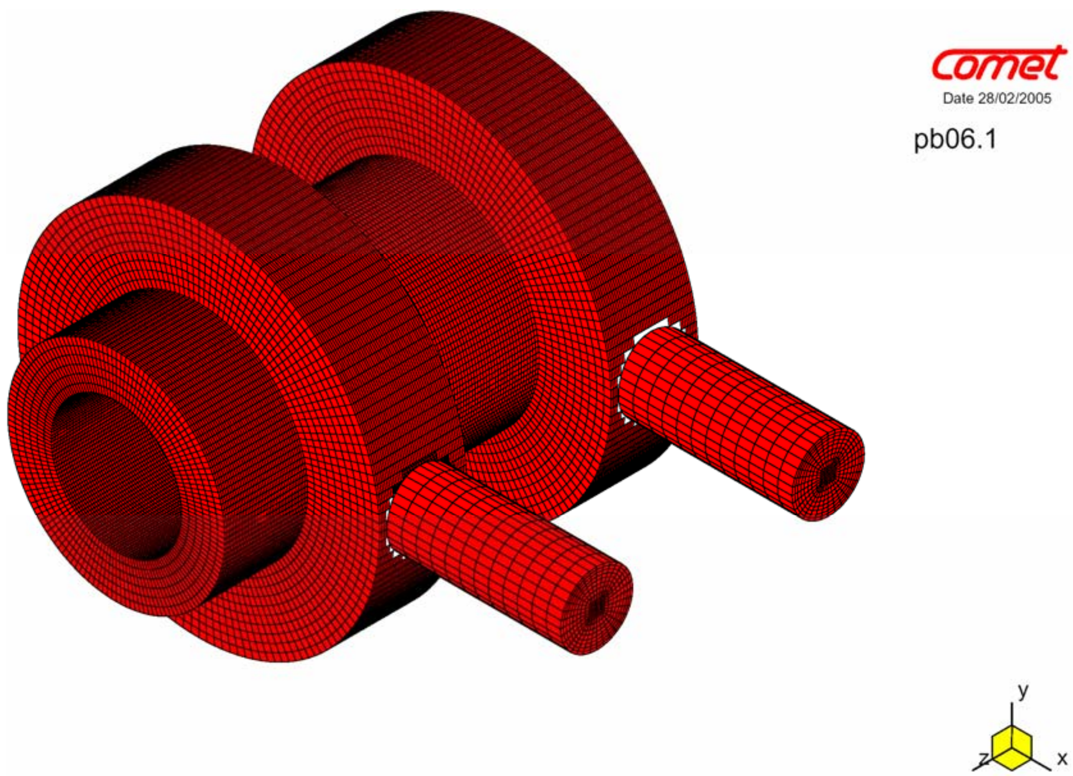




CAE - examples of application

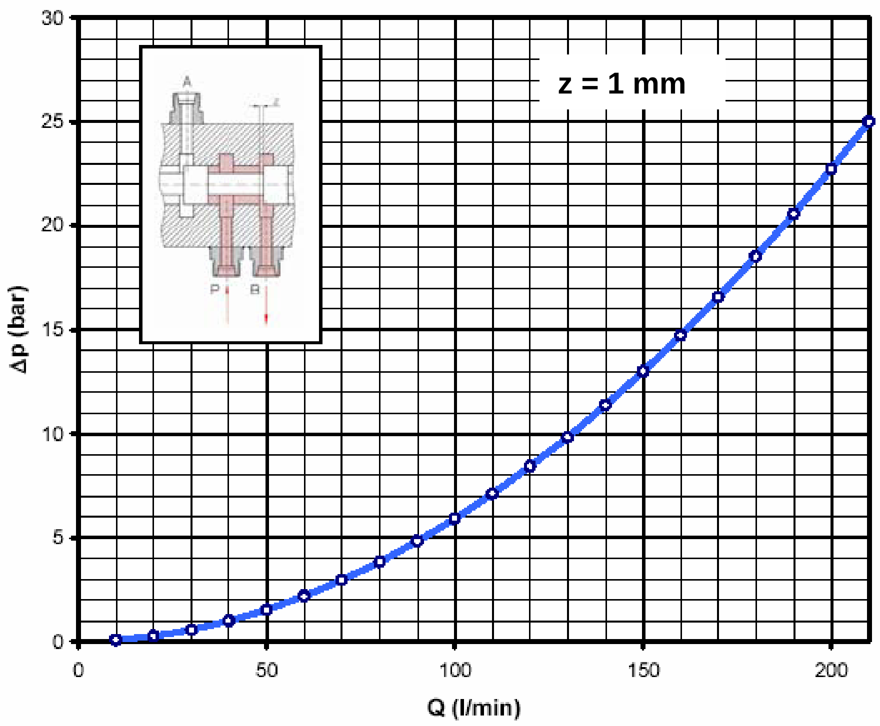
Fluid flow through hydrulic components

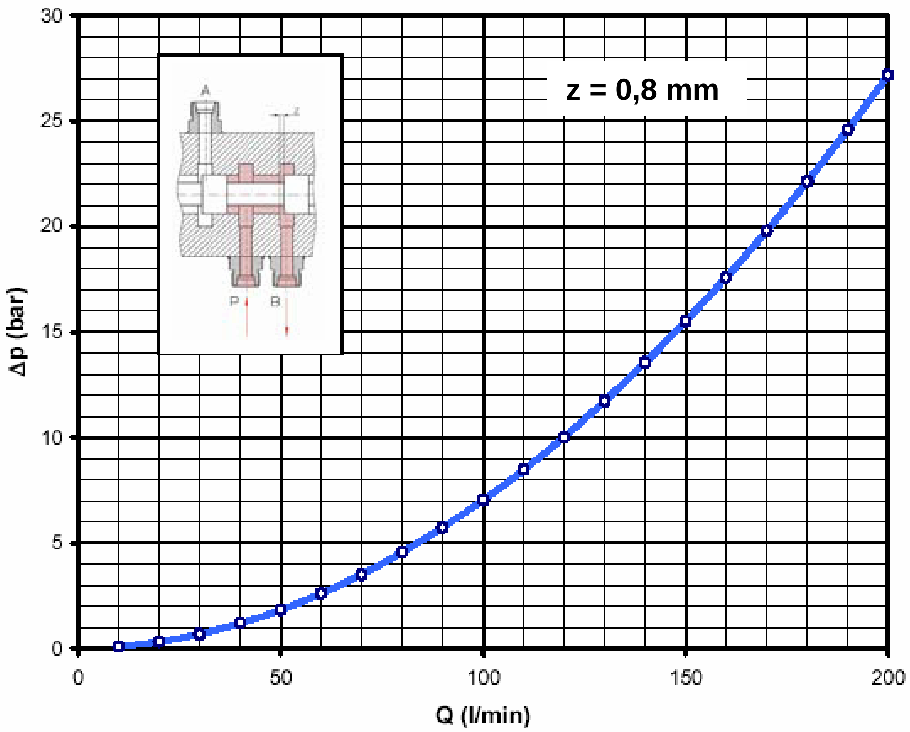




CAE - examples of application

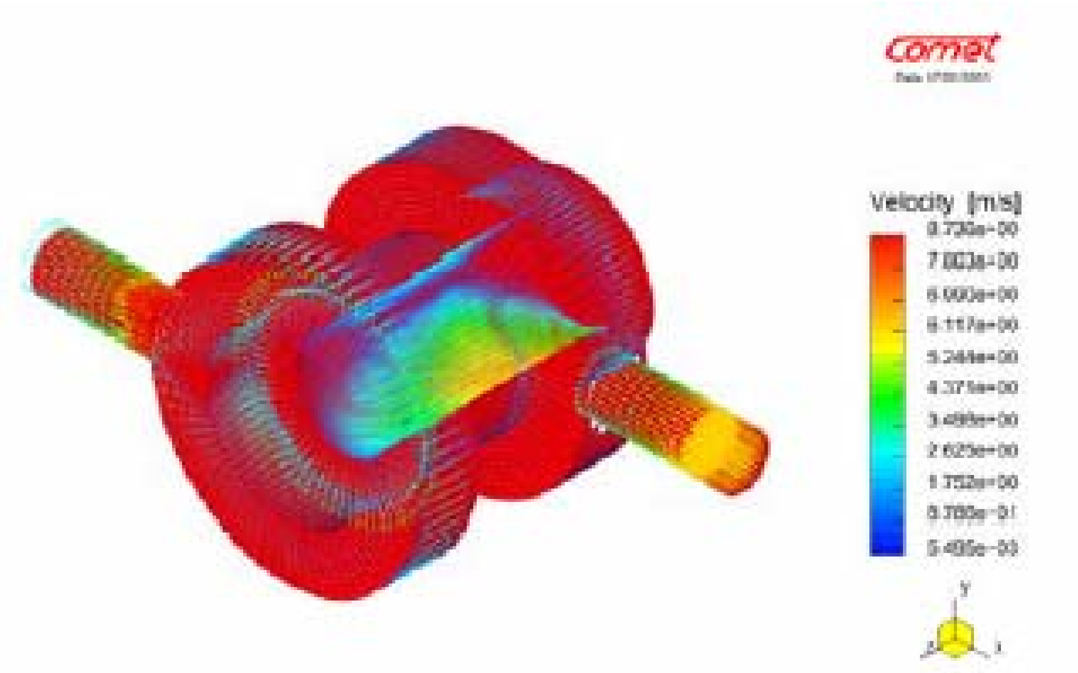
Fluid flow through hydrulic components

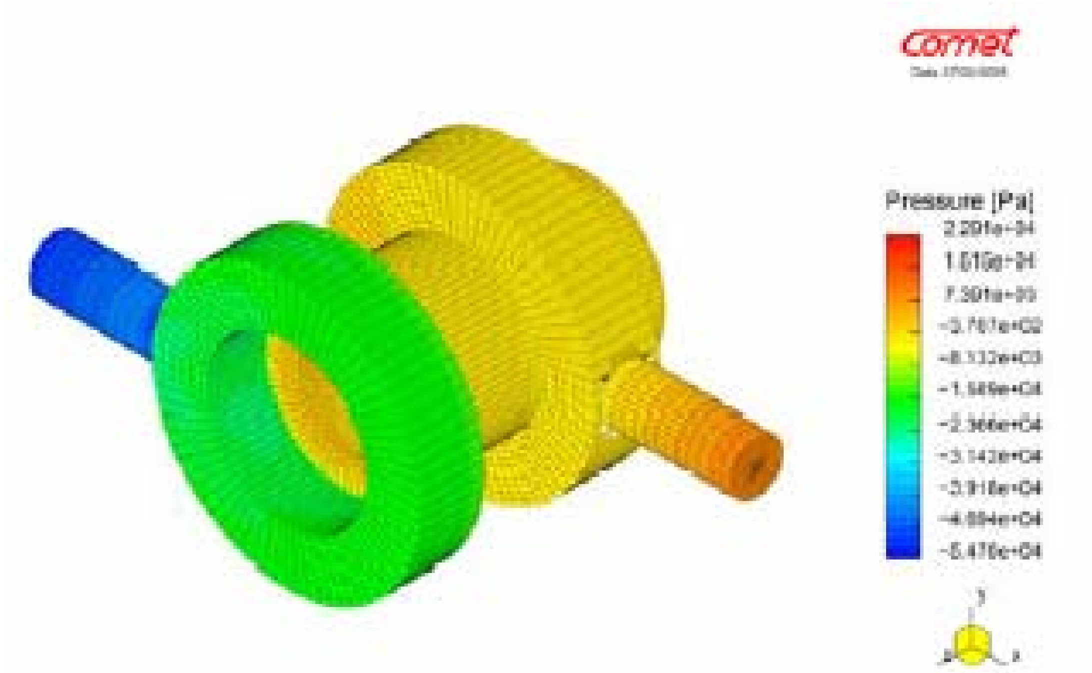




CAE - examples of application

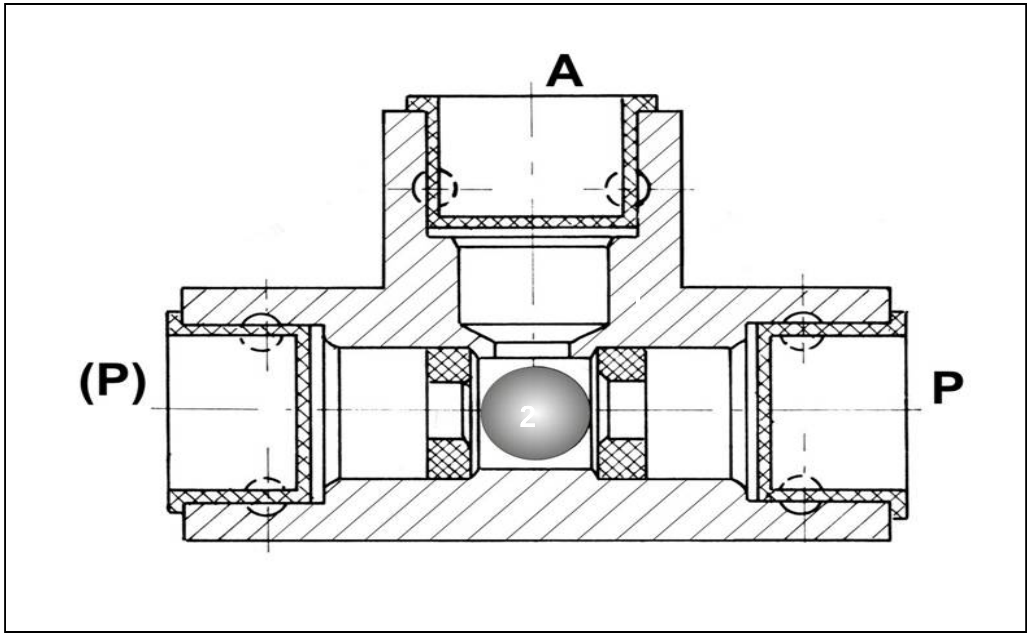
Fluid flow through hydrulic components



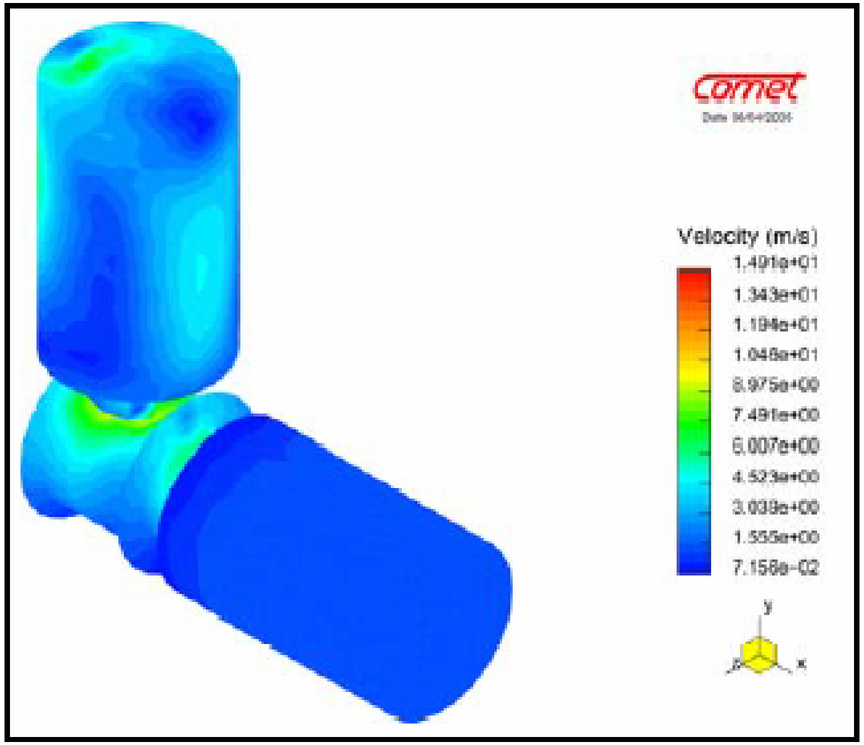


CAE - examples of application

Fluid flow through hydrulic components



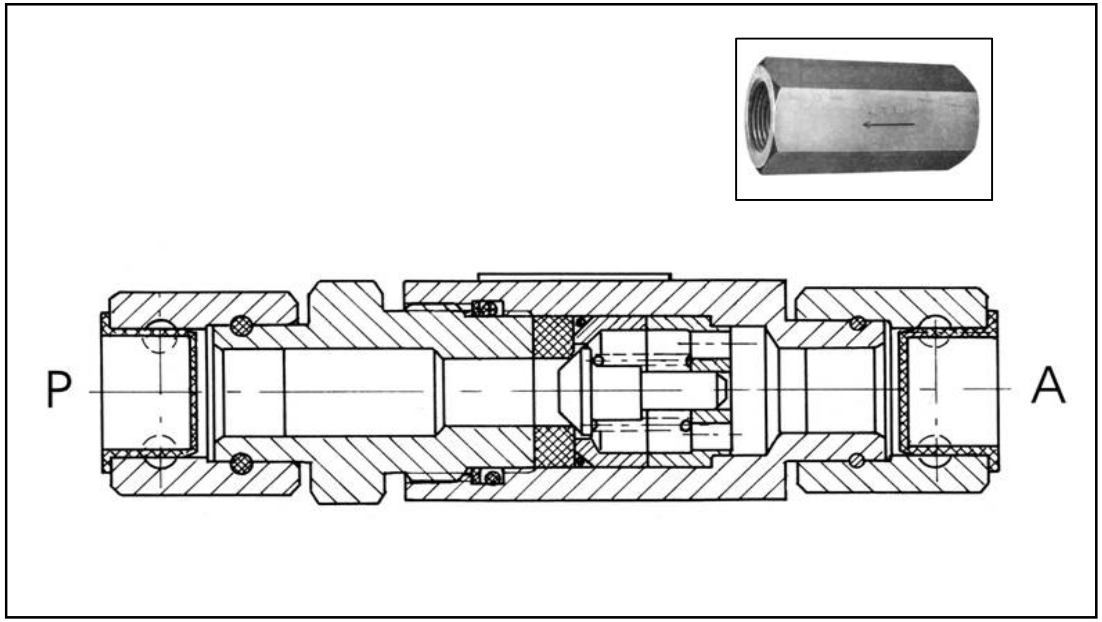
naizmjenično nepovratni ventil

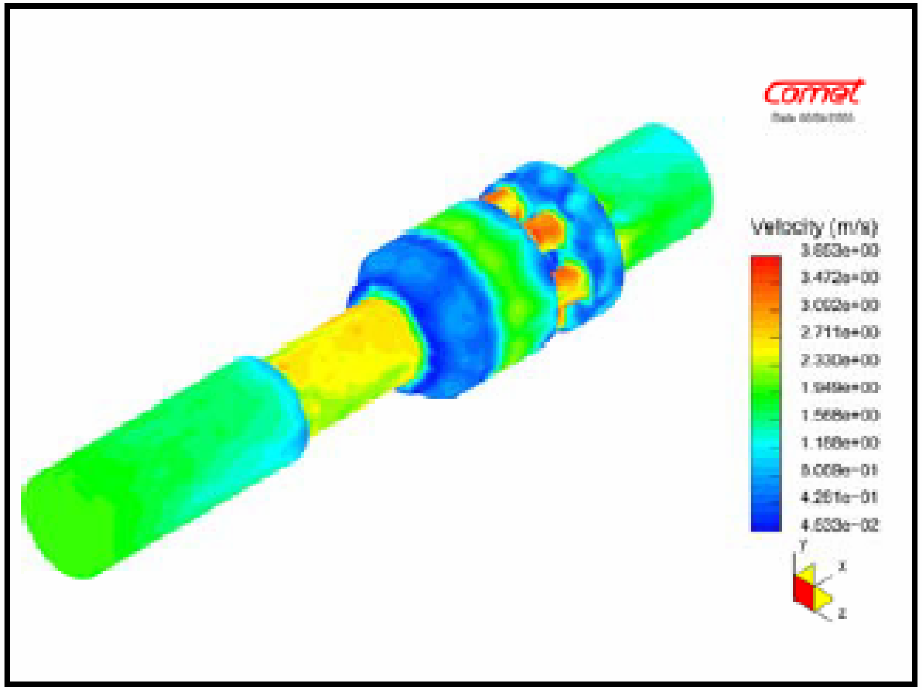


b) polje brzine

CAE - examples of application

Fluid flow through hydrulic components



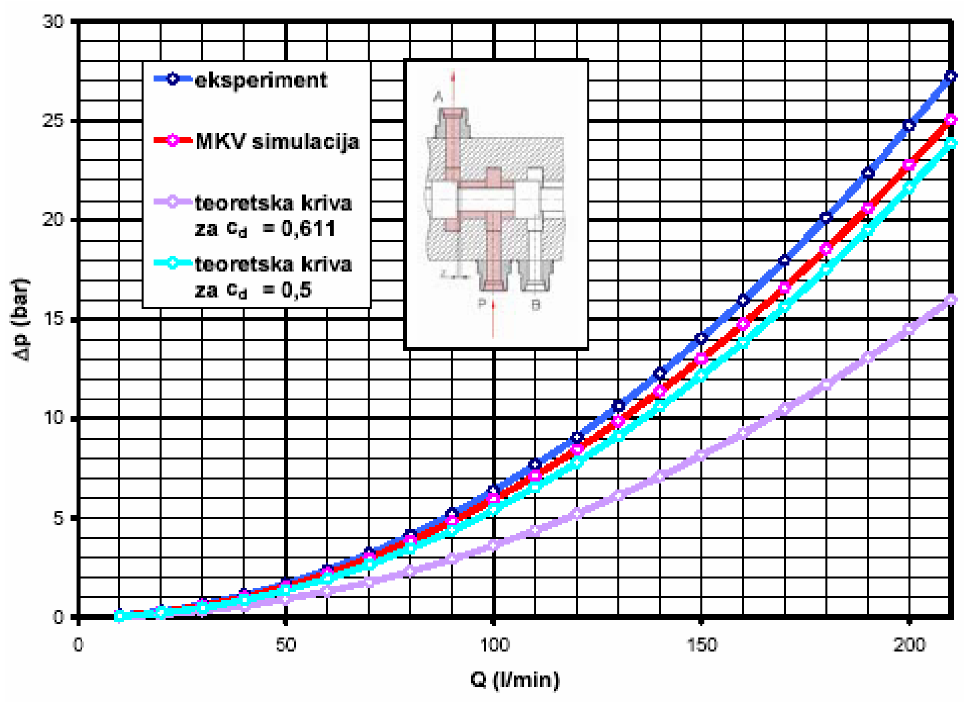


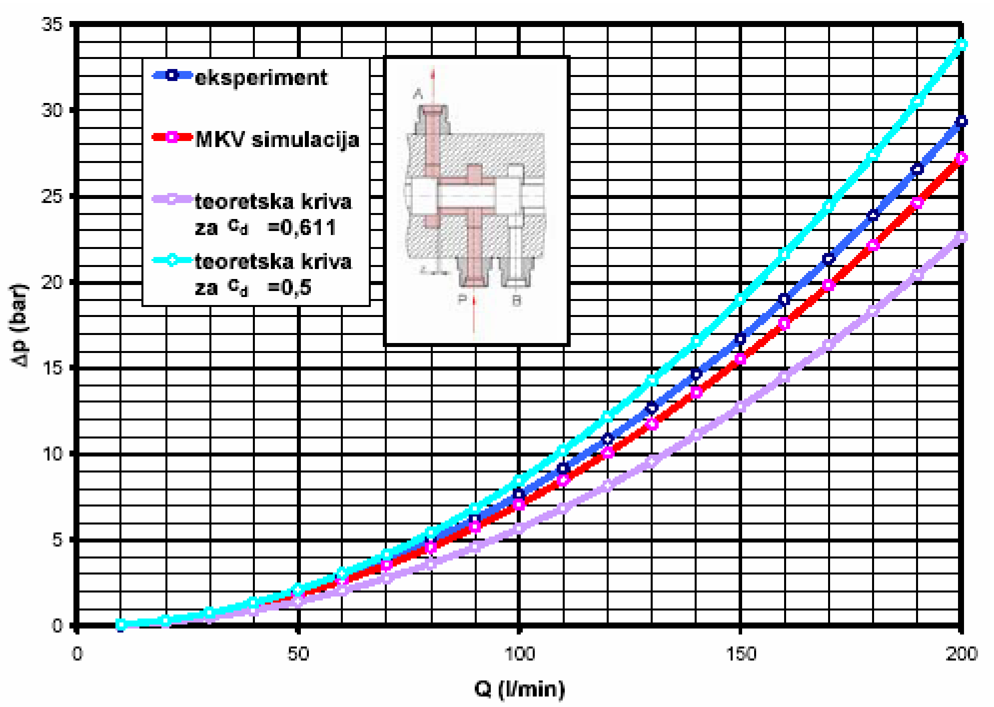
naizmjenično nepovratni ventil

b) polje brzine

CAE - examples of application

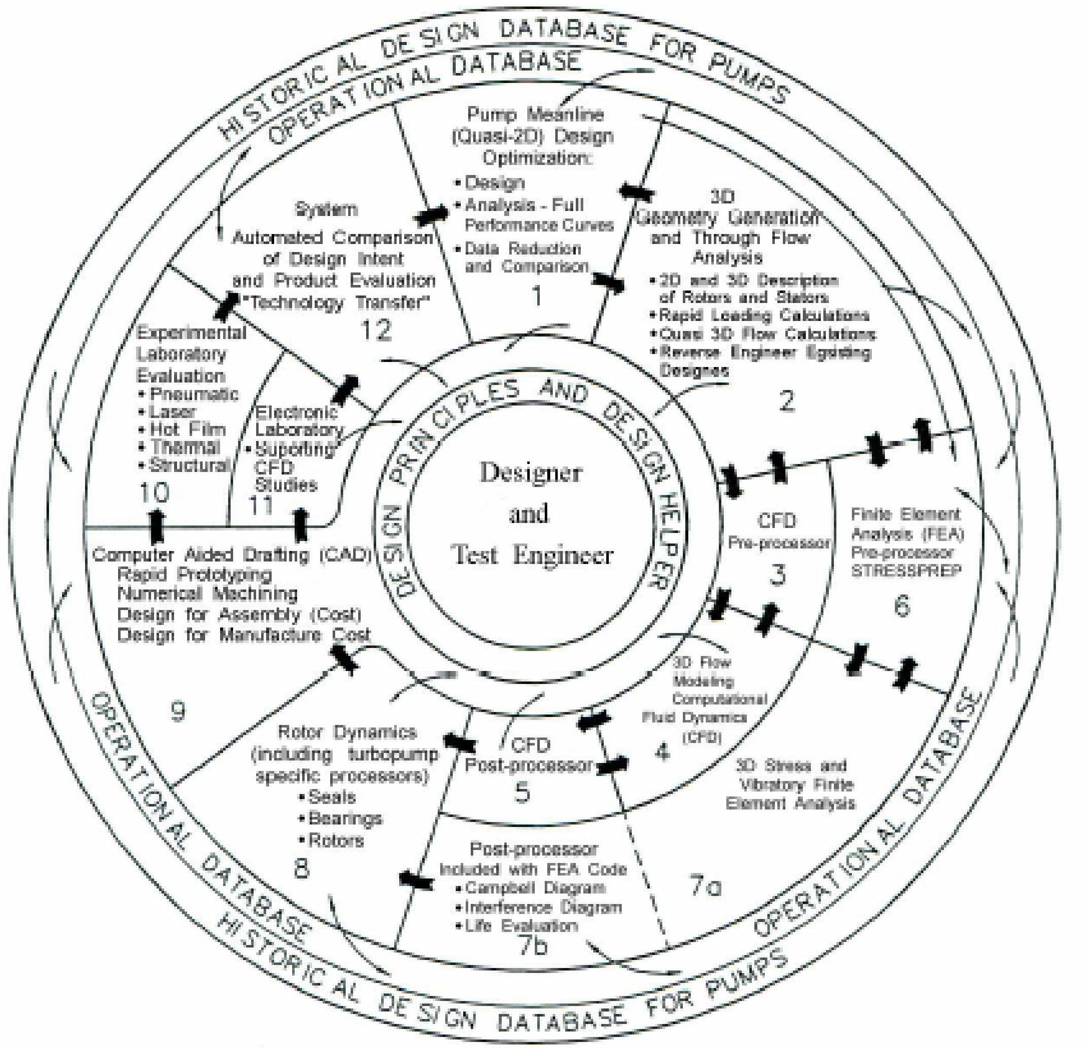
Fluid flow through hydrulic components





CAE - examples of application

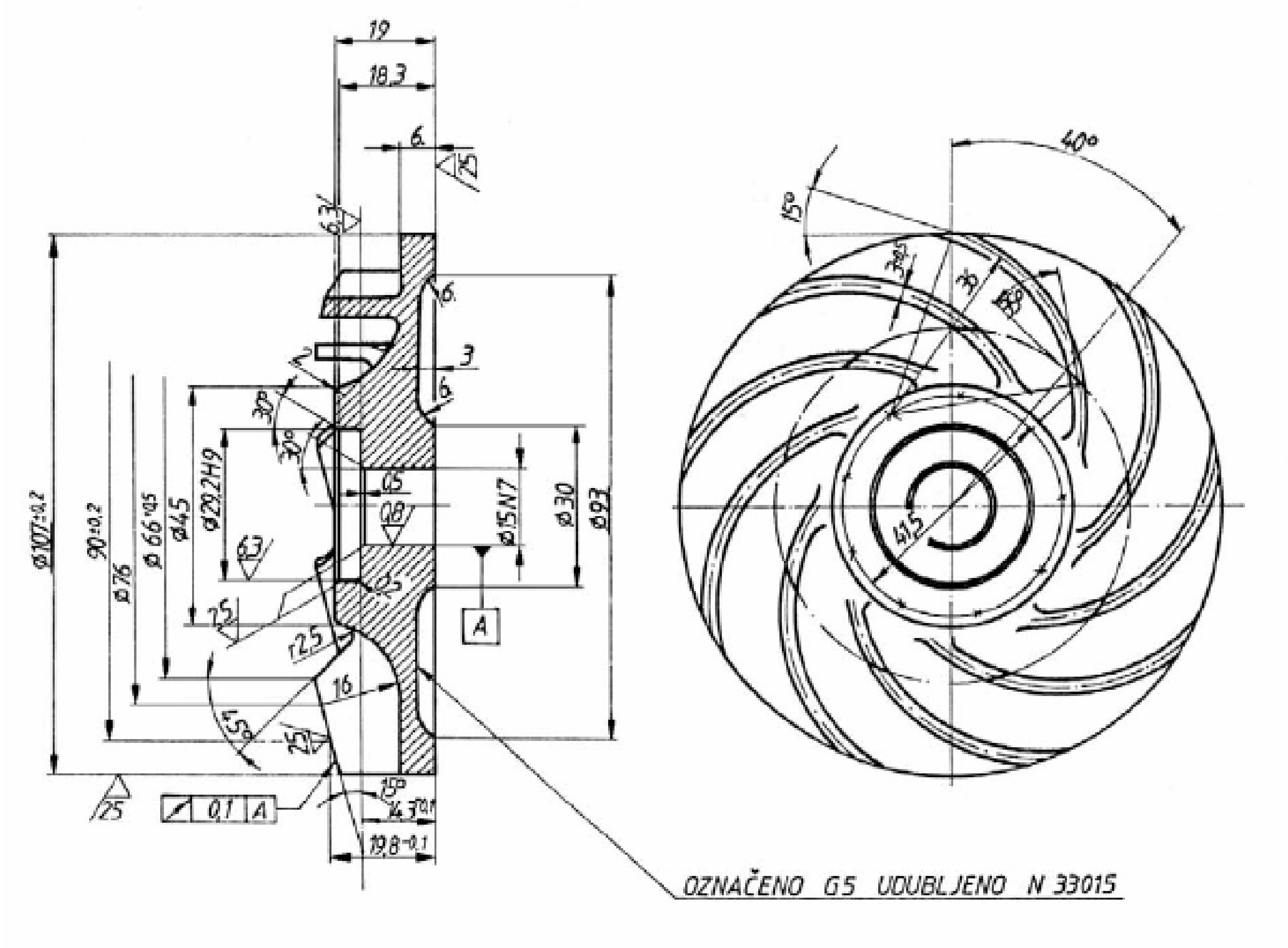
design optimisation of centrifugal pumps*



• Balić S., Numerička analiza procesa strujanja i naponskog stanja centrifugalnih pumpi u sistemima za hlađenje automobilskih motora, PhD, 2002

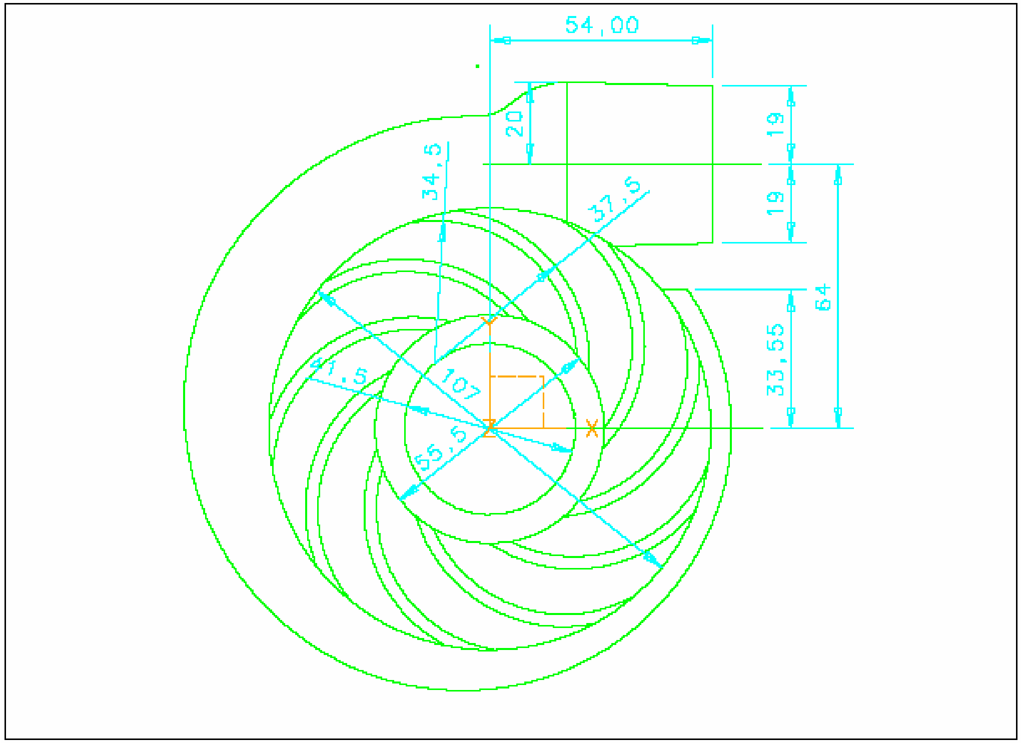
CAE - examples of application

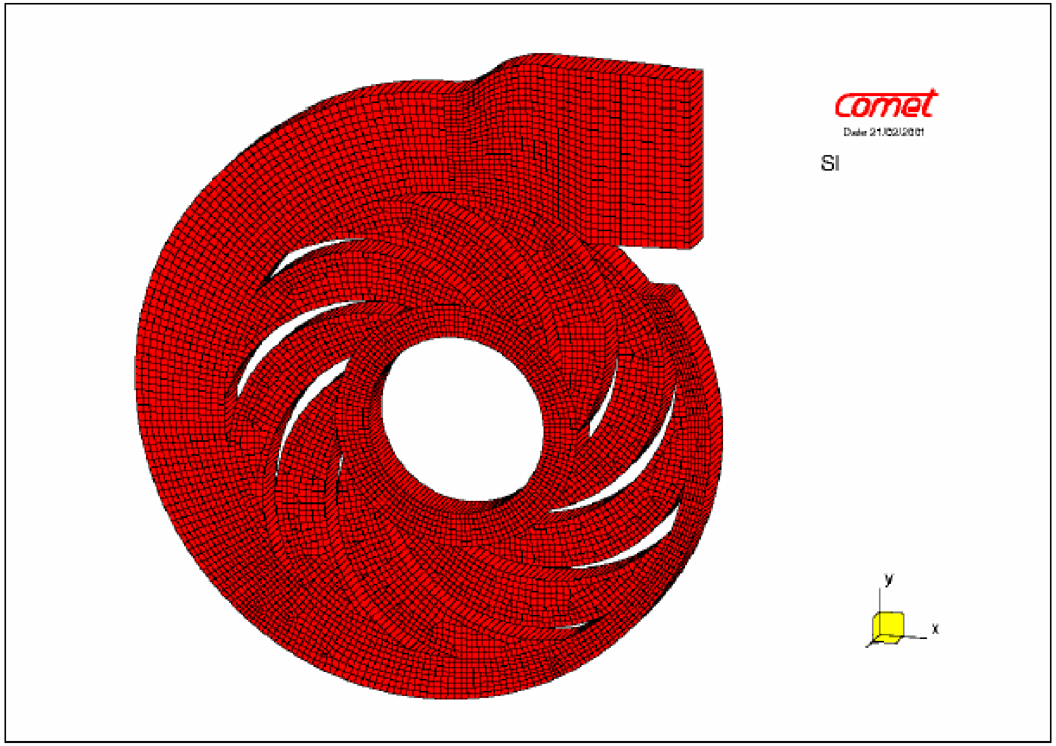
design optimisation of centrifugal pumps



CAE - examples of application

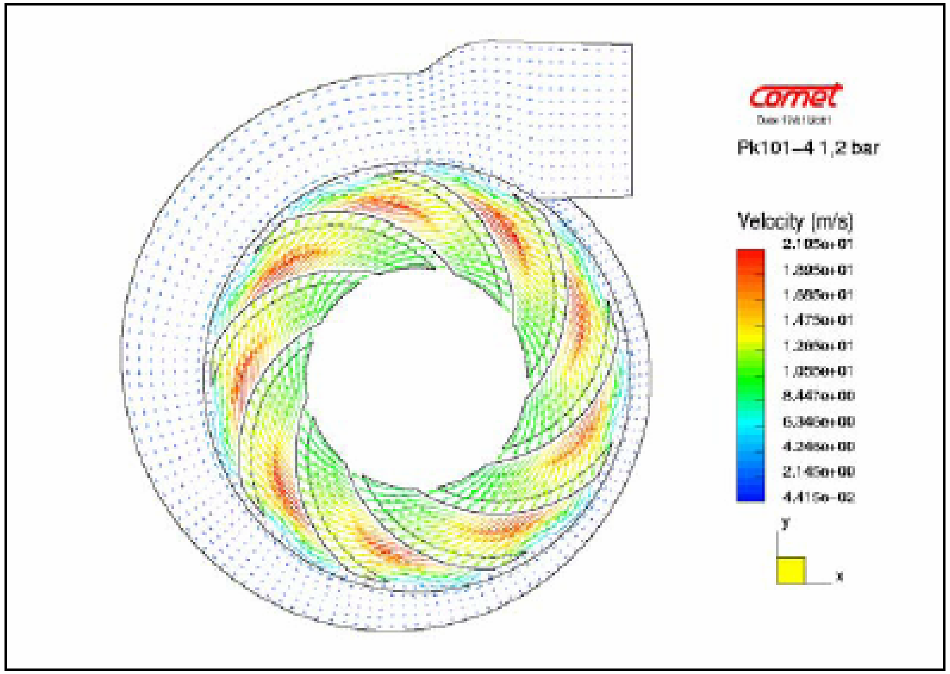
design optimisation of centrifugal pumps

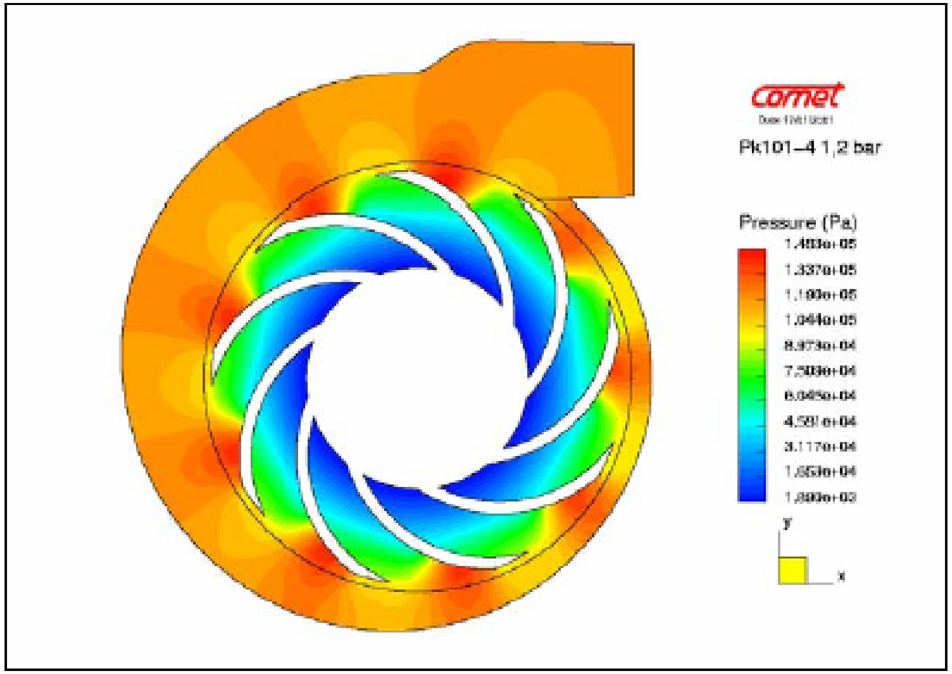




CAE - examples of application

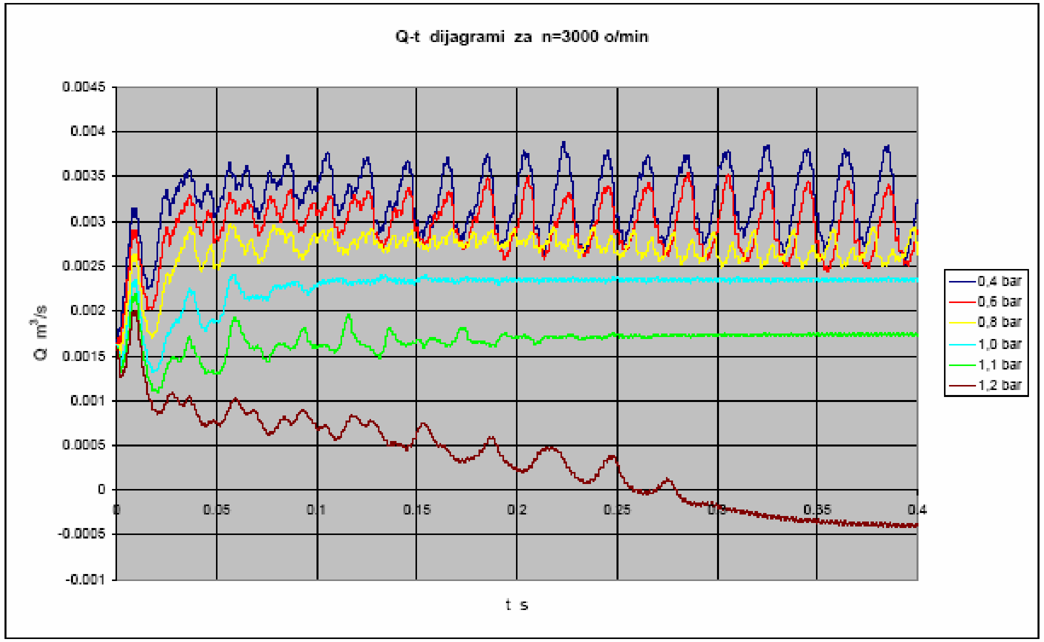
design optimisation of centrifugal pumps

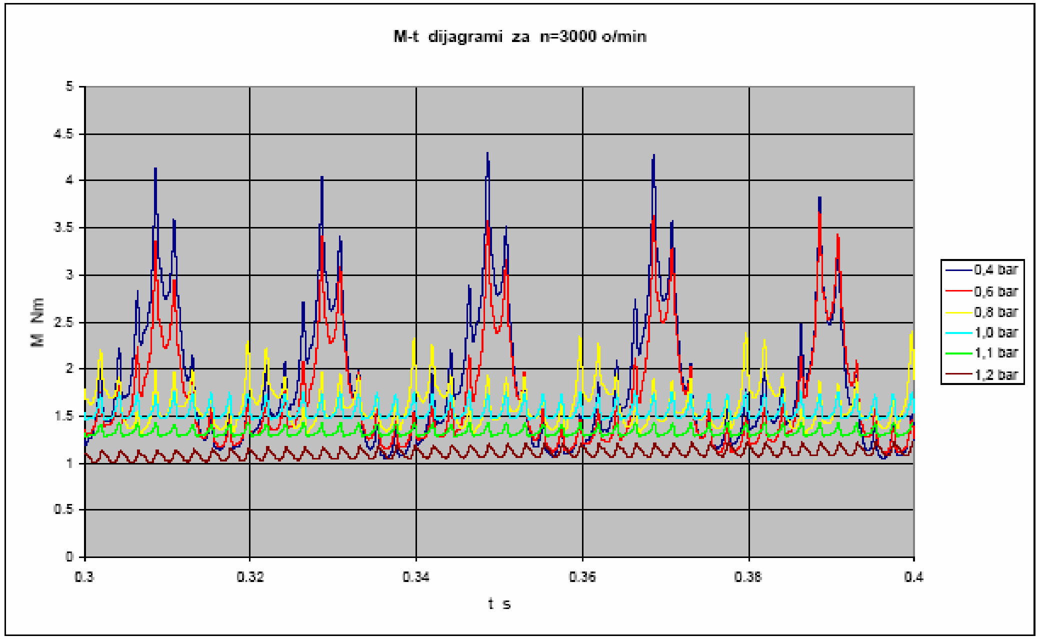




CAE - examples of application

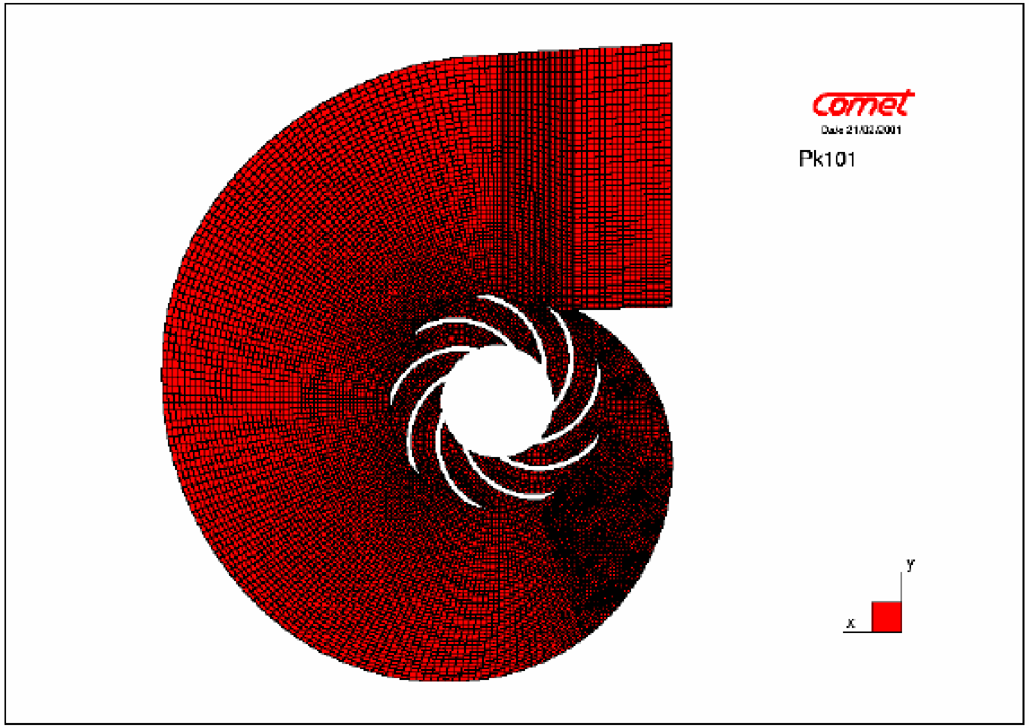
design optimisation of centrifugal pumps

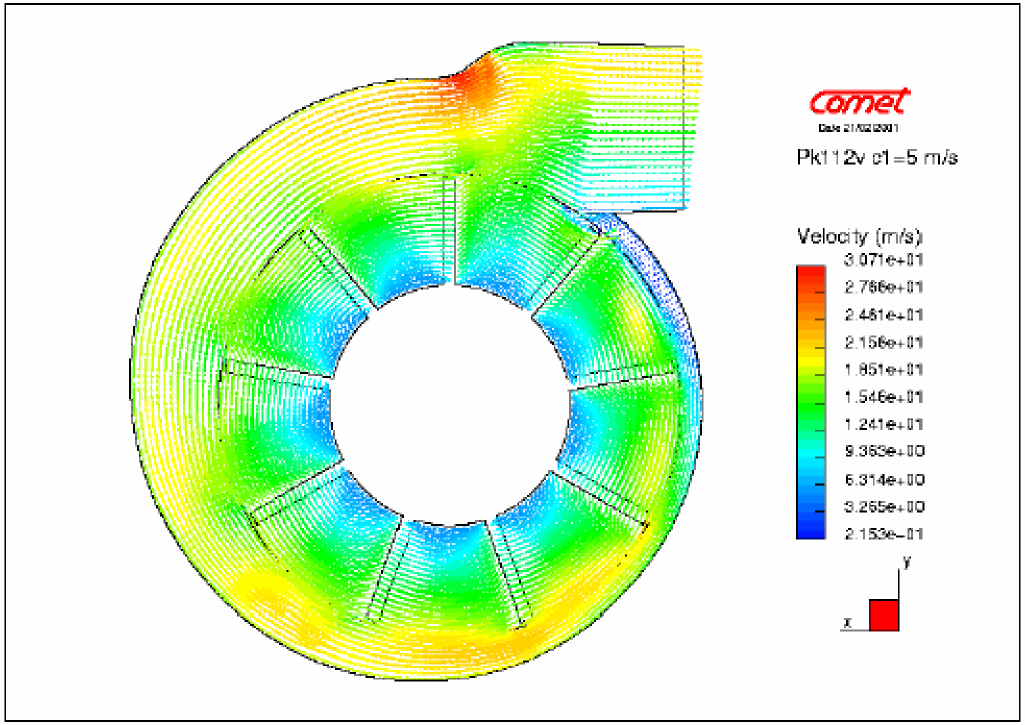




CAE - examples of application

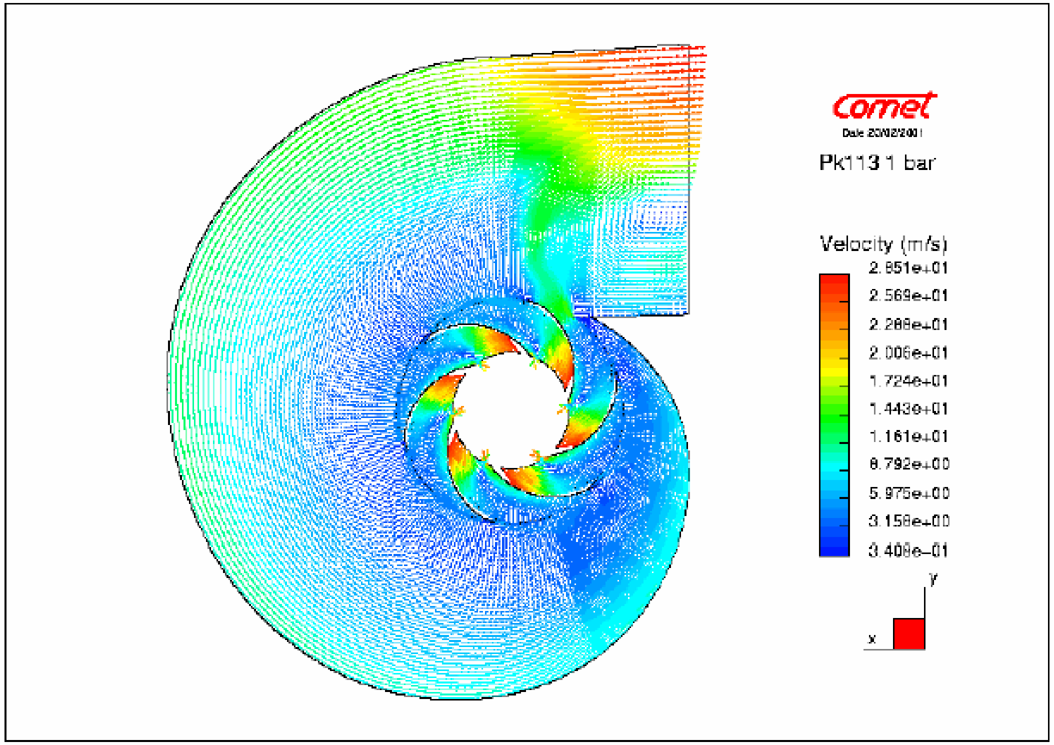
design optimisation of centrifugal pumps

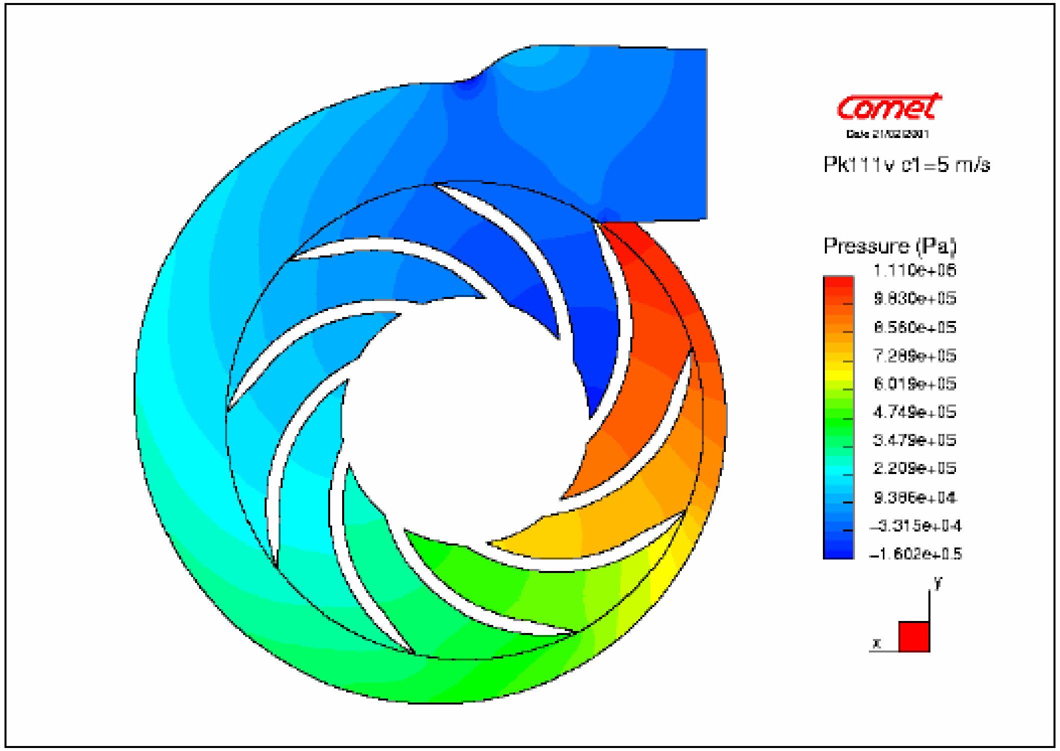




CAE - examples of application

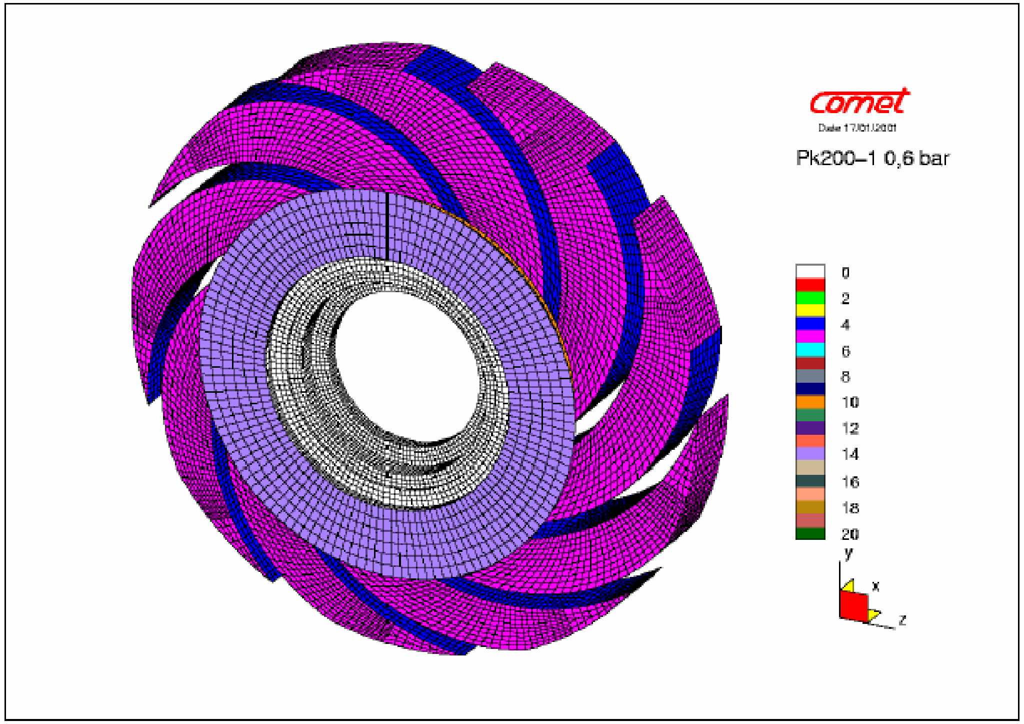
design optimisation of centrifugal pumps

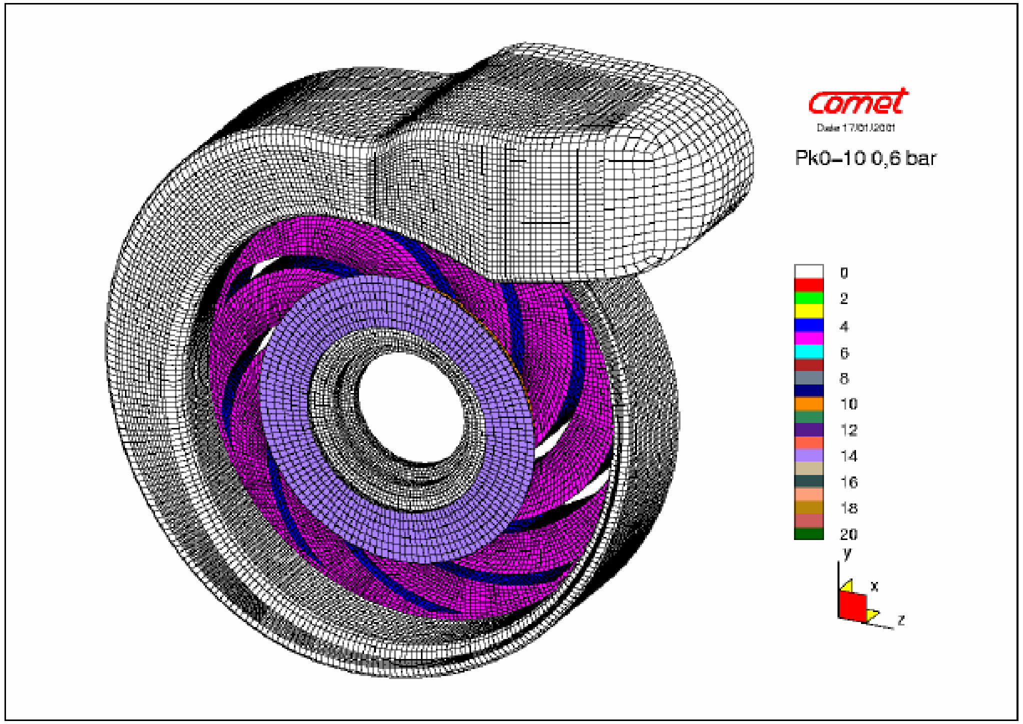




CAE - examples of application

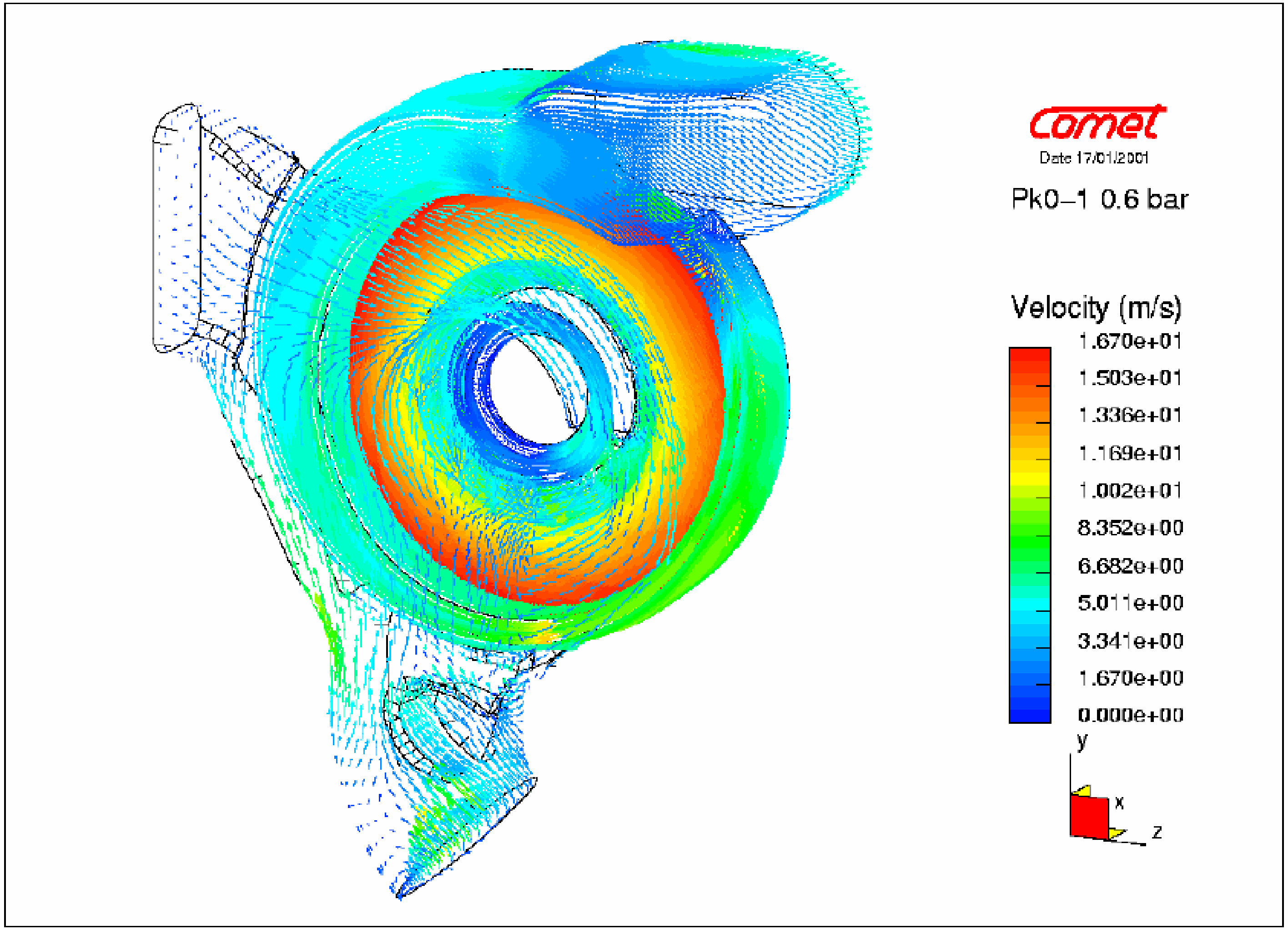
design optimisation of centrifugal pumps





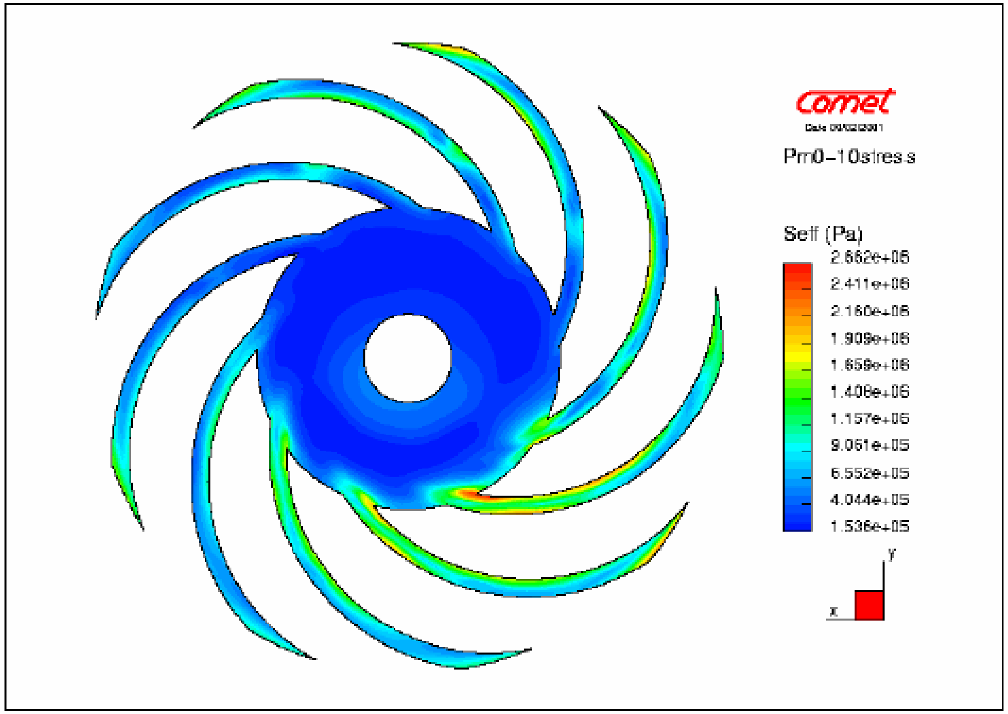
CAE - examples of application

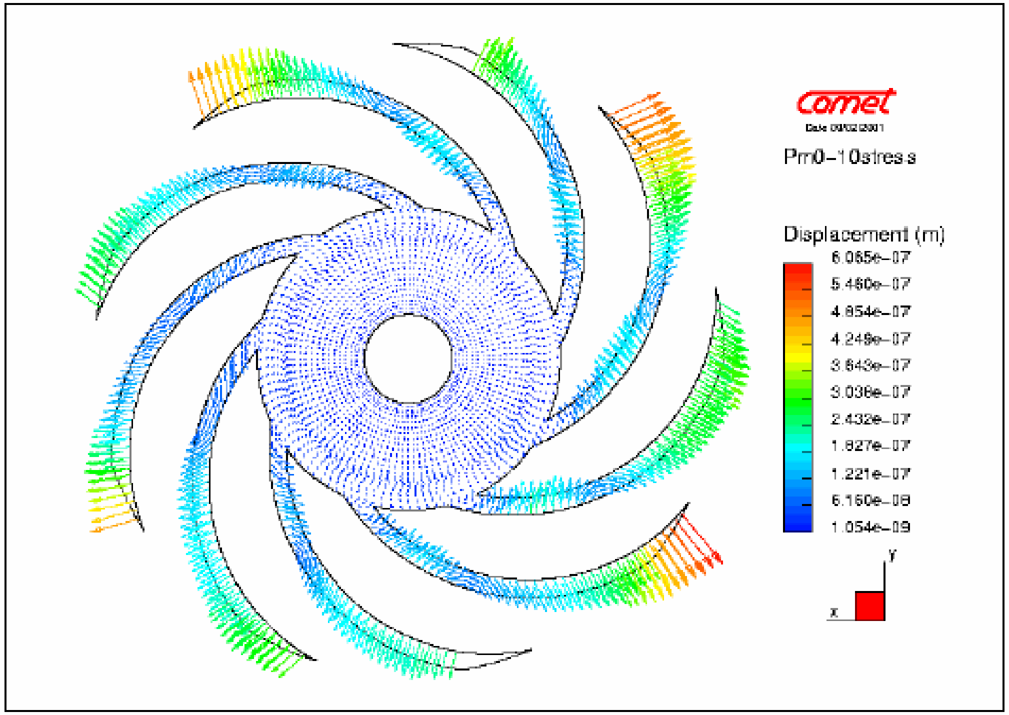
design optimisation of centrifugal pumps



CAE - examples of application

design optimisation of centrifugal pumps





CAE - examples of application

Mataln M, Particle filtration processes in deformable media

Technical application:

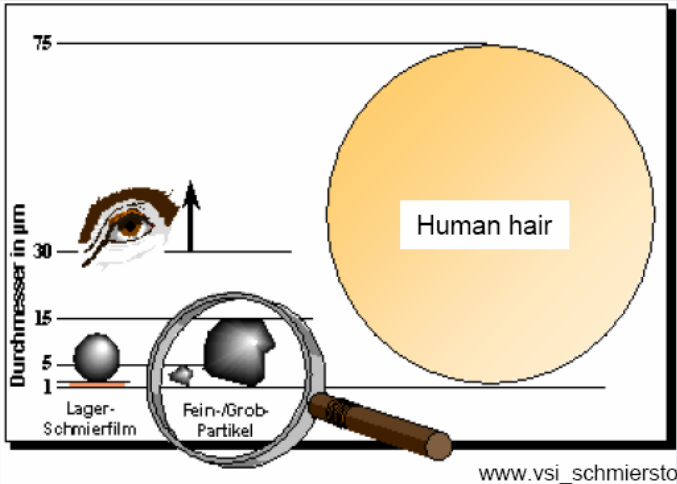
Oilfilter:
- fibers
- particles
- high viscous fluid (oil)

Main task:
How do the characteristics change with flow of oil and particles in a filter?

Oilfilter:

www.motorlexikon.de

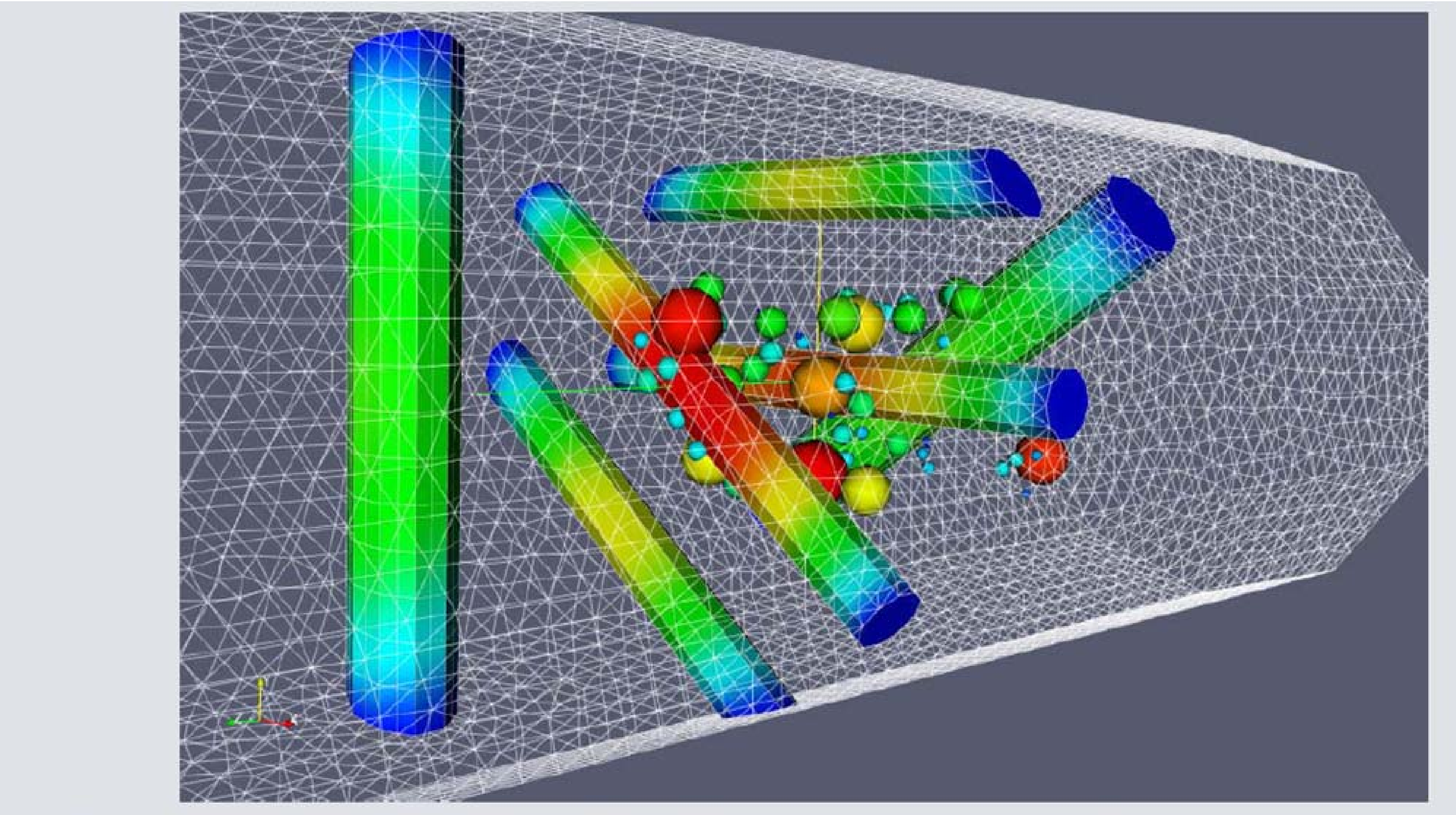
Comparison of particle size:



www.vsi_schmierstoffe.de

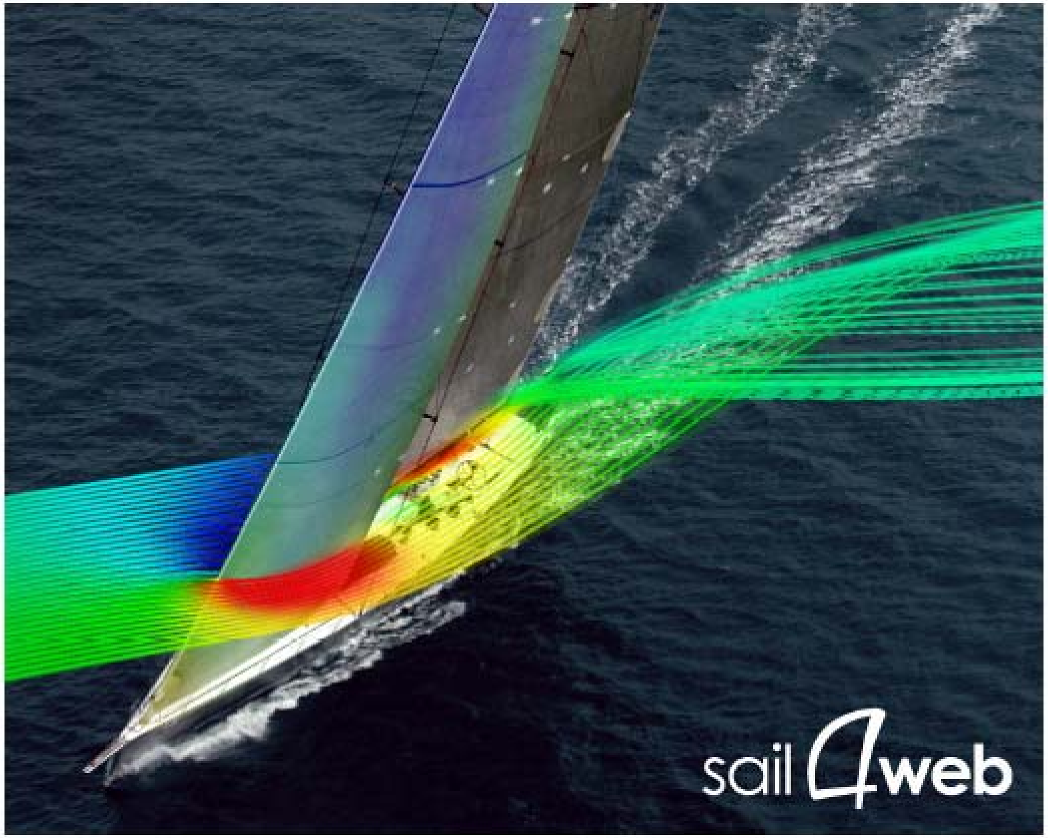
CAE - examples of application

Particle filtration processes in deformable media



CAE - examples of application

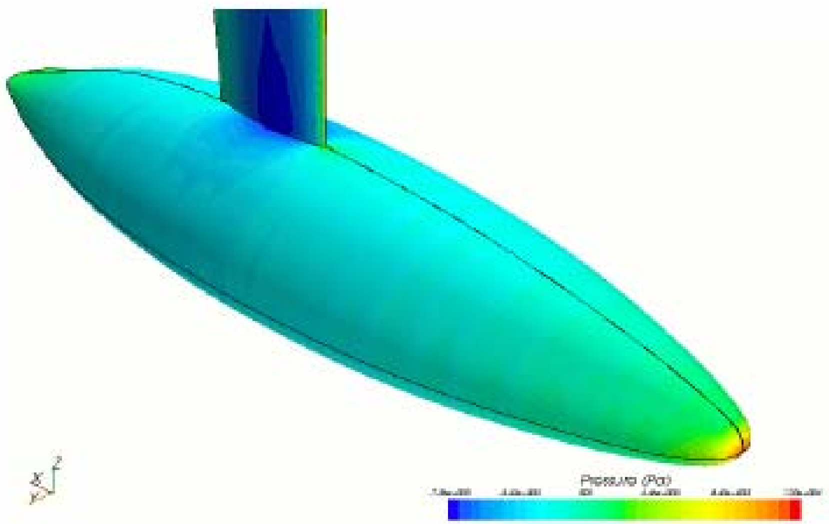
Ledri M, Poian M, Russo R, Aerodynamic analysis of Sails

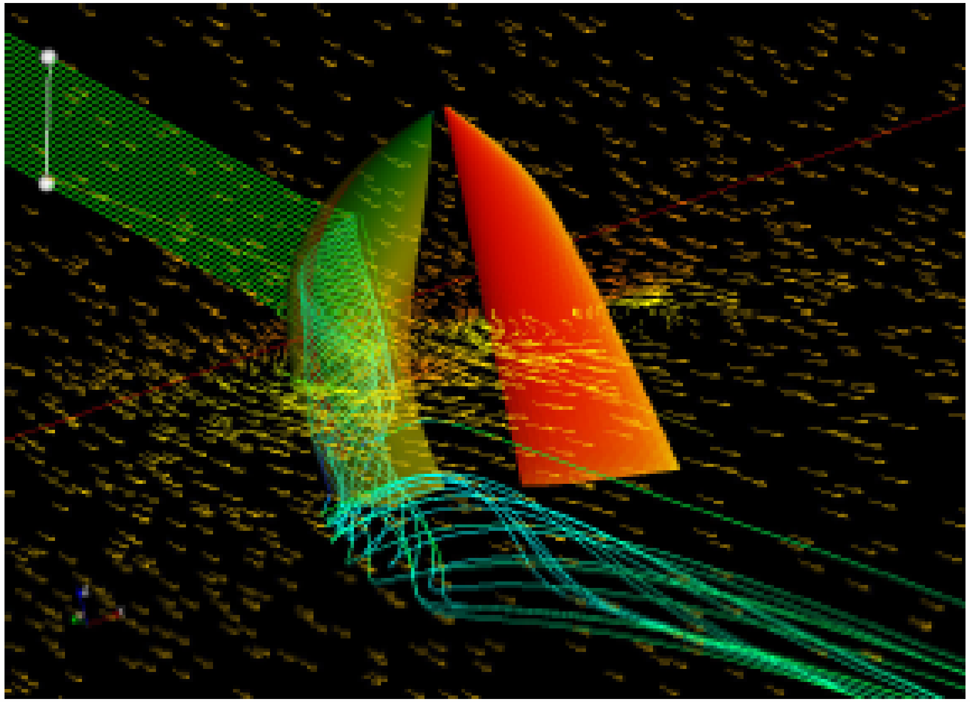


CAE - examples of application

Aerodynamic analysis of Sails

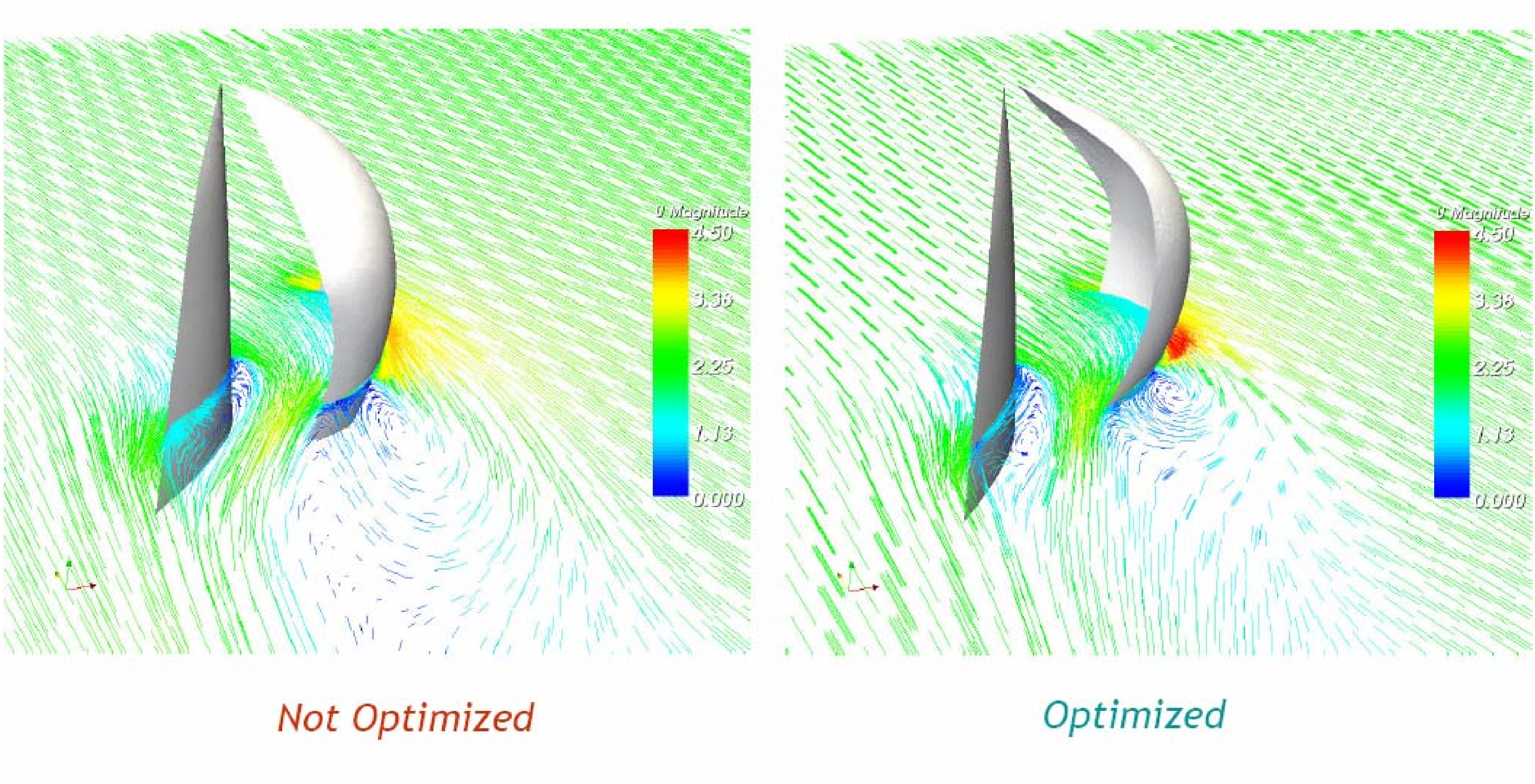
- Free surface flows
- Aerodynamic study of hull appendices
- Aerodynamic analysis of sails





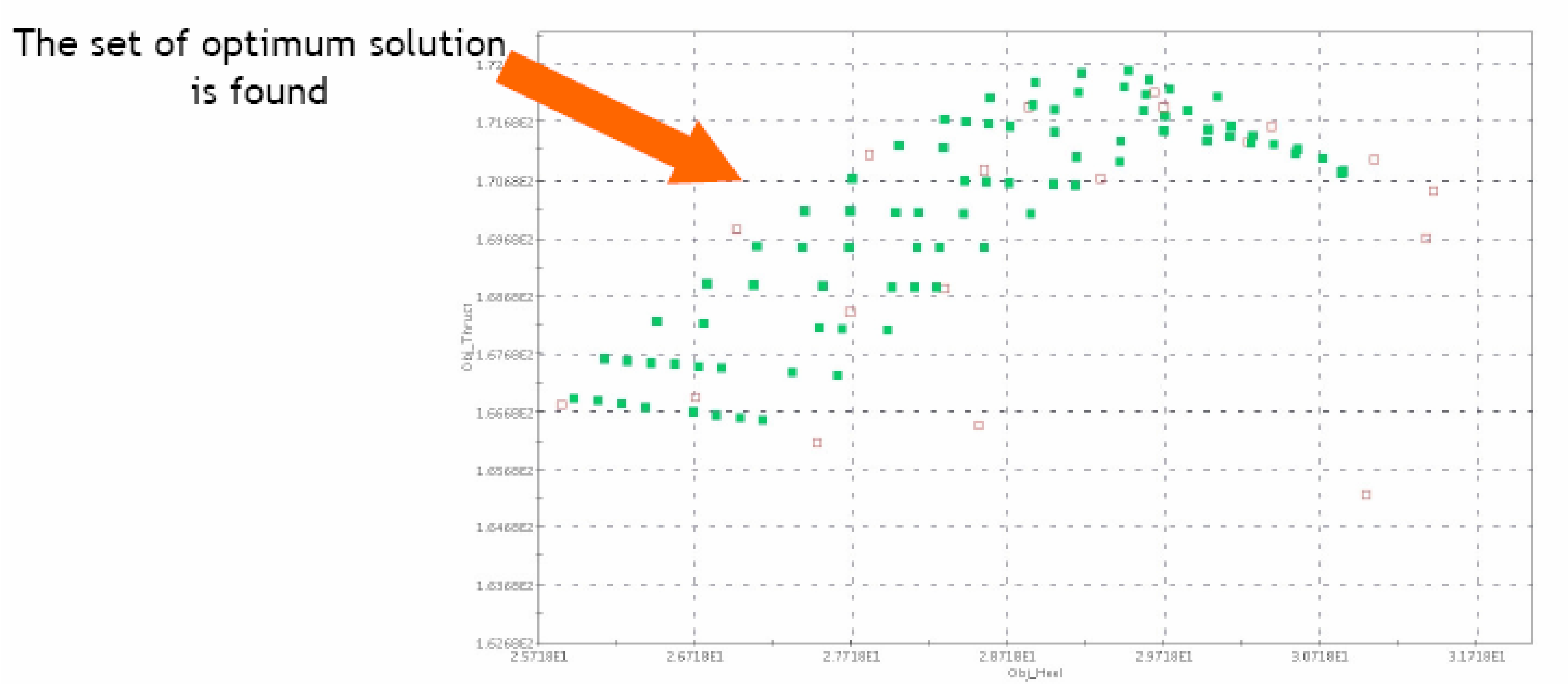
CAE - examples of application

Aerodynamic analysis of Sails



CAE - examples of application

Aerodynamic analysis of Sails



CAE - examples of application

Aerodynamic analysis of Sails

- All the computations have been run on a 64 cpu linux cluster.
- A queuing system (SGE) + parallel evaluations of designs allowed a profitable use of the computational capacity.

CAE - examples of application

Gallinger T *et al*, FSI on Light-weight structures

Wind Engineering

Collapse of the Tay-Bridge,1879

Source: Lewis, P.

Tacoma Narrows Bridge Collapse,1940

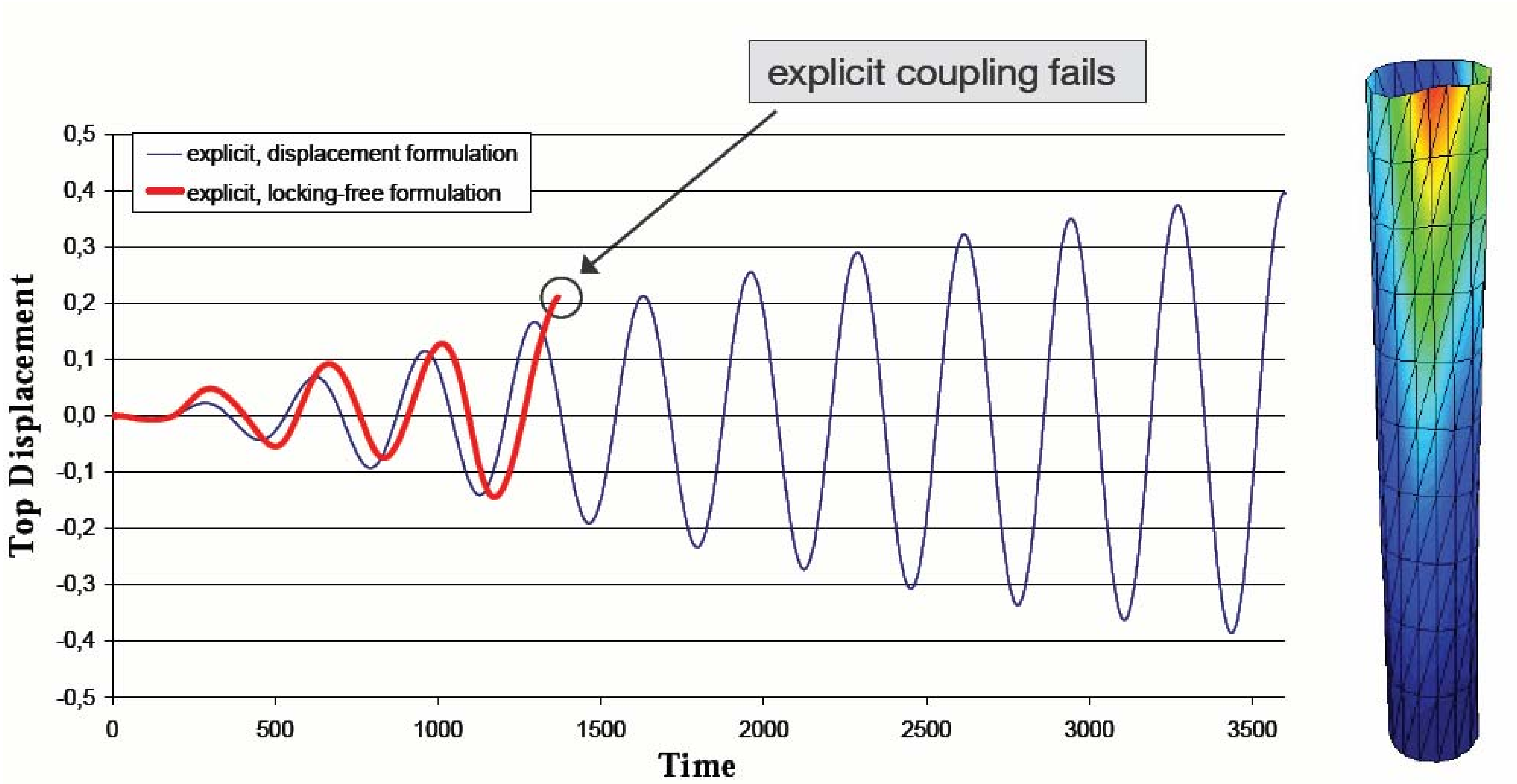
Source: Münchner Rück (1990)

Damages to cooling towers in Ferrybridge (England)

Source: Building Research Establ.

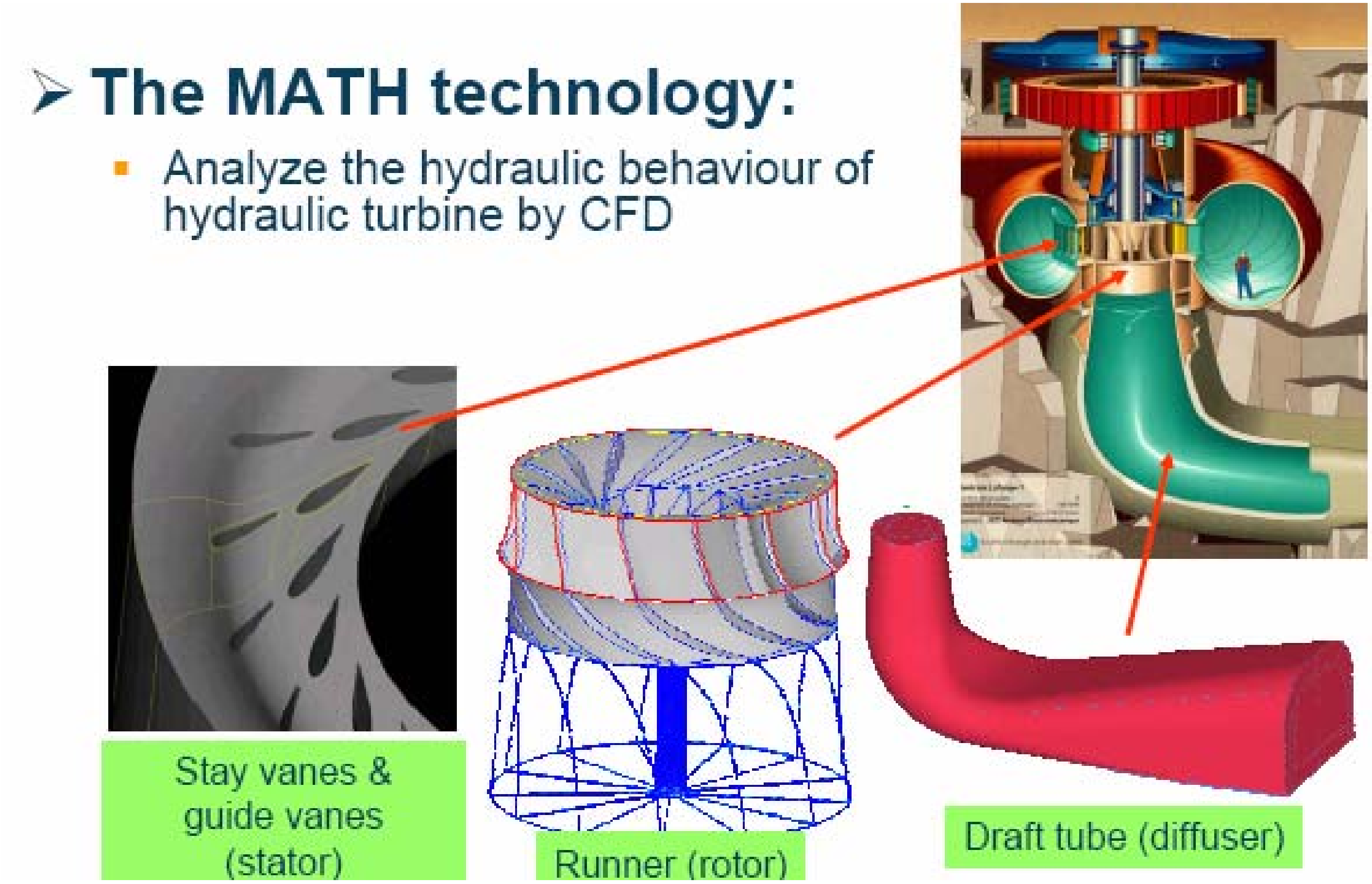
CAE - examples of application

FSI on Light-weight structures



CAE - examples of application

Page M and Beaudoin M, Turbomachinery Turbomachinery Applications Applications



CAE - examples of application

Turbomachinery Turbomachinery Applications Applications

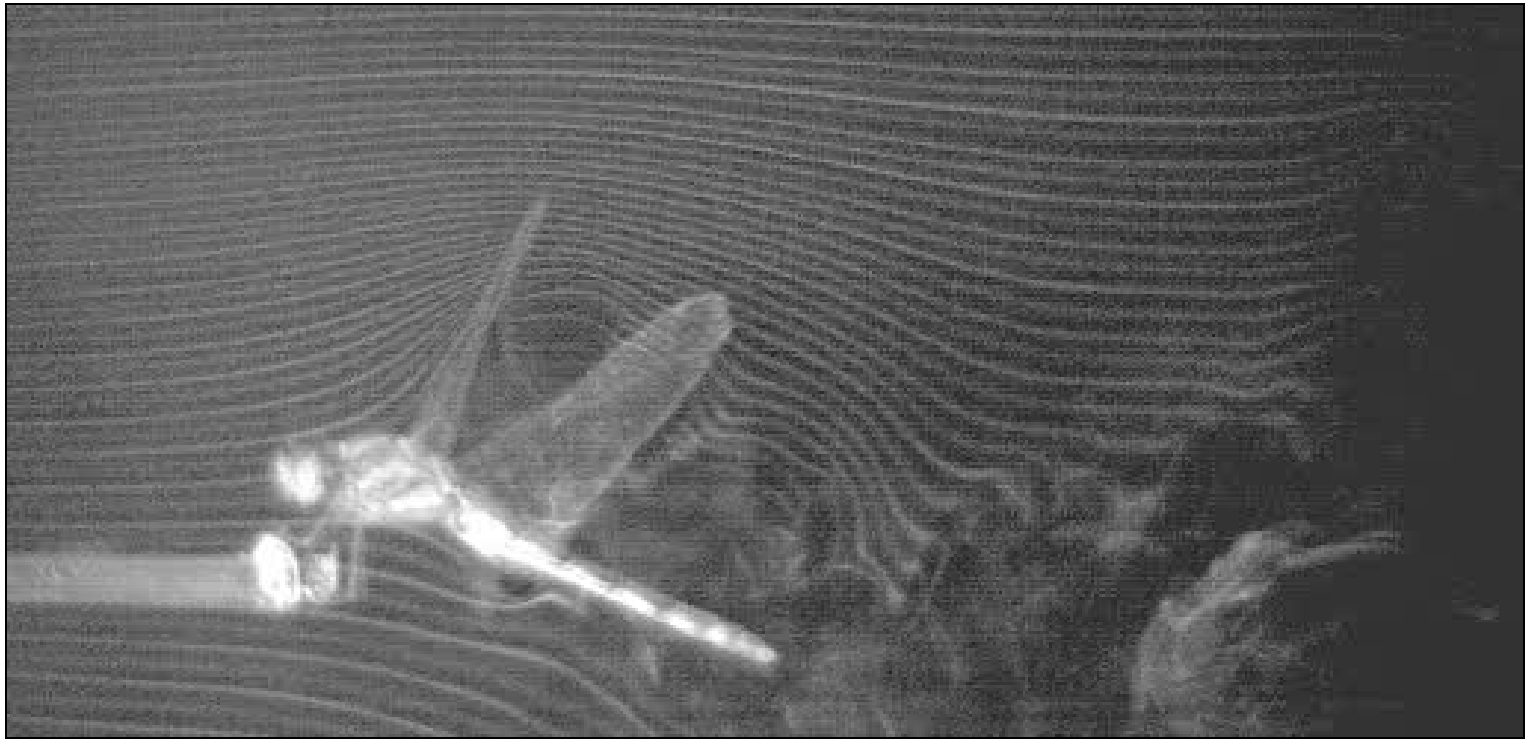
- IBM 1350 Beowulf cluster
- 500 AMD Opteron 64-bit CPUs (1000 cores)
- 250 x 8 GB = 2 TB of distributed RAM
- 30 TB of fast storage (IBM GPFS parallel file system)
- Infiniband 4x interconnect (10 Gbps)
- Water-cooled rear door heat exchangers
- Running NPACI Rocks 4.2.1 (Centos 4.4)

CAE - examples of application

Bos F, van Oudheusden B, Bijl B, Three-dimensional numerical simulations of flapping wings at low Reynolds numbers

CAE - examples of application

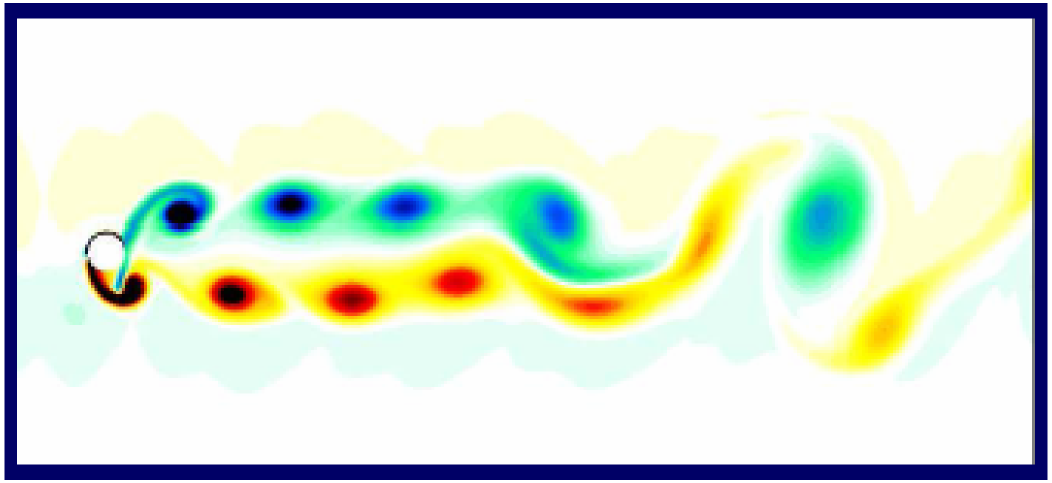
3D numerical simulations of flapping wings at low Reynolds numbers

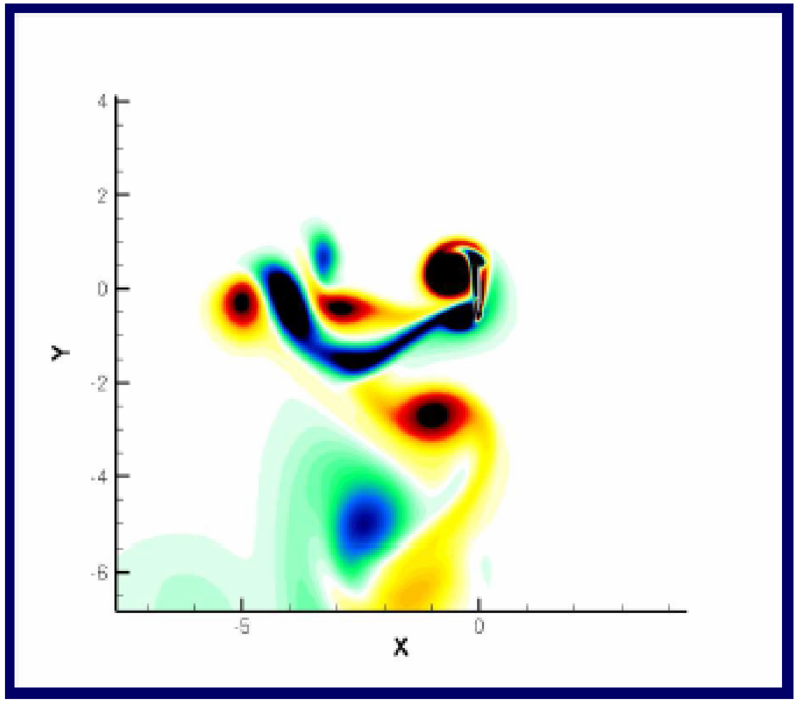


http://fluid.mech.kogakuin.ac.jp/~iida/mav/dragonfly.html

CAE - examples of application

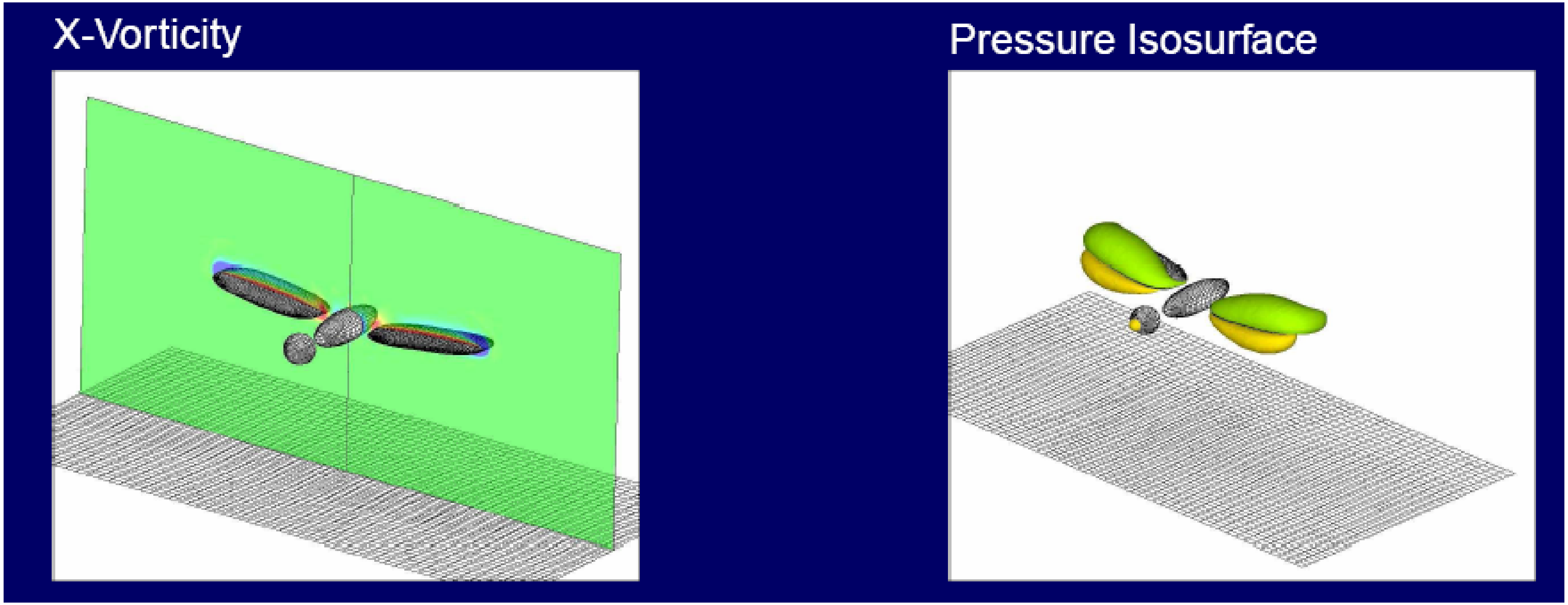
3D numerical simulations of flapping wings at low Reynolds numbers





CAE - examples of application

3D numerical simulations of flapping wings at low Reynolds numbers



Similarity theory (basics)

- the study of physical phenomena based on the concept of physical similarity
- testing performed on similar (usually smaller) model

Cauchy's similarity law

Term	Original	Model	Dimension
Ratio	λ	λ	-
Length	l^o	l^m	M
Force	F^o	F^m	N
Young's modulus	E^o	E^m	Pa
Strain	ε^o	ε^m	-
Stress	σ^o	σ^m	Pa
Area	A^o	A^m	m^2

Basic assumptions

- linear elasticity
- same stresses in the corresponding regions of the original and its model

length: $\lambda = \dfrac{l^m}{l^0}$

area: $\dfrac{\mathrm{A}^{\mathrm{m}}}{A^l} = \lambda^2$

volume: $\dfrac{\mathrm{V}^{\mathrm{m}}}{V^o} = \lambda^3$

stresses:

$$\sigma^0 = E^o \frac{\Delta l^0}{l^0} \qquad \sigma^{\mathrm{m}} = E^m \frac{\Delta l^m}{l^m}$$

$$\frac{\sigma^m}{\sigma^l} = \frac{E^m}{E^o}\frac{\Delta l^m}{\Delta l^o}\frac{l^o}{l^m} = \left| E^m = E^o \right| = 1 \cdot \lambda \cdot \frac{1}{\lambda} = 1$$

Lušija Z., Istraživanje mogućnosti primjene modelske sličnosti na razvoju konstrukcije visokotlačnih cilindara velikih gabarita, MSc, 2004.

PART II:

Testing polymeric materials and products

Aleksandar Karač
MFZE, room 1111
Tel: 449 120, ext. 140
Email: akarac@mf.unze.ba

TESTING PRODUCT CHARACTERISTICS