

Refrigeration and Cryogenics

Janusz Skrzypacz, PhD

Integrated Production Systems

Choose yourself and new technologies

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Integrated Production Systems

Lecture 4, 5

Introduction to CAD and CAE

Janusz Skrzypacz, PhD

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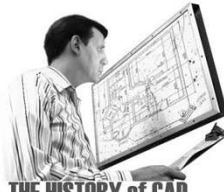
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The History of Computer Aided Design (CAD)

➤ Computer Aided Design (CAD) is defined as:

- “The use of computer facilities for creating and editing design drawings.”

(Hutchinson Concise Encyclopedia)



THE HISTORY of CAD

➤ Prior to 1960 all drawings were done with pencil and drafting instruments.

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History of CAD cont'd – Early 60's



1963 – Ivan Sutherland invents the “sketchpad”. He uses cathode ray tube and light pen for graphic input.

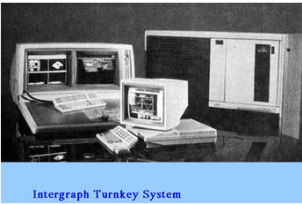
Evans & Sutherland refreshable vector scope

Source: <http://businesssoft.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Fwww.design.cadlab.vt.edu%2Fpages%2Fme4634%2Fcdpages%2FHistCADCAM.html>

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History of CAD cont'd – 60's and 70's



Intergraph Turnkey System

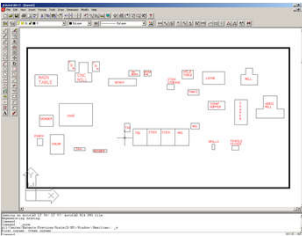
- Several aerospace, automotive companies and printed circuit board companies developed their own internal 2-D wireframe packages
- Ran on mainframes in cold, dark climate controlled rooms

Source: <http://businesssoft.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Fwww.design.cadlab.vt.edu%2Fpages%2Fme4634%2Fcdpages%2FHistCADCAM.html>

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History of CAD cont'd – 80's



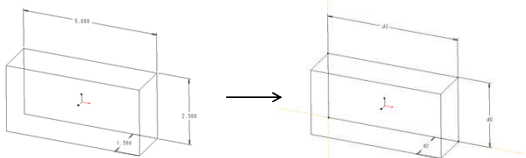
- 1984 – Autodesk introduced first CAD package written strictly for the PC. Again 2D wireframe.
- 1985/86 – 3D wireframe

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History of CAD cont'd

- 1987 – Parametric Technology Corporation introduces **parametric 3D feature based system** known as Pro/ENGINEER



Parametric – dimensions of object are represented as parameters

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CAD Advantages:

- Offers significant improvement in productivity:
 - Built in functions speed up geometry creation (i.e. copy, paste mirror, etc)
- Can store standard entities or parts (e.g. nuts, bolts, washers, etc)
 - Use of automatic fillets and chamfers
 - Drawings are easily produced after creation of model.
- Much easier to edit drawings or create a family of parts.

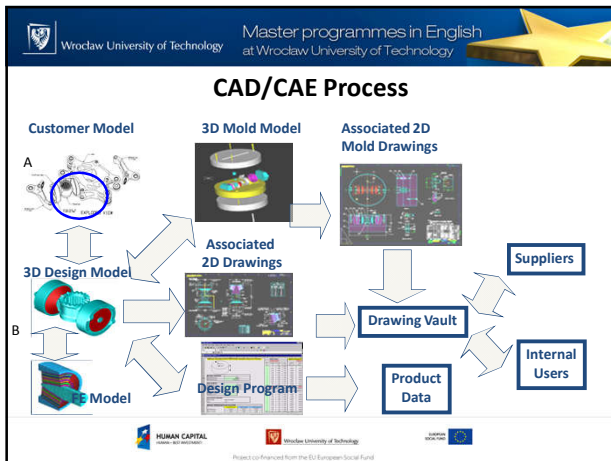
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CAD Advantages

- Supports “Concurrent Engineering Approach”
 - Same part model is shared throughout design and manufacturing team.
 - Allows engineering operations to be performed simultaneously!
 - Models can be e-mailed to other company locations, vendors, etc.

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Geometric Modeling

➤ **Definition:** Geometric modeling is the technique we use to describe the shape of an object.

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Functions of Computer-Aided Geometry Design

Specification of Design Geometry

- Computer-aided drafting (interactive graphics and user interface)
- Customizing CAD systems

Geometric Modeling and Representation

- Computer model of part and assembly design (data structure and database design)

Visualization

- Architectural view of a design
- Computer games and education programs

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Functions of Computer-Aided Geometry Design

- Generation of Manufacturing Oriented Database**
 - Feature-based design
 - Parametric design
- Tolerance Representation and Automated Tolerancing**
 - Dimension relation analysis
 - Tolerance analysis (error stack-up)
 - Tolerance synthesis (tolerance design, tolerance specification)
- Pre- and Post-interfaces to Finite Element Analysis Programs**
 - Automated mesh generation
 - Graphical display of stress distribution

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Functions of Computer-Aided Geometry Design

- Design Automation**
 - Design optimization
 - Design for manufacturing
 - Design for automated assembly
 - Concurrent engineering design
- Virtual (or Soft) Prototyping**
- Reverse Engineering**
- Animation and Simulation** (mechanism, CNC machining, robot trajectory, automobile crash)

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Output to Rapid Prototyping w/ 3D Printer



Z-Corp, model 2810 System,
Build Volume = 20" x 24" x 16"



Full Scale Engine Block printed
on the 2810 System (18"x19"x13")

CAD Model

↓

Import into 3D
printer as STF file

↓

Produce physical
prototype
(starch/plaster)

Source: Z-Corp <http://www.zcorp.com/>

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Output - Manufacturing

CAD Model
↓
Import into CAM package
↓
Post Process
↓
Download g-code into machine tool

Haas: Mini Mill
(7.5 hp spindle w/ 16" x 12" x 10" travel)

Mori Seiki: SL-603 Turning Center

Source: <http://www.haascnc.com> Source: <http://www.moriseiki.com>

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CAD System Architecture

Data/Human knowledge
Database: Component models, Drawings, Standards, Library data
Working data: Geometry, Associated data, Manufacturing

Design Engine
Software: Model definition, Manipulation, Picture generation, Utilities, Database management, Applications
Hardware: Input, Output

User (diamond shape) interacts with the Design Engine.

Source: [6]

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CAD system kernels

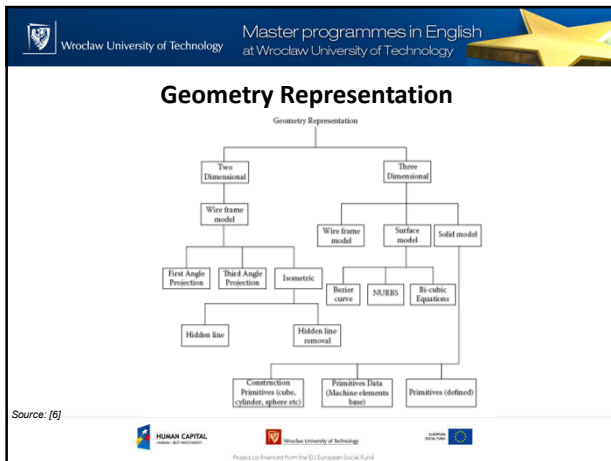
User Interface
Application
Kernel Interface (KI) / PC Interface
PARASOLID Modeler
Geometric / Foreign (Geometry) / Primitive
Database Interface (DI)
Database
Operating System

ACIS® Applications
Spatial Corporation
AutoCAD
Inventor
CADKEY
Ironcad
Working Model
Abaqus
Cosmos
Nastran

Parasolid innovator
Unigraphics
Solid Edge
Solid Works
Microstation

The engine of CAD systems is called a "kernel". There are two dominating kernels:
– ACIS from Spatial Corporation, owned by Dassault, the company behind CATIA and SolidWorks.
– Parasolid from UG.

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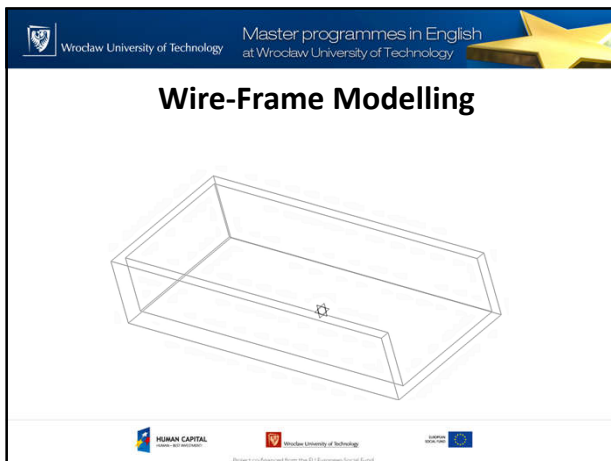


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GEOMETRIC MODELLING APPROACHES

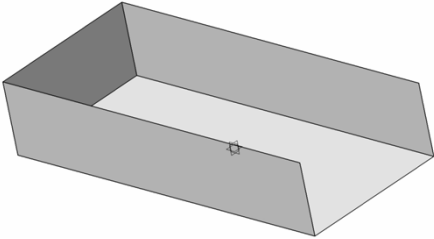
- Wire-Frame Modelling
- Surface Modelling
- Solid Modelling

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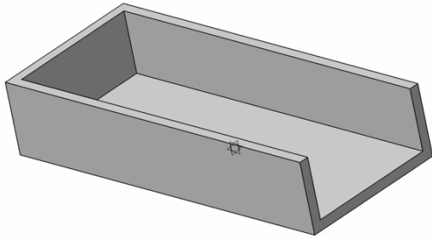
Surface Modelling



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Solid Modelling



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Constructive solid geometry (CSG)

- Objects are represented as a combination of simpler solid objects (*primitives*).
- The primitives are such as cube, cylinder, cone, torus, sphere etc.
- Copies or “instances” of these primitive shapes are created and positioned.
- A complete solid model is constructed by combining these “instances” using set specific, logic operations (Boolean).

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Constructive Solid Geometry

(a) $\text{Solid} = \text{Cube} - (\text{Prism}_1 \cup \text{Prism}_2)$

(b) $\text{Solid} = \text{Cube} - (\text{Prism}_1 \cup \text{Prism}_2 \cup \text{Prism}_3)$

(c) $\text{Solid} = \text{Cube} - (\text{Prism}_1 \cup \text{Prism}_2 \cup \text{Prism}_3)$

Source: [6]

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Boundary representation (B-Rep)

- A solid model is defined by its enclosing surfaces or boundaries. This technique consists of the geometric information about the faces, edges and vertices of an object with the topological data on how these are connected.
- A solid is represented as a closed space in 3D space (surface connects without gaps)
- The boundary of a solid separates points inside from points outside solid.

Source: http://gmm.fskm.utm.my/~suriati/gm/SOLID_MODEL.ppt

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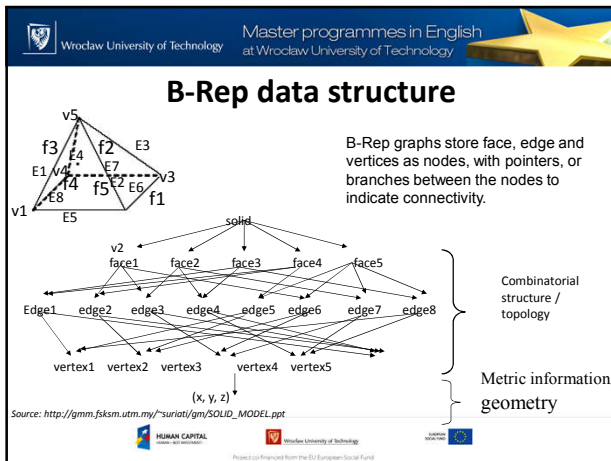
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B-Rep vs surface modeling

- Surface model
 - A collection of surface entities which simply enclose a volume lacks the connective data to define a solid (i.e topology).
- B-Rep model
 - This technique guarantees that surfaces definitively divide model space into solid and void, even after model modification commands.

Source: http://gmm.fskm.utm.my/~suriati/gm/SOLID_MODEL.ppt

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Boundary representation- advantages

- Capability to construct unusual shapes that would not be possible with the available CSG → aircraft fuselages, swing shapes.
- Less computational time to reconstruct the image.

Source: http://gmm.fskm.utm.my/~suriati/gm/SOLID_MODEL.ppt

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Parametric Design Variational Design

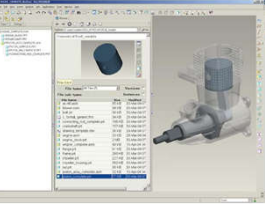
(a) (b)

IF $d1 > d2$ length = 12.1 ENDIF
IF $d1 \leq d2$ length = 23.2 ENDIF

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Pro/ENGINEER



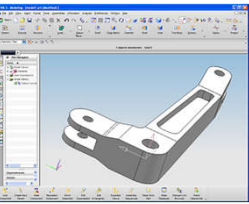
- One of the CAD/CAM/CAE industry's leading suppliers of software tools from Parametric Technology Corp. (PTC)
- A pioneer of the new feature-based, parametrically driven design paradigm in late 1980s, now industrial standard.
- A system used to automate the development of a mechanical product from its conceptual design through production.
- Offering integrated software technologies to reduce time to market, improve engineering process, and optimize product quality.
- One of the fastest growing companies in the mechanical design automation market
- Improved user's interface in recent release.

Source: http://www.ptc.com/products/proe/wildfire2/tryout/tutorials/en/intro/front_cover.jpg

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Unigraphics



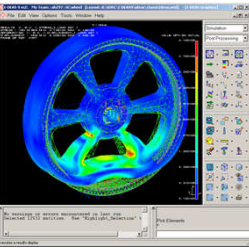
- A full spectrum design modeling, analysis, simulation, and manufacturing CAD/CAE/CAM software from Unigraphics Solutions
- One of the older and well-established CAD/CAE system.
- A software of choice for a wide variety of applications, especially in automotive and aerospace product development.

Source: http://www.edgcam.pl/edgcam_dla/ekran-Unigraphics-NKS.jpg

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I-DEAS



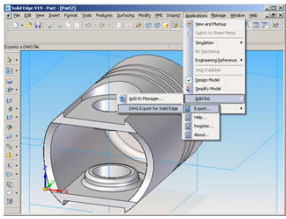
- A full spectrum design modeling, analysis, simulation, and manufacturing CAD/CAE/CAM software from Structural Dynamics Research Corporation (SDRC)
- One of the older and well-established CAD/CAE system, having a significant market share.
- Having very strong CAE capabilities
- A software of choice for a wide variety of applications ranging from consumer goods and machinery to automotive (Ford Motor Company)

Source: http://www.aquaphoenix.com/lecture/ideas-wheel/images-large/505_ideas_results_deformed.jpg

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Solid Edge



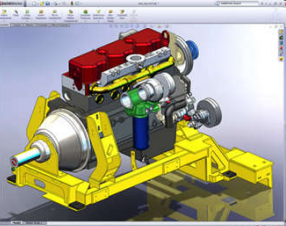
- Powerful modeling tools
- Integrated design management
- Productivity for large assemblies
- Ease of adoption
- Faster Modeling
- Error elimination by means of engineering aids
- Drafting tools
- Unmatched interoperability
- Design-through-manufacturing

Source: <http://www.softpedia.com/progScreenshots/DWG-Export-for-Solid-Edge-Screenshot-95092.html>

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SolidWorks



- 3D Computer-aided Mechanical Design software from SolidWorks Corp. founded in 1993 and acquired by Dassault System in 1997.
- A leader of the group of new lower-priced mechanical design solution companies based upon component software.
- A system used for designing and engineering parts and assemblies in a completed 3D-centric process linked to automated assembly and drafting functions.
- The first solid modeling program to run in native Windows environments, and sells for a fraction of the cost of similar programs

Source: <http://img518.imageshack.us/solidworks2008unveiledm14.jpg/>

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MicroStation



- A premier CAD software for infrastructure engineering and major architectural and civil engineering from Bentley Systems, incorporated, the worldwide leader in engineering software products, user services and overall quality.
- The software foundation underlying the engineering of well-known buildings, airports, hospitals, highways, bridges and industrial plants throughout the world, used in over 70% of the largest US engineering firms.
- Bentley System now serves over 250,000 professionals in construction engineering, geo-engineering, and mechanical engineering fields.

Source: http://www.iderherts.ac.uk/cad/images/microstation_title.jpg

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Alibre

PROFESSIONAL

- 3D model creation
- 2D documentation
- Sheetmetal design
- Part Library
- Rendering
- Import/Export

EXPERT

- Configurations
- Direct Editing
- FEA
- CAM
- Motion
- Vault
- Extra Import/Export

Source: www.alibre.com

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CATIA

- A process-centric CAD/CAM software solution marketed exclusively by IBM and developed by Dassault Systems
- A system used to design and manufacture many complex 3D products. Today, 7 out of every 10 airplanes and 4 out of every 10 cars are designed using CATIA-CADAM Solutions, making it the de facto standard for these markets.
- A software of choice for a wide variety of applications ranging from consumer goods and machinery to plant design and shipbuilding.
- 300,000 CATIA users worldwide, nearly half in English language markets.

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CATIA

- Infrastructure
- Geometrical Design
 - Sketch
 - Surfaces & Simulation
 - ASD Part
 - Modeling
 - Digital Mockup
 - Equipment & Systems
 - Digital Process for Manufacturing
 - Modeling Simulation
 - Ergonomics Design & Analysis
 - Knowledgebase
 - 3D/2D/1D View
 - 1 Color...Product
 - 2 Finish...Product
 - 3 Mesh...Product
 - 4 Draft...Drawing
 - 5 Analysis...Analysis
- Part Design
 - Sketch
 - Assembly Design
 - Sketcher
 - Product Functional Tolerancing & Annotation
 - 3D Model Design
 - 3D Tolerancing Design
 - Structure Design
 - 3D Layout for 3D Design
 - Drilling
 - Core & Cavity Design
 - Drilling Assistant
 - Functional Model Part
 - Sheet Metal Design
 - Sheet Metal Production
 - Composites Design
 - Interface and Surface Design
 - Generative Structural Design
 - Functional Tolerancing & Annotation

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Integrated CAD/CAE Tools

- ANSYS (from ANSYS Inc.)
 - A growing leader in CAE and integrated design analysis and optimization (DAO) software
 - Covering solid mechanics, kinematics, dynamics, and multi-physics (CFD, EMAG, HT, Acoustics)
 - Interfacing with key CAD systems
- NASTRAN (from MacNeal-Schwendler)
 - A powerful structural analysis program for analyzing stress, vibration, dynamic, nonlinear and heat transfer characteristics.
 - PATRAN provides an open flexible MCAE environment for multidisciplinary design analysis, and simulates product performance and manufacturing processes.
- Pro/MECHANICA (integrated with Pro/E). This system provides an open flexible MCAE environment for multidisciplinary design analysis, and simulates product performance and manufacturing processes.



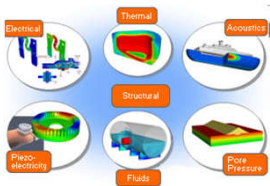


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Integrated CAD/CAE Tools

Abaqus - SIMULIA



SIMULIA is the Dassault Systèmes brand that delivers a scalable portfolio of Realistic Simulation solutions including the Abaqus product suite for Unified Finite Element Analysis, multiphysics solutions for insight into challenging engineering problems, and SIMULIA SLM for managing simulation data, processes, and intellectual property.

Source: <http://www.simulia.com/products/>



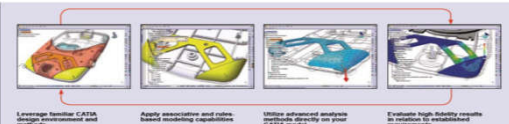


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Integrated CAD/CAE Tools

Abaqus for CATIA V5



Abaqus for CATIA V5 brings Abaqus finite element analysis (FEA) technology into the CATIA V5 user environment. CATIA V5 provides powerful and flexible design capabilities, and Abaqus for CATIA V5 makes the design model and the simulation model one and the same. The result is a complete package for deploying proven FEA-based simulation throughout the design process.

Source: <http://www.simulia.com/products/>





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CAE Definition

Computer-aided engineering (CAE) is the broad usage of computer software to aid in engineering tasks. CAE areas covered include:

- Stress analysis on components and assemblies using FEA (Finite Element Analysis);
- Thermal and fluid flow analysis Computational fluid dynamics (CFD);
- Kinematics and Mechanical event simulation (MES).
- Analysis tools for process simulation for operations such as casting, molding, etc.
- Optimization of the product or process.

Source: Wikipedia

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CAD to CAE link

Geometry Transfer

IGES VDA-FS SET STEP PDES

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An Introduction to the Finite Element Analysis

- Many problems in engineering and applied science are governed by differential or integral equations.
- The solutions to these equations would provide an exact, closed-form solution to the particular problem being studied.
- However, complexities in the geometry, properties and in the boundary conditions that are seen in most real-world problems *usually* mean that an exact solution cannot be obtained or obtained in a reasonable amount of time.

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An Introduction to the Finite Element Analysis

- Current product design cycle times imply that engineers must obtain design solutions in a 'short' amount of time.
- They are content to obtain approximate solutions that can be readily obtained in a reasonable time frame, and with reasonable effort. The FEM is one such approximate solution technique.
- The FEM is a numerical procedure for obtaining approximate solutions to many of the problems encountered in engineering analysis.

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An Introduction to the Finite Element Analysis

Search approximate solution

Continuum object $\rightarrow$ a discrete approximation

$dx \rightarrow \Delta x$
 $dt \rightarrow \Delta t$

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An Introduction to the Finite Element Analysis

- In the FEM, a complex region defining a continuum is discretized into simple geometric shapes called *elements*.
- The properties and the governing relationships are assumed over these elements and expressed mathematically in terms of unknown values at specific points in the elements called *nodes*.
- An assembly process is used to link the individual elements to the given system. When the effects of loads and boundary conditions are considered, a set of linear or nonlinear algebraic equations is usually obtained.
- Solution of these equations gives the *approximate* behavior of the continuum or system.

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An Introduction to the Finite Element Analysis

- The continuum has an infinite number of degrees-of-freedom (DOF), while the discretized model has a finite number of DOF. This is the origin of the name, *finite element* method.
- The number of equations is usually rather large for most real-world applications of the FEM, and requires the computational power of the digital computer. *The FEM has little practical value if the digital computer were not available.*
- Advances in and ready availability of computers and software has brought the FEM within reach of engineers working in small industries, and even students.

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An Introduction to the Finite Element Analysis

Two features of the finite element method are worth noting.

- The piecewise approximation of the physical field (continuum) on finite elements provides good precision even with simple approximating functions. Simply increasing the number of elements can achieve increasing precision.
- The locality of the approximation leads to sparse equation systems for a discretized problem. This helps to ease the solution of problems having very large numbers of nodal unknowns. It is not uncommon today to solve systems containing a million primary unknowns.

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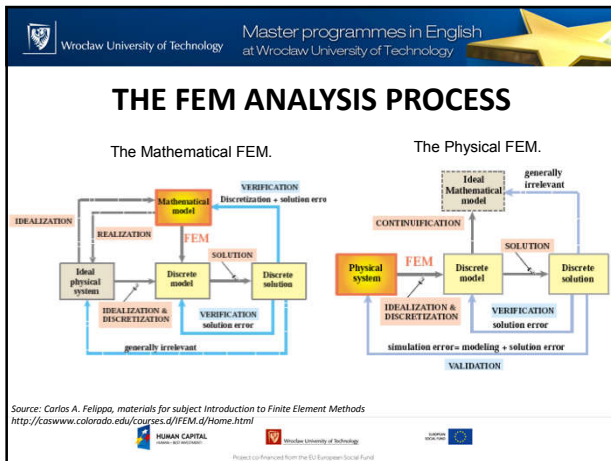
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Discretization methods

Spatial discretization method {

- Finite Element Method (FEM)
- Boundary Element Method (BEM)
- Finite Difference Method (FDM)
- Finite Volume Method (FVM)
- Spectral Method
- Mesh-Free Method

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Theoretical Basis: Formulating Element Equations

- Several approaches can be used to transform the physical formulation of a problem to its finite element discrete analogue.
- If the physical formulation of the problem is described as a differential equation, then the most popular solution method is the Method of Weighted Residuals.
- If the physical problem can be formulated as the minimization of a functional, then the Variational Formulation is usually used.

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Theoretical Basis: Formulating Element Equations

Application Problem	State (DOF) vector $\mathbf{u}$ represents	Conjugate vector $\mathbf{f}$ represents
Structures and solid mechanics	Displacement	Mechanical force
Heat conduction	Temperature	Heat flux
Acoustic fluid	Displacement potential	Particle velocity
Potential flows	Pressure	Particle velocity
General flows	Velocity	Fluxes
Electrostatics	Electric potential	Charge density
Magnetostatics	Magnetic potential	Magnetic intensity

Ku=f

$\mathbf{K}$ - is universally called the stiffness matrix
 $\mathbf{u}$ - is called the DOF vector or state vector. The term nodal displacement vector for $\mathbf{u}$ is reserved to mechanical applications.
 $\mathbf{f}$ - forces or forcing terms

Source: Carlos A. Felippa, materials for subject Introduction to Finite Element Methods
<http://caswww.colorado.edu/courses.d/IFEM.d/Home.html>

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Types of finite elements

Source: Carlos A. Felippa, materials for subject Introduction to Finite Element Methods
<http://caswww.colorado.edu/courses.d/IFEM.d/Home.html>

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Application of finite elements

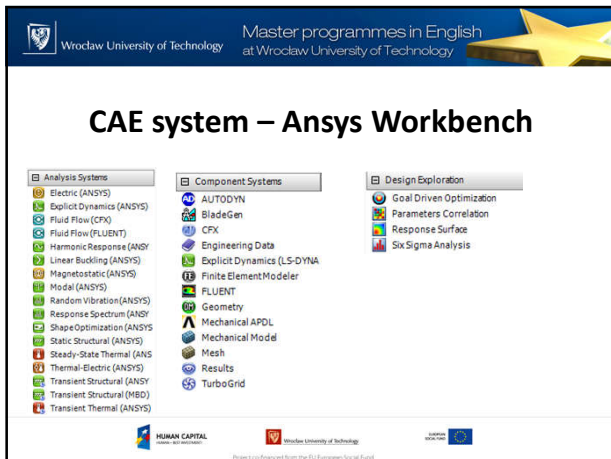
Source: Carlos A. Felippa, materials for subject Introduction to Finite Element Methods
<http://caswww.colorado.edu/courses.d/IFEM.d/Home.html>

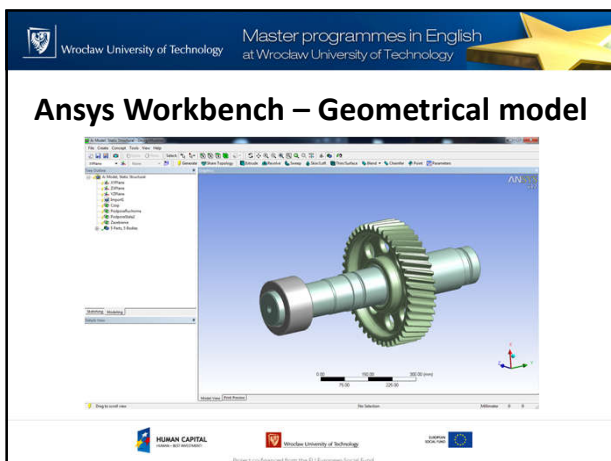
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CAE system – Ansys Workbench

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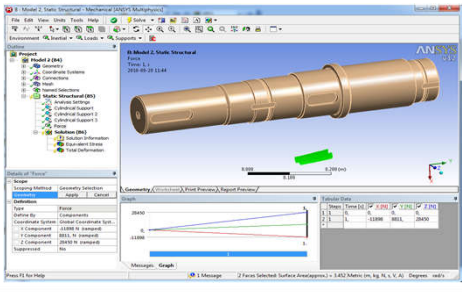




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Ansys Workbench – Boundary Conditions







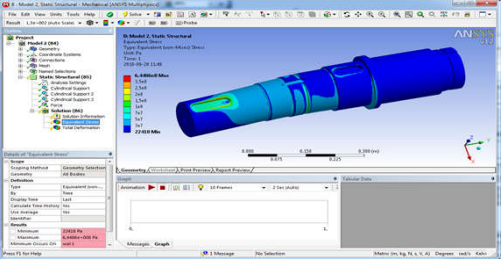
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Ansys Workbench – Results







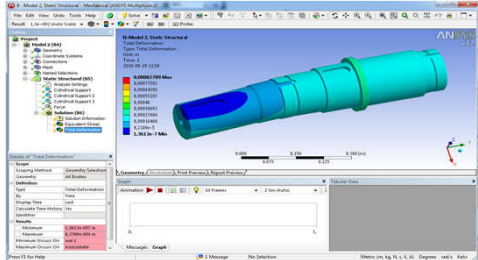
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Ansys Workbench – Results







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What is CFD?

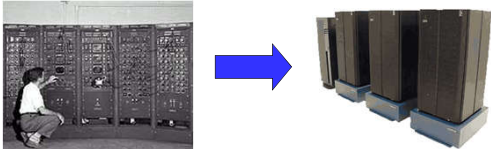
- CFD is the simulation of fluids engineering systems using modeling (mathematical and physical problem formulation) and numerical methods (discretization methods, solvers, numerical parameters, and grid generations, etc.).
- Historically only Analytical Fluid Dynamics (AFD) and Experimental Fluid Dynamics (EFD).
- CFD made possible by the advent of digital computer and advancing with improvements of computer resources.

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What is CFD?

(500 flops, 1947→20 teraflops, 2003 →1.3 petaflops, Roadrunner at Las Alamos National Lab, 2009.)

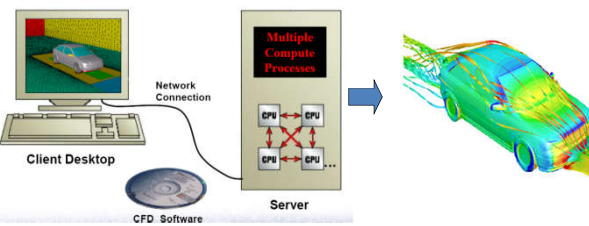


Source: Tao Xing, Shanti Bhushan and Fred Stern Introduction to Computational Fluid Dynamics (CFD)
C. Maxwell Stanley Hydraulics Laboratory The University of Iowa <http://css.engineering.uiowa.edu/~fluid/>

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Why we use CFD ?



Client Desktop Network Connection Server Multiple Compute Processes CPU GPU GPU CPU GPU GPU ...

Source: www.fluent.com

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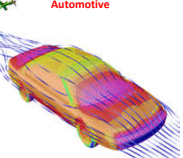
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CFD Applications

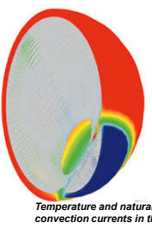
Aerospace



Automotive



Biomedical



Temperature and natural convection currents in the eye following laser heating.

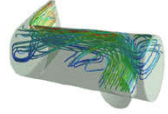
Source: Tao Xing, Shanti Bhushan and Fred Stern Introduction to Computational Fluid Dynamics (CFD)
C. Maxwell Stanley Hydraulics Laboratory The University of Iowa <http://css.engineering.uiowa.edu/~fluids/>

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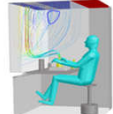
CFD Applications

Chemical Processing

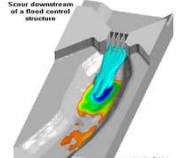


Polymerization reactor vessel - prediction of flow separation and residence time effects.

HVAC



Hydraulics



Scour downstream of a flood control structure

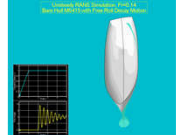
Source: Tao Xing, Shanti Bhushan and Fred Stern Introduction to Computational Fluid Dynamics (CFD)
C. Maxwell Stanley Hydraulics Laboratory The University of Iowa <http://css.engineering.uiowa.edu/~fluids/>

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CFD Applications

Marine (ocean)

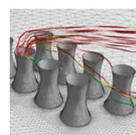


Oil & Gas



Flow of lubricating mud over drill bit

Power Generation



Flow around cooling towers

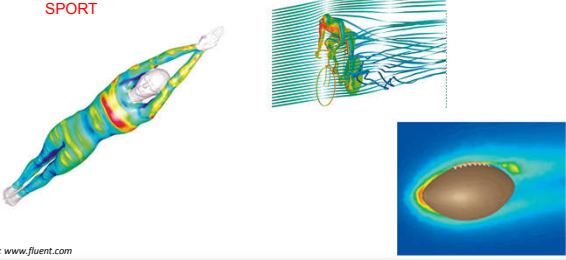
Source: Tao Xing, Shanti Bhushan and Fred Stern Introduction to Computational Fluid Dynamics (CFD)
C. Maxwell Stanley Hydraulics Laboratory The University of Iowa <http://css.engineering.uiowa.edu/~fluids/>

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CFD Applications

SPORT



Source: www.fluent.com

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CFD Applications

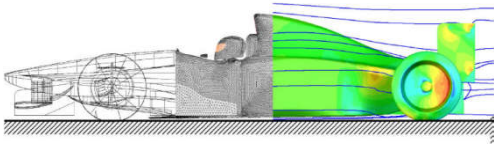
Turbomachinery



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CFD in Brief



Geometry Mesh Results

Source: K. Werner, Seibert Simulation of Vehicle Aerodynamics using FLUENT CFD-Software, Automotive User's Group Meeting, 2001

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Governing Equations

$$\frac{\partial \rho}{\partial t} + \text{div}(\rho \mathbf{u}) = 0$$

$$\frac{\partial(\rho \mathbf{u})}{\partial t} + \text{div}(\rho \mathbf{u} \mathbf{u}) = -\frac{\partial p}{\partial x} + \text{div}(\mu \text{grad } \mathbf{u}) + S_{Mx}$$

$$\frac{\partial(\rho i)}{\partial t} + \text{div}(\rho i \mathbf{u}) = -p \text{div } \mathbf{u} + \text{div}(k \text{grad } T) + \Phi + S_i$$

$p = p(\rho, T)$ and $i = i(\rho, T)$
 e.g. perfect gas
 $p = \rho R T$ and $i = C_v T$

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Governing Equations

Transport equation

$$\underbrace{\frac{\partial}{\partial t} \int_V \rho \phi dV}_{\text{Non-stationary Term}} + \underbrace{\oint_A \rho \phi \mathbf{V} \cdot d\mathbf{A}}_{\text{Convection Term}} = \underbrace{\oint_A \Gamma \nabla \phi \cdot d\mathbf{A}}_{\text{Diffusion Term}} + \underbrace{\int_V S_\phi dV}_{\text{Source Term}}$$

If: $\phi = 1 \Rightarrow$ mass conservation equation
 $\phi = u \Rightarrow$ momentum conservation equation
 $\phi = h \Rightarrow$ energy conservation equation

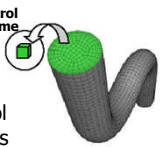
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Finite Volume Method

Domain is divided into finite number of control volumes

Transport equation is applied to every control volume and discretized (differential equation is changed into algebraic equation)



$$\frac{(\rho \phi_p)^{i+\Delta t} - (\rho \phi_p)^i}{\Delta t} \Delta V + \sum_{j \in \text{faces}} \rho_j \phi_j V_j A_j = \sum_{j \in \text{faces}} \Gamma_j (\nabla \phi)_{\perp j} A_j + S_\phi \Delta V$$

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Finite Volume Method

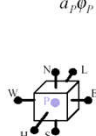
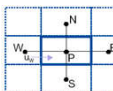
The values of searched variables are stored in the center of the control volume.

The value of the selected variable can be represented by values of surrounding cells.

$$a_P \phi_P = a_E \phi_E + a_W \phi_W + a_N \phi_N + a_S \phi_S + a_H \phi_H + a_L \phi_L + S_\phi$$

$$a_P \phi_P = \sum a_{nb} \phi_{nb} + S_\phi$$

every a_x represents diffusion and convection e.g. for a_w

$$a_w = \left(-\rho_w u_w + \frac{\Gamma_w}{\Delta_w} \right) A_w$$



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Finite Volume Method

$$\left[\begin{matrix} A \\ \phi \end{matrix} \right] = \left[\begin{matrix} R \end{matrix} \right]$$

$$A = \left[\begin{matrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{matrix} \right] \left\{ \begin{matrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{matrix} \right\} \# \text{ cells}$$

The system of equations is solved iteratively until the conditions will fulfill:

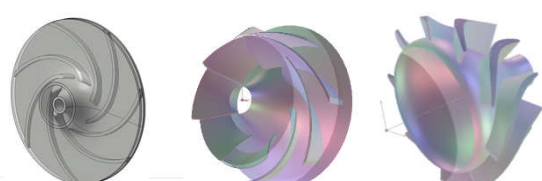
$$|\phi_i - \phi_{i+1}| < \varepsilon$$

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Steps of numerical calculations

1. Geometry creation process in 3D

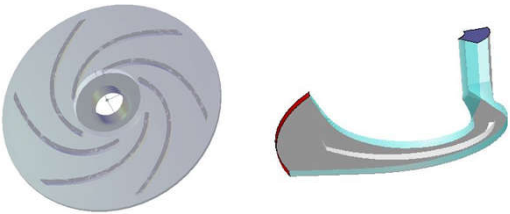


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Steps of numerical calculations

2. Mapping the flow volumes

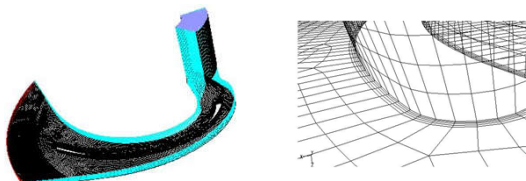


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Steps of numerical calculations

3. Mesh generation



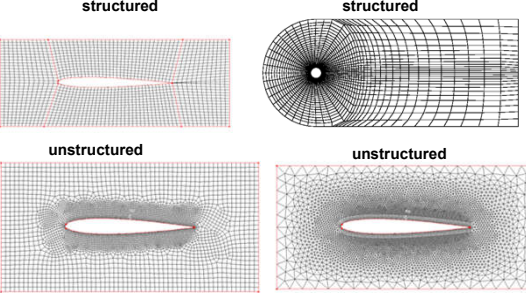
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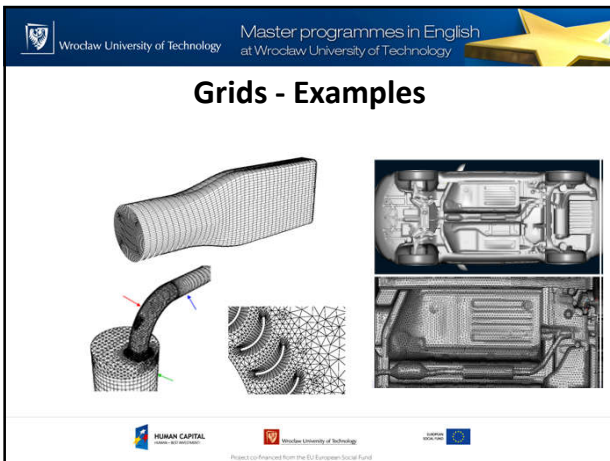
Mesh - types

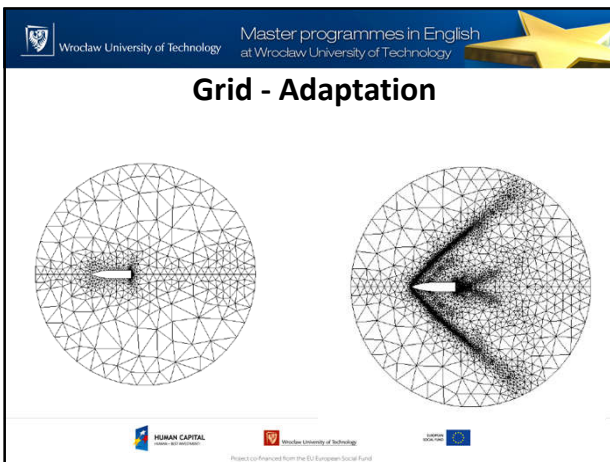
structured structured

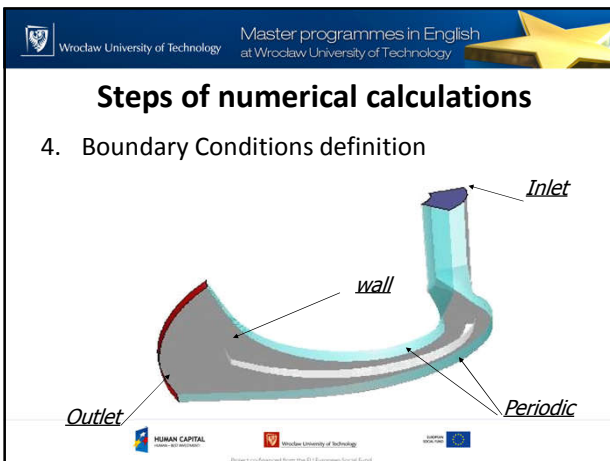
unstructured unstructured



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Boundary Conditions

E.g. - no-slip or slip-free on walls, periodic, **inlet** (velocity inlet, mass flow rate, constant pressure, etc.), **outlet** (constant pressure, velocity convective, numerical beach, zero-gradient), and non-reflecting (for compressible flows, such as acoustics), etc.

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Steps of numerical calculations

5. Calculation parameters definition

1. Definition of the under-relaxation factors
2. Choice of the discretisation scheme
3. Choice of the Turbulence model

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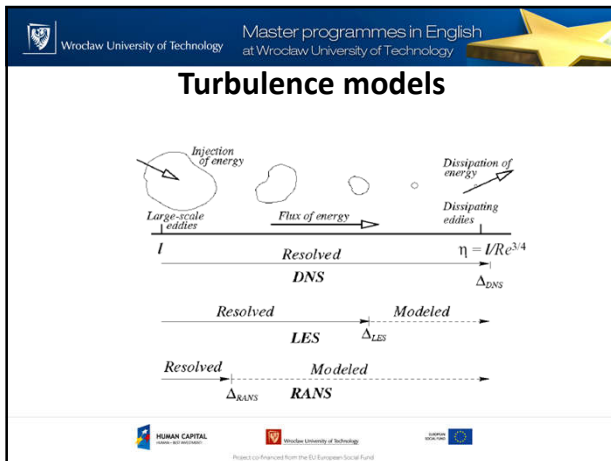
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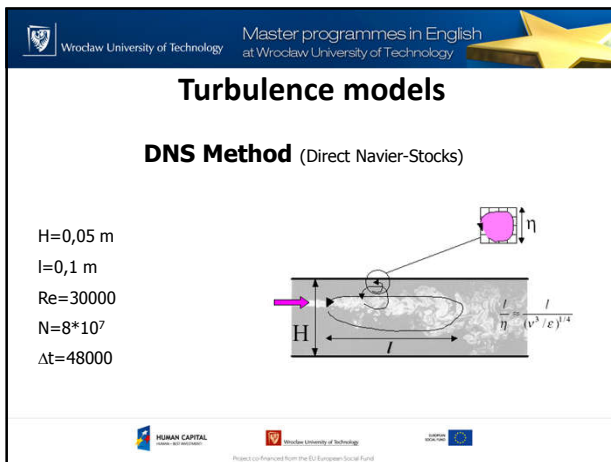
Calculation Parameters

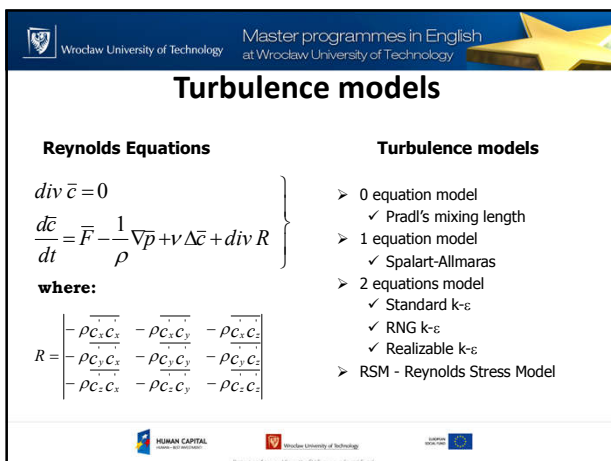
Discretisation scheme Under-relaxation Factors

$$\phi_p = \phi_{p,old} + \alpha \Delta \phi_p$$

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Steps of numerical calculations

6. Calculation

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Calculation Time

case	cells	model	physics	CPUs	total CPU hrs	elapsed hrs	elapsed days
1	5.5	RKE	steady	4	450	113	5
2	11	RKE	steady	16	750	47	2
3	11	RSM	steady	16	1200	75	3
4	11	RSM	transient	32	7000	219	9

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Steps of numerical calculations

7. Results validation

160D30

a)

b)

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CAE in CATIA - available simulation

Reduces physical prototypes - Reduces errors - Reduces costs.

Source: DASSAULT SYSTEMES - CATIA/ENOVIA Training - Digital Mock-Up Basics EDU-DMU-EN-DM8-FI-VSR17

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CAE in CATIA - available simulation

Source: DASSAULT SYSTEMES - CATIA/ENOVIA Training - Digital Mock-Up Basics EDU-DMU-EN-DM8-FI-VSR17

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CATIA – Kinematics Simulation

Source: www.youtube.com

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