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ENVIROBANAT
Common History, Common Future

The General Aspects of Computational Fluid Dynamics

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What is computational fluid dynamics ?

Computational Fluid Dynamics (CFD) can be defined as the use of computers to obtain information about fluid flow behavior in specific situations.

Is it a multidisciplinary topic ?

CFD comprises a variety of technologies including mathematics, computer science, engineering and physics, and these disciplines have to be brought together to provide the means of modelling fluid flows.

Is it restrected to highly trained experts ?

Until recently the user of CFD has been a specialist, probably trained to doctoral level, working in a research and development department. Now, however, the technology is more widely available both in industry and academia and so it is being used to provide insights into many aspects of fluid motion.

What is CFD from mathematical and physical point of view ?

Computational fluid dynamics (CFD) is concerned with numerical solution of differential equations governing transport of mass, momentum, and energy in moving fluids. CFD activity emerged and gained prominence with availability of computers in the early 1960s.

The continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

The momentum equation (Navier-Stokes):

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{dx}+\left(\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)\right)+S_x$$

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{dy}+\left(\frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)\right)+S_y$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{dp}{dz}+\left(\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)\right)+S_z$$

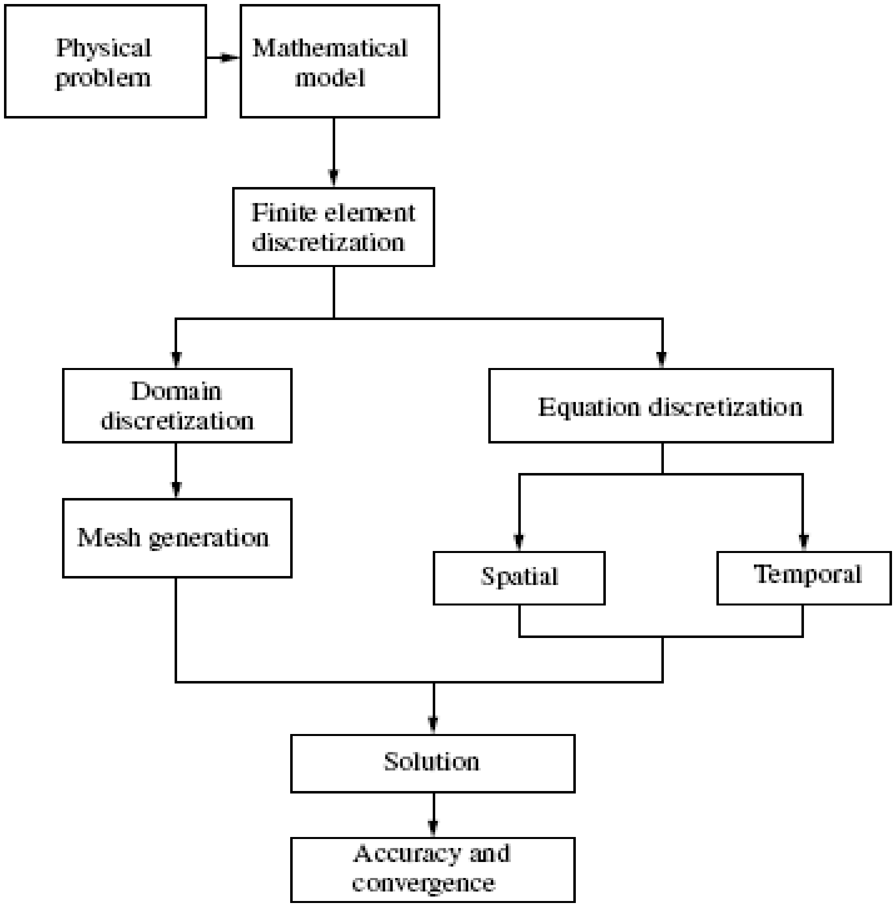
The energy equation (for both fluid and solid):

$$\rho\cdot c_p\cdot\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)$$

The species transport equation:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=D\cdot\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}+\frac{\partial^2 C}{\partial z^2}\right)$$

SOLUTION PROCEDURE



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The possible ways for solving the PDEs:

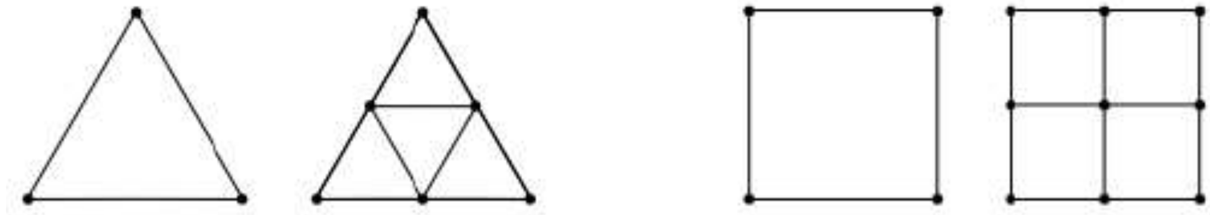
- analytical, by making the substantial simplifications that is not always possible
- the numerical solutions where the necessary information about the flow field temperature or concentrations are obtained at *discrete points* rather than at every point in space as in a continuum.
- There are several methods used for numerical solution of the PDE (1) – (6). Two of them are mostly used, the control volume and the finite element method. Applying both of the methods, one may obtain the following general form of the algebraic equation for every discrete point from the mesh:

$$a_P T_P = \sum a_{nb} \cdot T_{nb} + b$$

	Phoenics	Ansys Fluent
Discretization models	Hybrid Upwind Quick SMART, Van Leer UMIST Total of 19 schemes	First order upwind scheme Power law scheme Second order upwind scheme QUICK scheme Third order MUSCL scheme

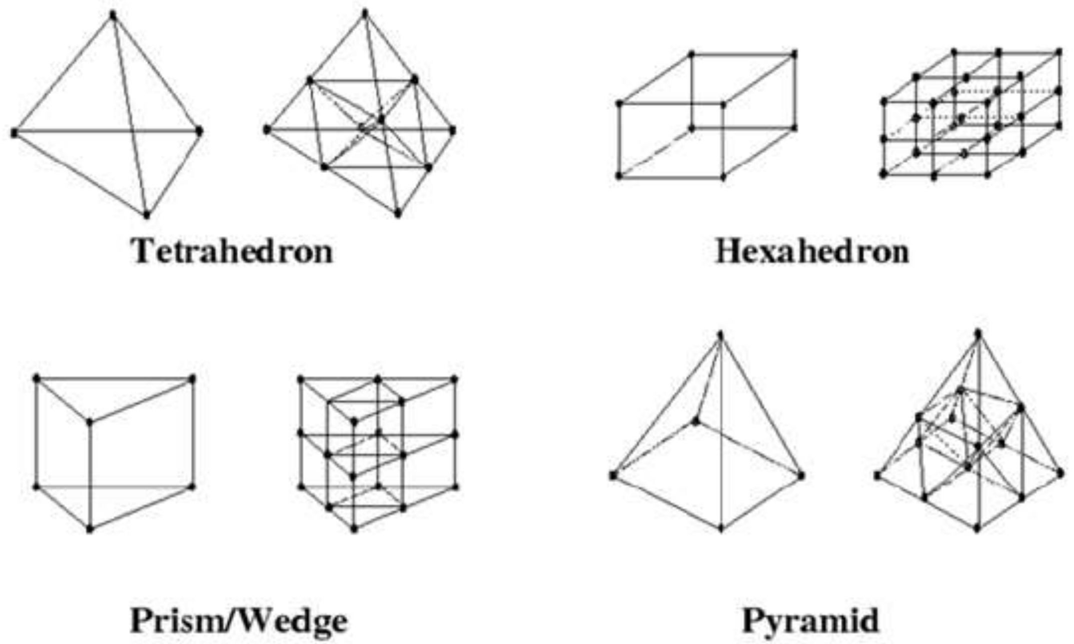
Spatial discretization

2D: quadrilateral and triangle



Triangle   Quadrilateral

3D: TETRAHEDRON, HEXAHEDRON, PRISM/WEDGE, PYRAMID



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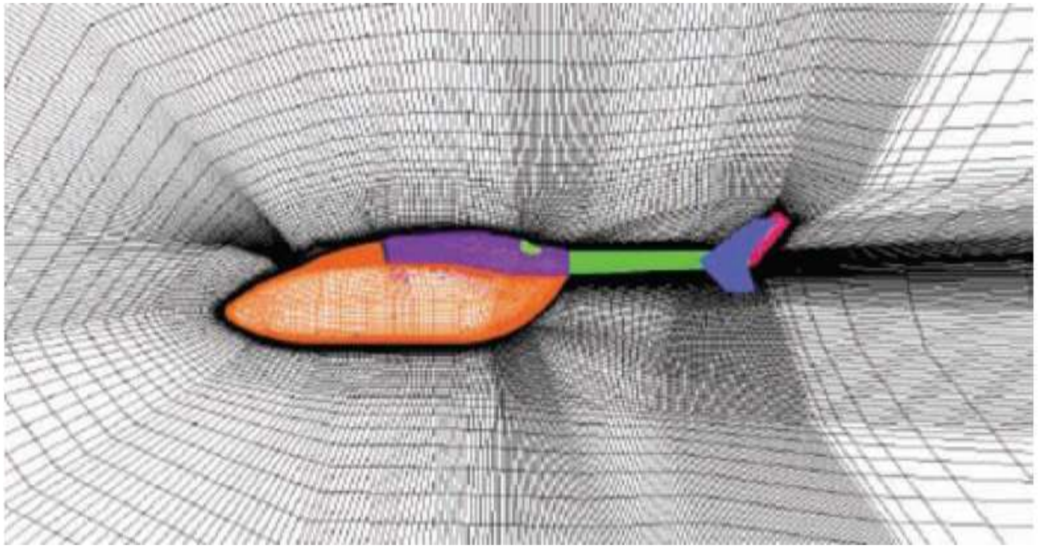
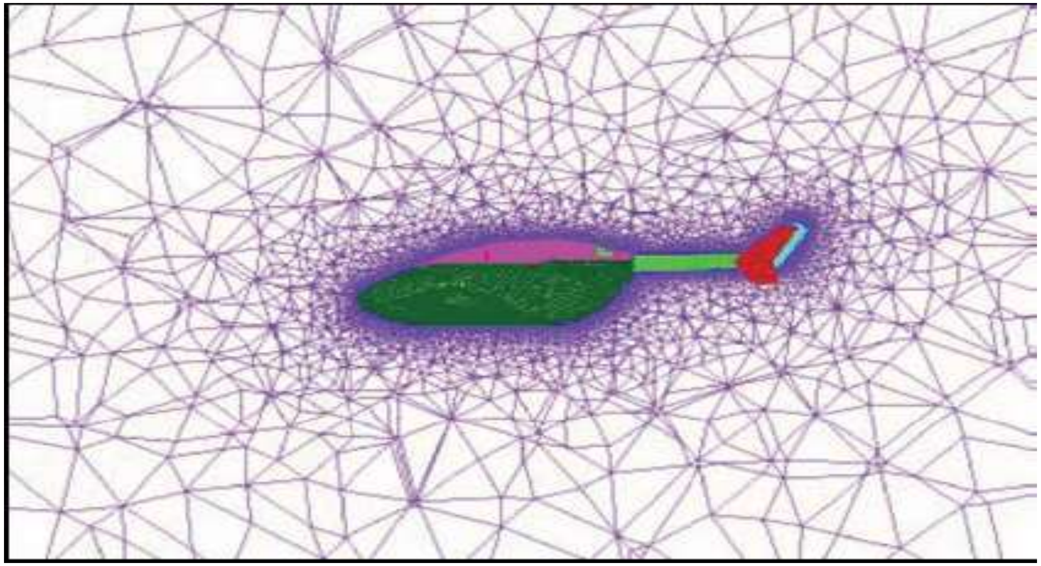


STRUCTURED MESH



UNSTRUCTURED MESH

Solution methods

Navier – Stokes equations: 4 unknowns (*u*, *v*, *w* and *p*) and only 3 equations.

how you can you obtain the solution for this problem:

1. Estimate the pressure field
2. Solve the velocity field
3. Calculate the net mass imbalance from the continuity equation
4. Correct the pressure field
5. Correct the velocity field
6. Continue the iterative procedure until the mass imbalance is vanishing

This procedure is known as the *SIMPLE* algorithm for velocity – pressure coupling and is used both by *Phoenics* commercial software and *Ansys* based softwares (*Fluent*, *CFX*): *Simple*, *Simpler*, *Simple-like*, *Simplec* or *Piso*.

Solution of the algebraic equations:

- the *TDMA* algorithm along with *line by line* procedure is applied in the case of *Phoenics*, and
- *Steady-state iterative algorithm* respectively *Time-advancement algorithm* is applied in the case of *Ansys* based codes (*Fluent* and *CFX*).

The multigrid method for solution acceleration is the standard option in the case of *Ansys* based commercial codes and in the case of *Phoenics* it is optional module made by third part (*Migal*).

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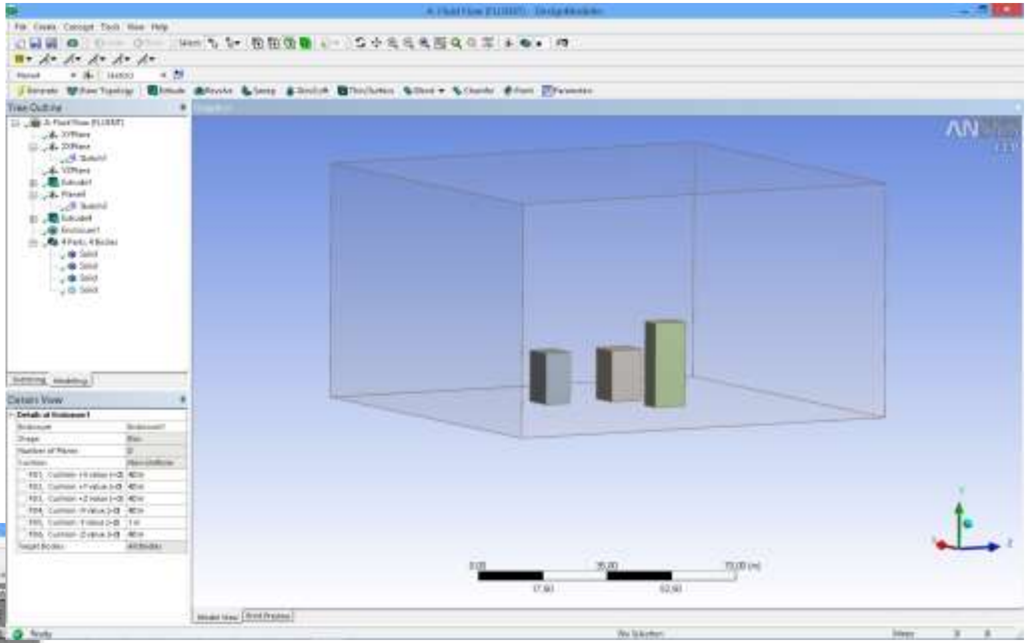
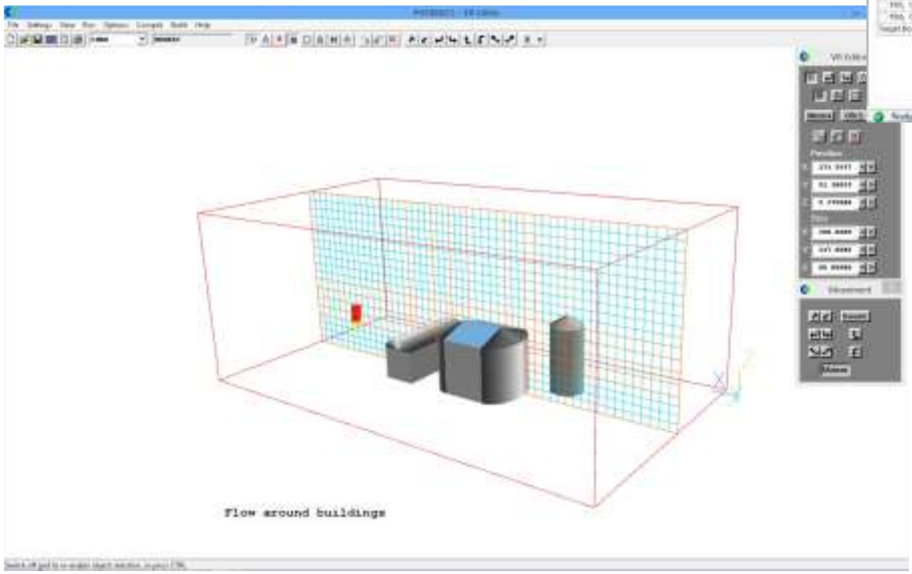
Preprocesing – graphic tools



Design Modeler- Ansys Fluent



Virtual reality - Phoenics

The application examples

The aircraft design

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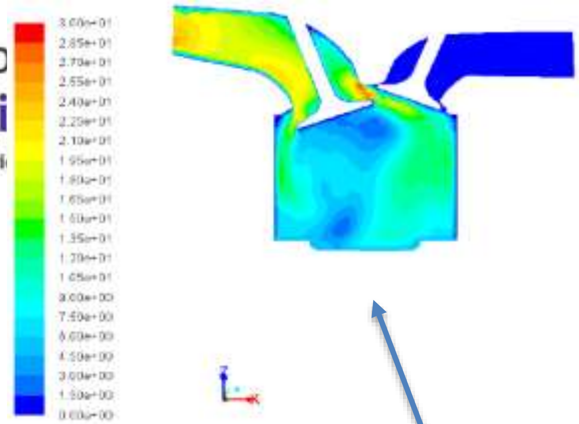
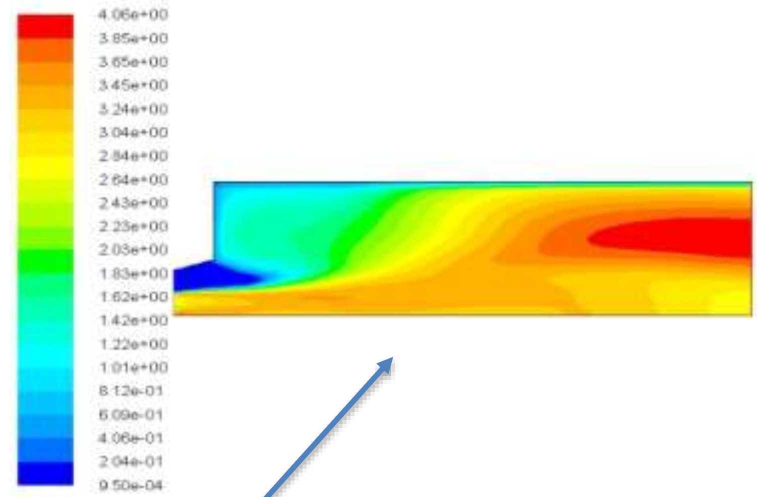
Air flow inside internal combustion engines



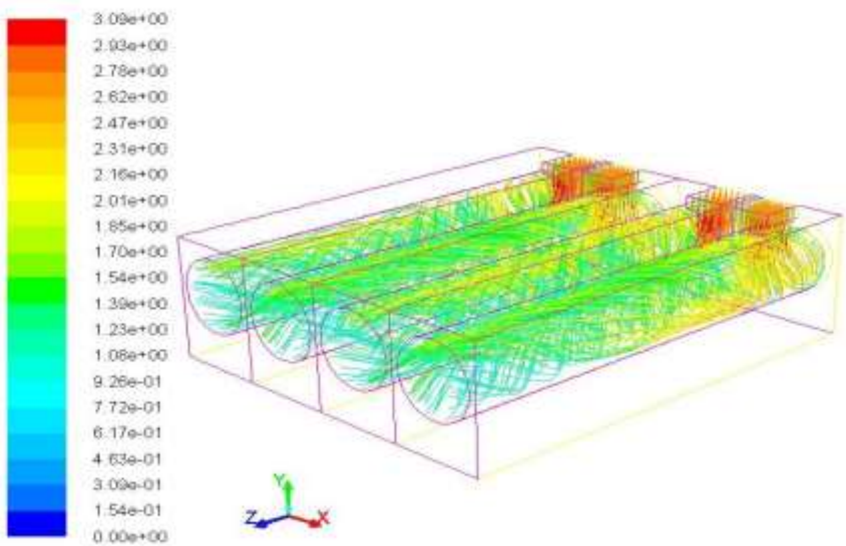
The velocity contours inside the IC engine

Flames in burners



The turbulent flame speed of the premixed combustion inside the co-axial burner

Cooling of the electrical equipment



The velocity pathlines inside the microchannel tangential heat sink for electronics cooling

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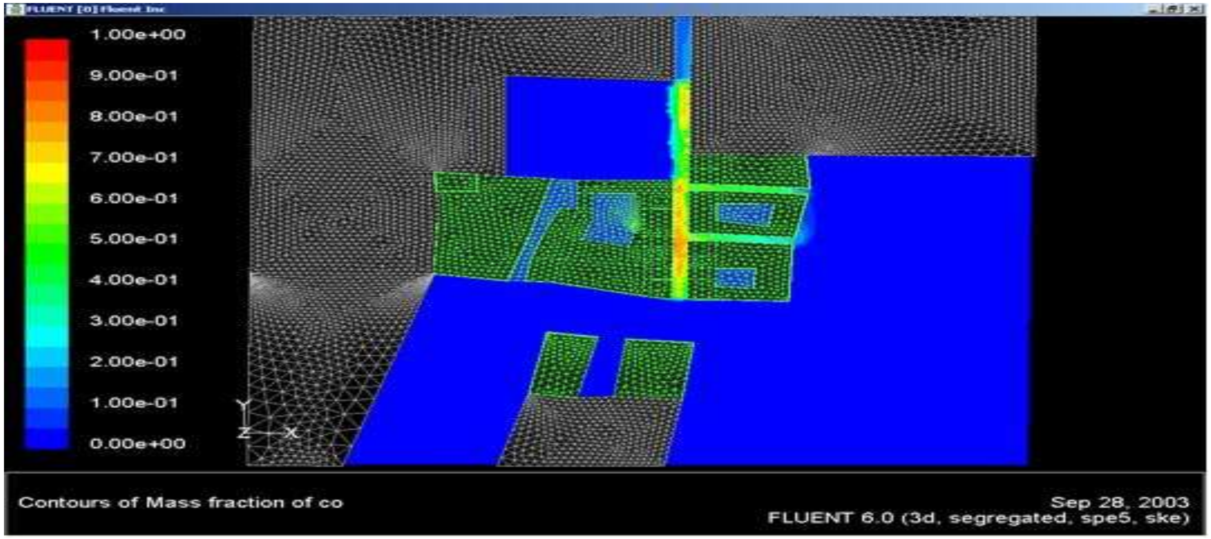
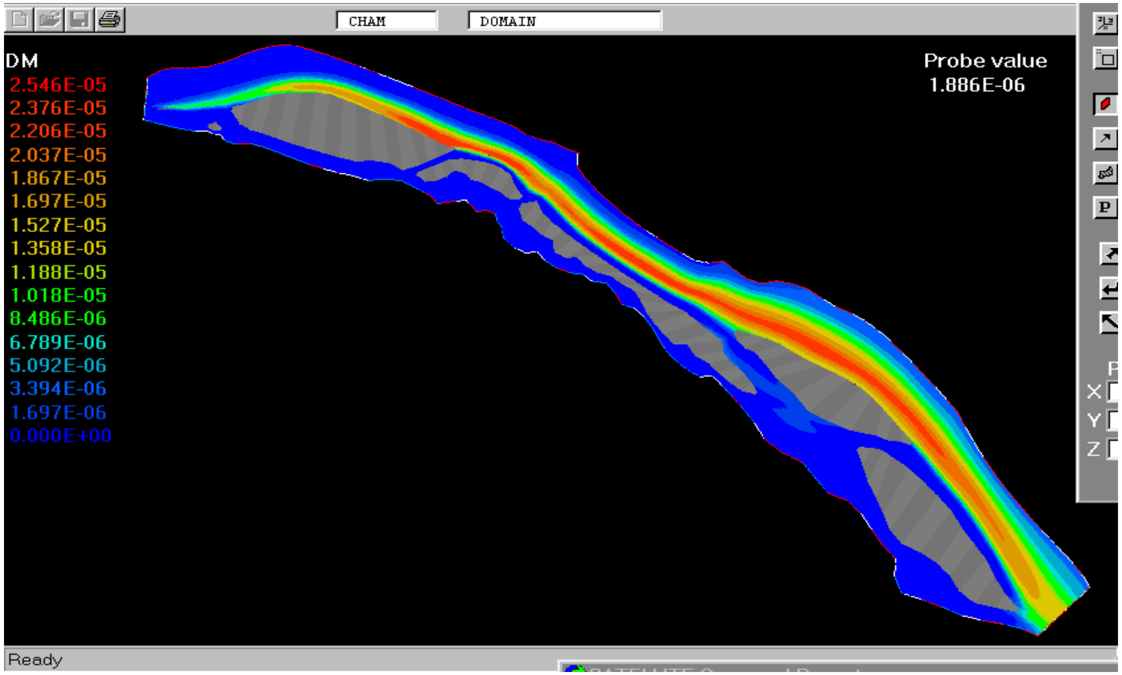
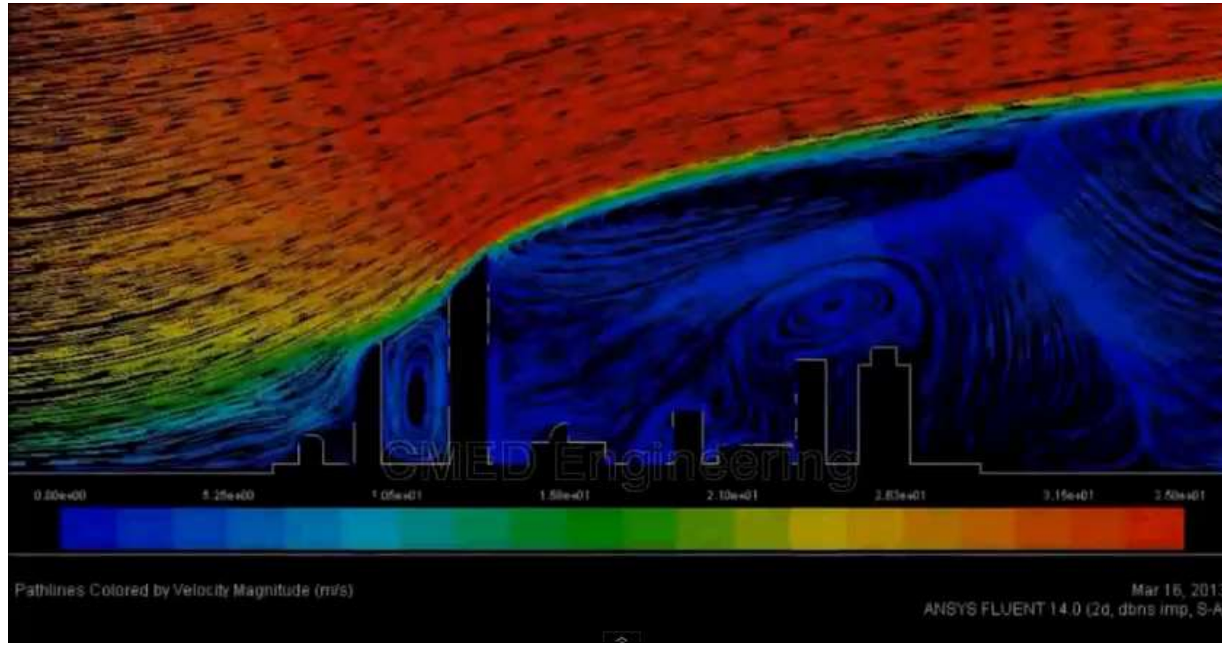
The dispersion of pollutants in the air



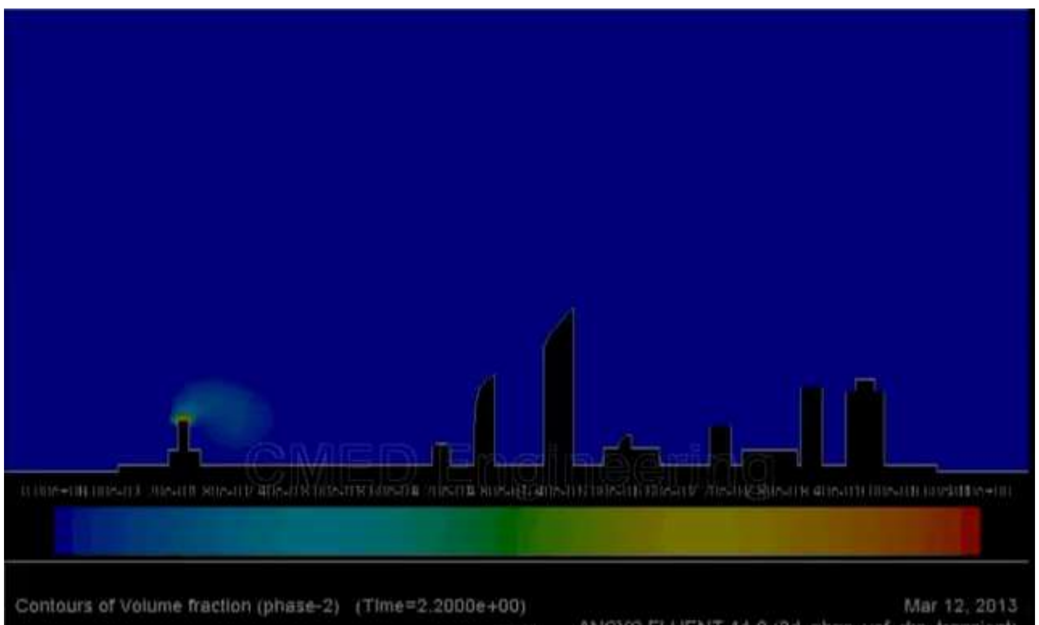


The dispersion of pollutants into river

The velocity pathlines of the wind in the urban area



The contours of the polutant volume fraction in the urban area



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