Lecture to Heat Transfer Society, June 24, 2009

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Gateways to PHOENICS:
SHELLFLO

Advanced Stream Analysis: Predicting the Flow in Shell-and-Tube Heat Exchangers

by

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June 2009

What do we **need to know** about flow patterns in heat-exchanger shells?

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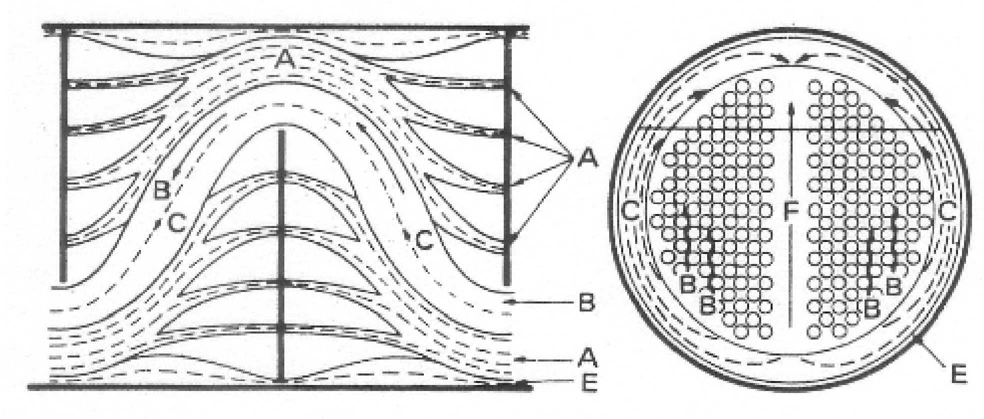
Most shell-and-tube heat-exchangers are designed on the basis of the '**stream-analysis**' proposed in 1958 by **T.Tinker.**



It **may** be satisfactory for predicting their steady-state **thermal performance** (although many designers have reason to doubt it);

but it is certainly **not satisfactory** for determining locations of
- **high velocity** likely to cause tube vibrations,
- **low velocity** where deposition of solids may occur;
- **deviations from presumed-uniform heat-transfer coefficients;**

or
- **time-dependent** effects..

Space-averaged CFD contrasted with conventional, *i.e* **fine-grid,** CFD

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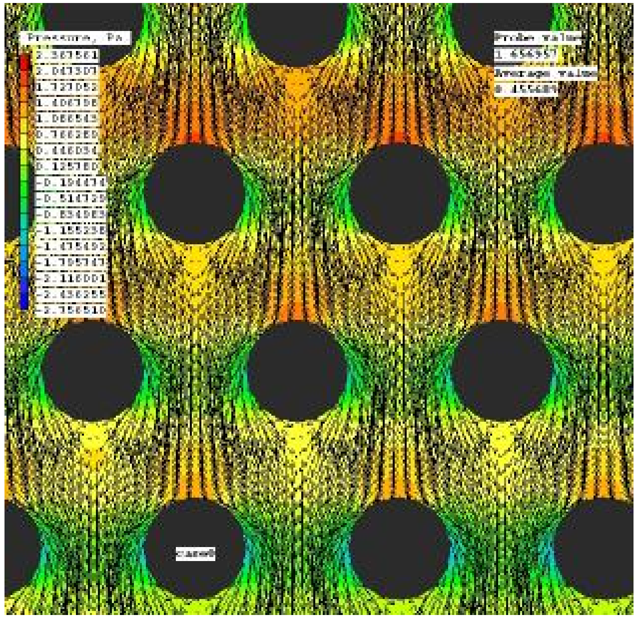
Space-averaged computational fluid dynamics (SACFD) **can** provide such information, and more.

What is the **difference** between SACFD and fine-grid CFD in the heat-exchanger context?

Fine-grid CFD seeks to compute the flow **between** the tubes in **detail.**

SACFD computes the **average** velocities, temperatures, *etc* over larger volumes containing many tubes.



SACFD **is economical** enough to be used in everyday design; Detailed CFD **is not**; and ignorance about **turbulence** and two-phase effects also limits its reliability .

More about space-averaged CFD

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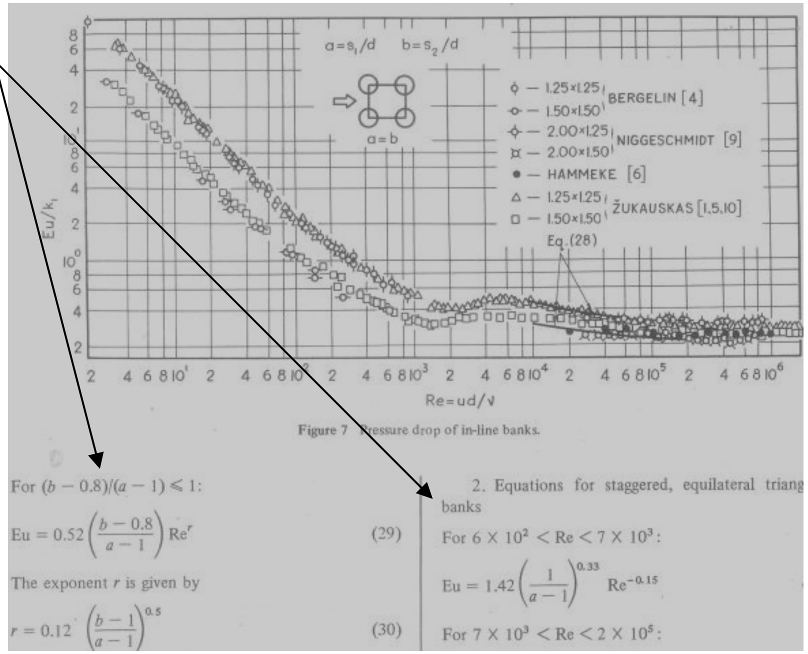
SACFD uses **empirical formulae** for volumetric heat-transfer and friction coefficients, unlike fine-grid CFD which seeks (expensively and uncertainly) to compute them.



In this it is **like standard heat-exchanger-design packages**, BUT **they** presume that the coefficients are **constant** for the whole heat exchanger.

But they are **not** constant: the **relative velocities** and the **fluid properties** vary greatly with position inside the shell.

SACFD might be called '**Advanced Stream Analysis**'; it **shares** some earlier concepts, but embodies better **physical knowledge**.

Still more about space-averaged CFD

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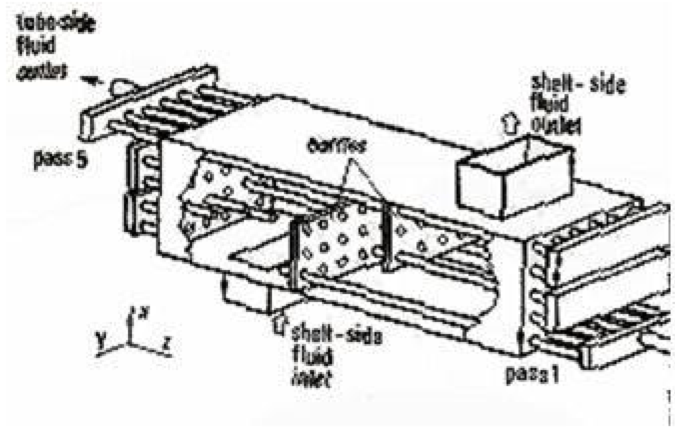
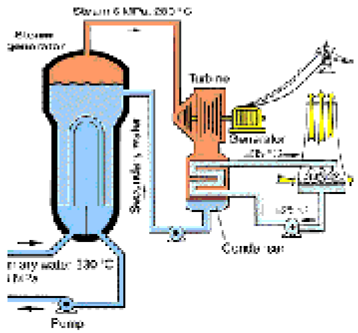
SACFD has been available for heat-exchanger analysis **for many years.**

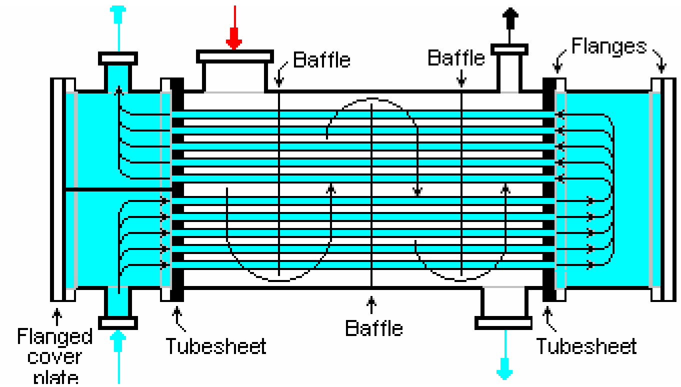
The image on the right dates from 1975.





It was first **successfully used** for simulating **nuclear**-plant steam-generators (left), once plagued by **flow-induced tube vibrations**

Another use is for **power-station condensers** (right) in which **shell-side air content** varies enormously between inlet and outlet.



SACFD could & should now be used for design of **all** types of heat-exchangers

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The advantages will be:

- performance will be **more accurately** predicted;
- **specification-satisfying** designs will therefore be **cheaper**;
- **insight** will be enhanced by **flow visualisation** ;
- currently **unpredictable** phenomena, *e.g.* transient effects and mechanical stresses will be brought to light.

BUT HOW? Easy-to-use and inexpensive **software** must be created and distributed; and

ease of use implies doing what the user wants, and **no more.**

SHELLFLO is CHAM's first attempt to provide such a package.

Comments are invited on whether it **is** what the user wants.

What is SHELLFLO?

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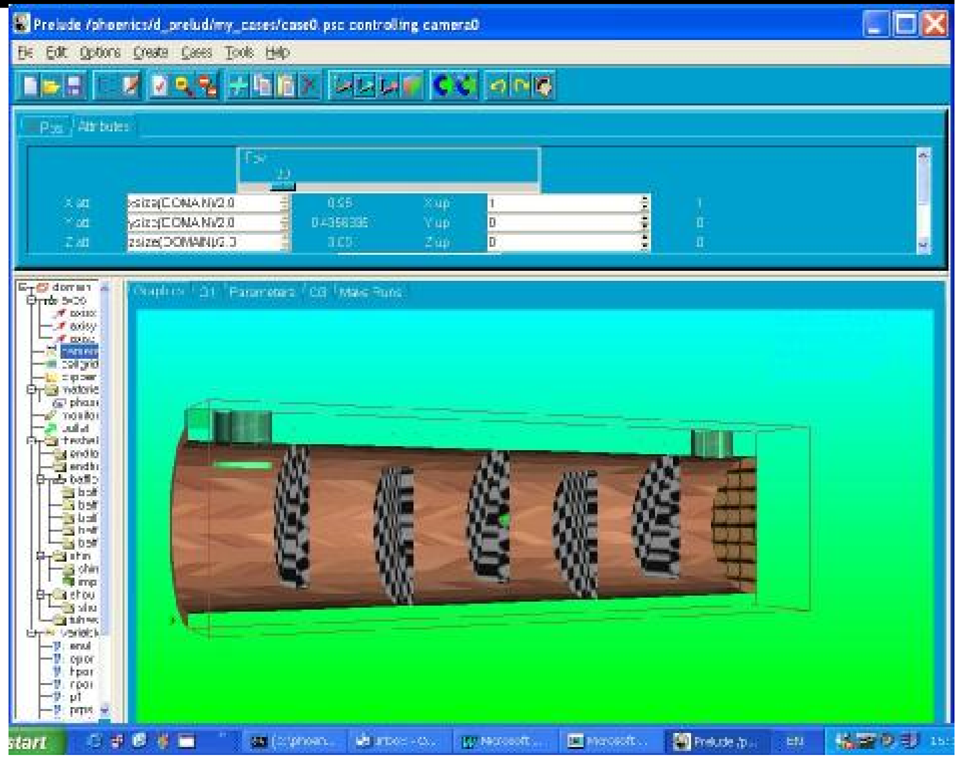
SHELLFLO is an easy-to-use software package devoted mainly to the task of **flow prediction** in shell-and-tube heat exchangers.

Although distributed as a stand-alone package, it is one of many '**Gateways**' to the general-purpose **PHOENICS** program.

Its graphical user interface (above right) is the **PRELUDE** module of the PHOENICS, in which **REL** stands for **RELational.**



SHELLFLO can be used on any personal computer.

Its users require no CFD expertise.

What SHELLFLO does:
1. predicts how dimensions of baffles, tubes, *etc* influence the flow

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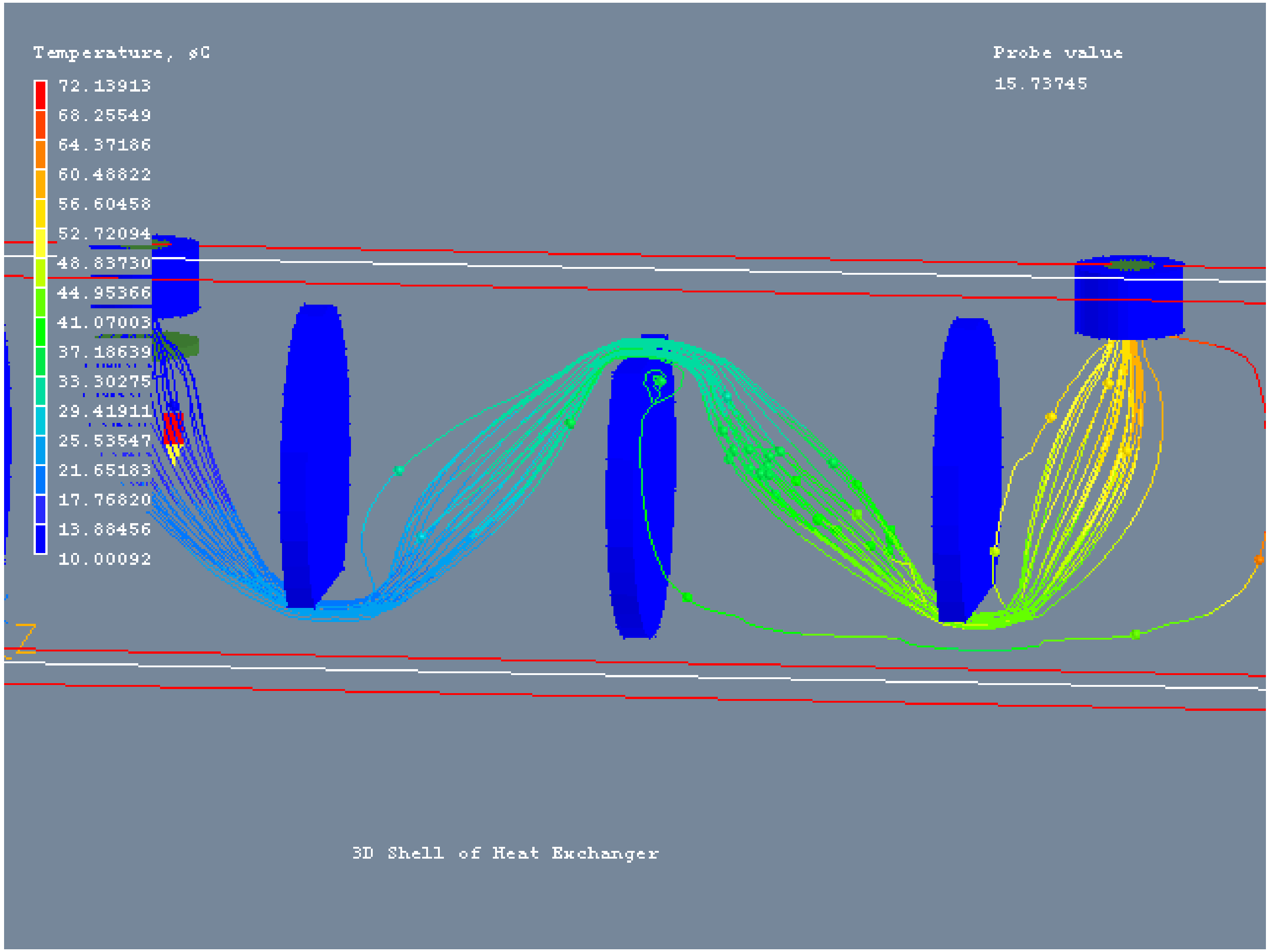

What SHELLFLO does:
2. displays results in various ways
e.g. via contours and vectors

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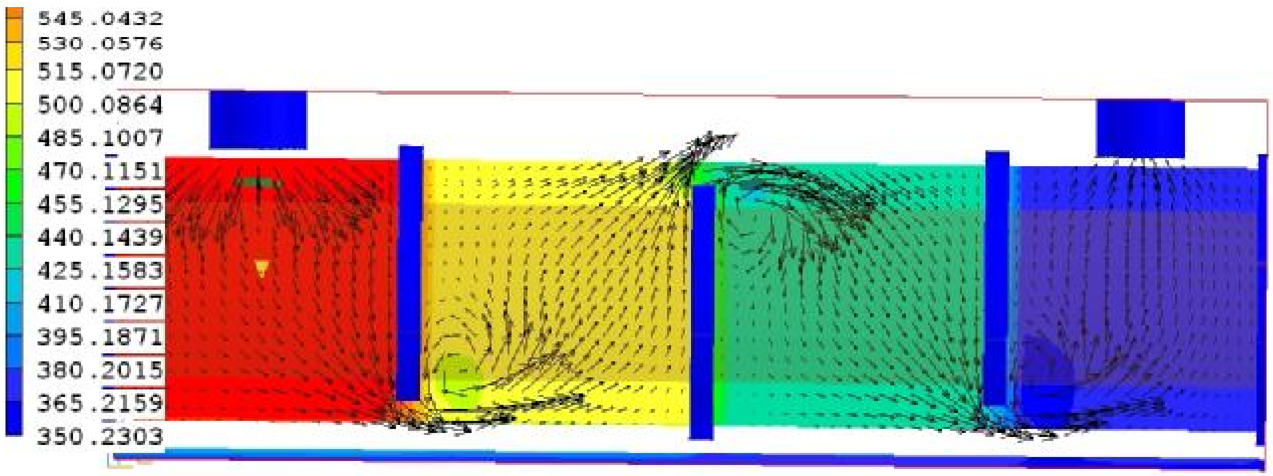

Note the pressure drop across baffles

Here are seen the computed central-plane **pressure contours** in a shell in which the baffles block a large proportion of the shell cross-sectional area.

Also shown, as black arrows, are the shell-fluid **velocity vectors**.

The effect of the **impingement plate** is evident on the left.

What SHELLFLO does:
3. predicts shell-fluid temperature from **prescribed** tube-fluid inlet temperature.

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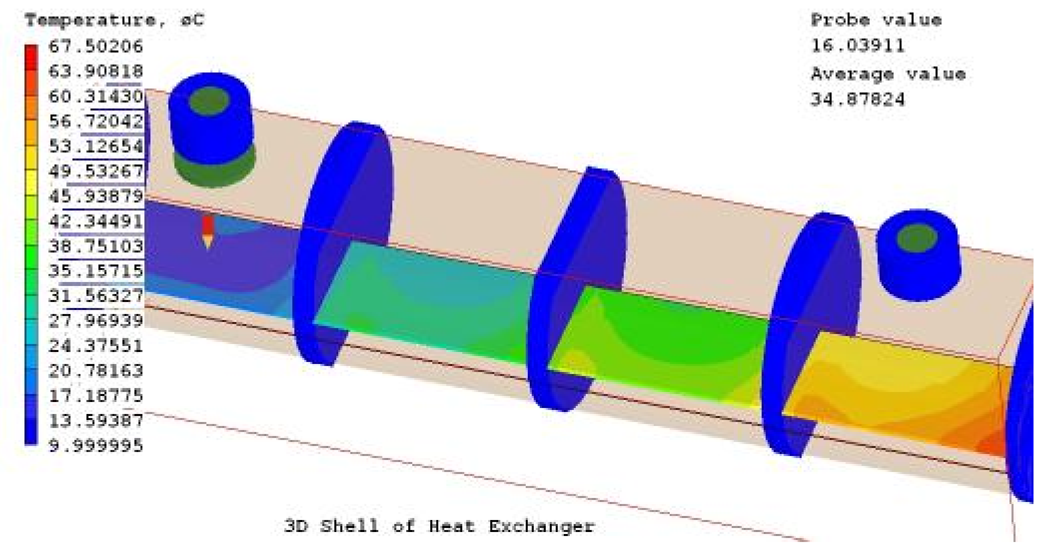
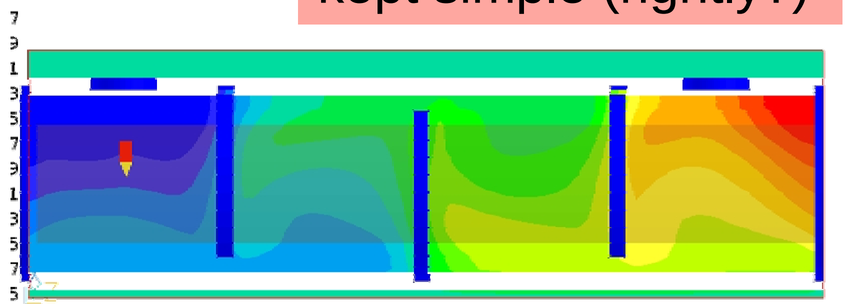


Shell-fluid temperature in (left) horizontal and (below) vertical planes

Tube-fluid flow-distribution **calculation** could be provided also; but SHELLFLO has been deliberately kept simple (rightly?)

The temperature distribution in the **shell-side fluid** is calculated from **local** heat-transfer coefficients which **vary** in accordance with the local shell-side fluid velocities, viscosity, *etc*,



What SHELLFLO does:
4. deduces material properties of shell-side fluid (water) from its temperature

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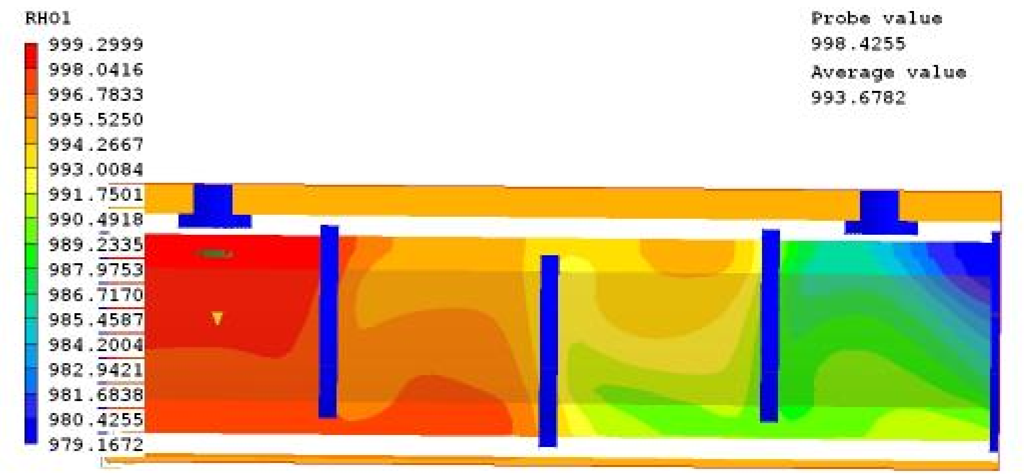
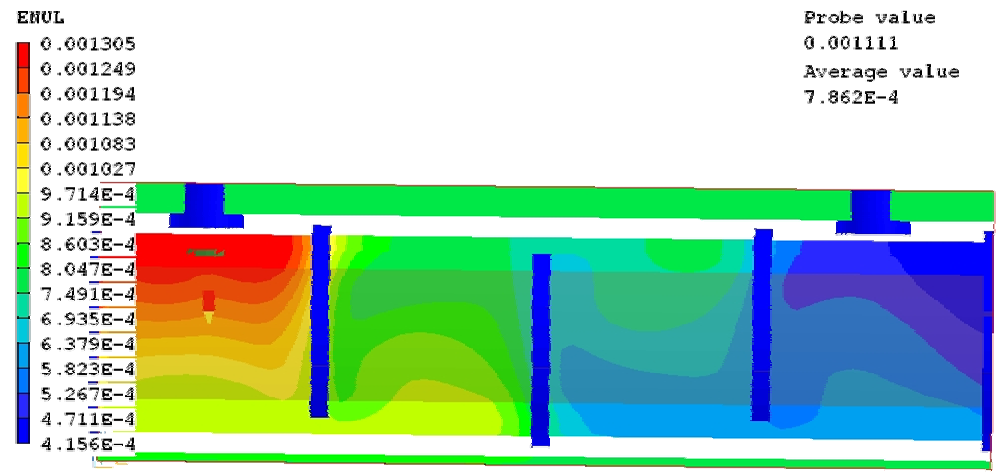


Density of water inferred from Tem1, *via* user-selected formula



3D Shell of Heat Exchanger

Viscosity of water, likewise inferred from Tem1 *via* a formula

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What SHELLFLO does:
5. displays and allows editing of material-property formulae

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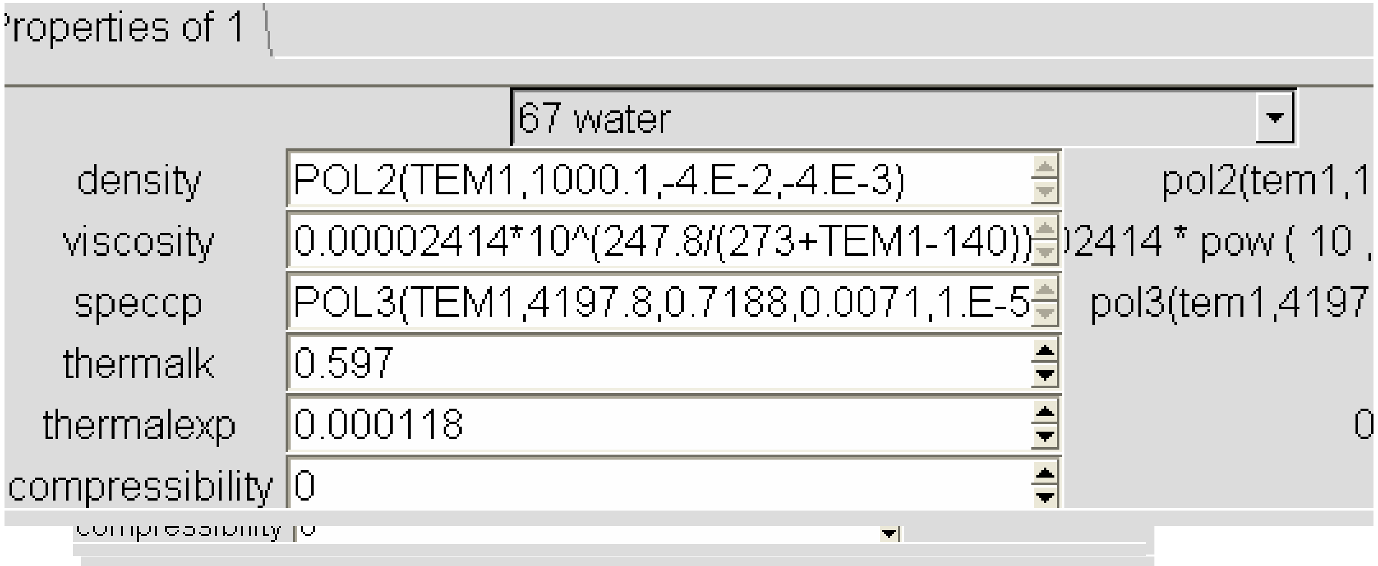

Material properties are set by **user-chosen formulae** which are directly interpreted by the SHELLFLO solver.

Here TEM1 stands for temperature. POL2 and POL3 are polynomial evaluators (used for density and specific heat).

Viscosity is set by a formula fitted to **experimental data** (by separate use of Excel, in this case).

What SHELLFLO does:
6. displays and allows editing of friction and heat-transfer formulae

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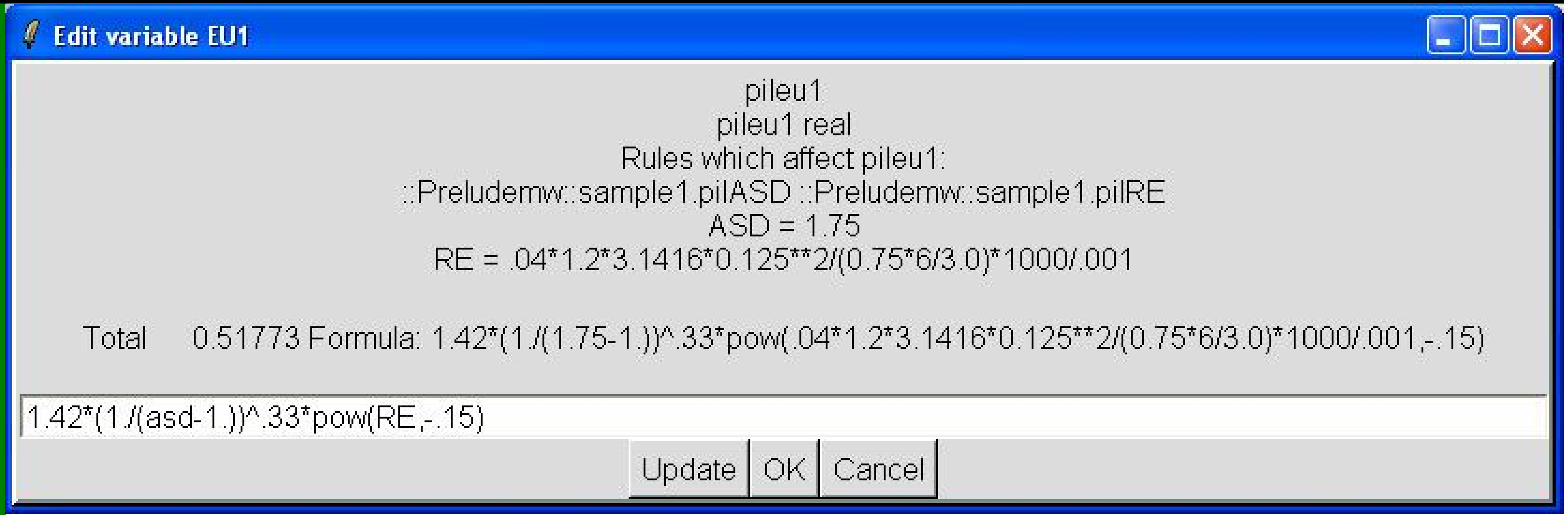

The **Euler** number is a dimensionless volumetric **pressure-drop** coefficient. **Pileu1** is its name in SHELLFLO**.**

It depends on Reynolds number (RE) and tube spacing *via* a **handbook formula,** shown here in the white box.

It can be **edited** by the user; then the interface shows its evaluation. RE depends on velocity and viscosity, **different at each location**; ASD is ratio, here 1.75, of tube_diameter/spacing.

How to use SHELLFLO:
1. Choosing the SHELLFLO gateway

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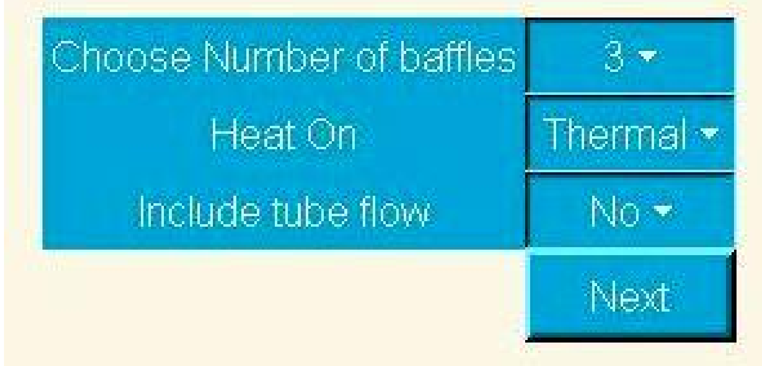
When the PRELUDE program is launched. It offers the user several gateways.

To get the one needed by the heat-exchanger designer, click 'shellflo'.

The next screen will give you the choices shown below.



SHELLFLO comes with many settings already made, *e.g.* just 3 baffles; and it offers an early opportunity to change some of them.

Otherwise just click 'Next'.

How to use SHELLFLO:
2. Choosing the number of baffles

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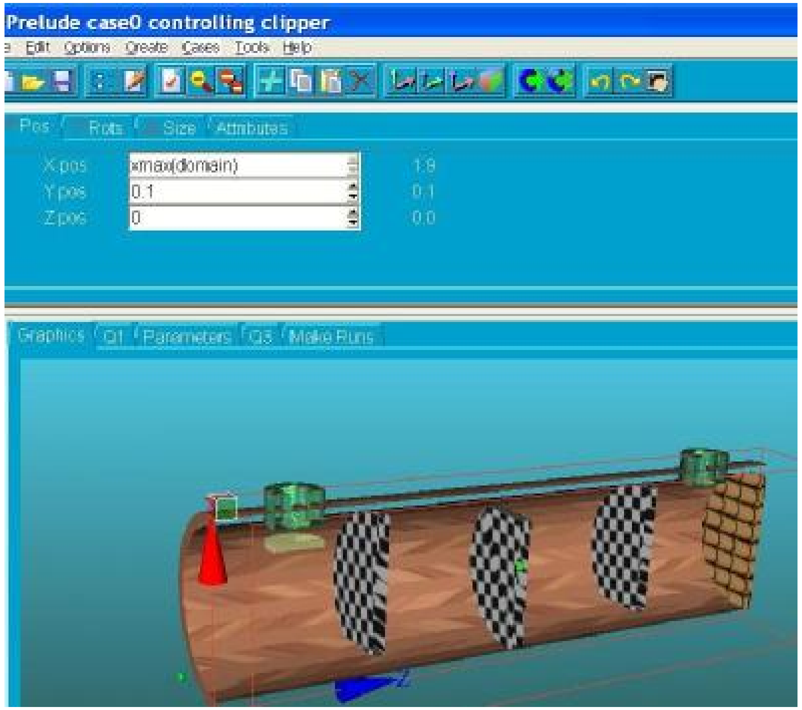
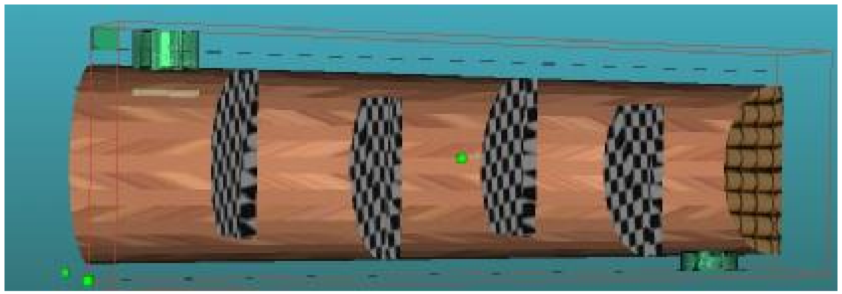
SHELLFLO

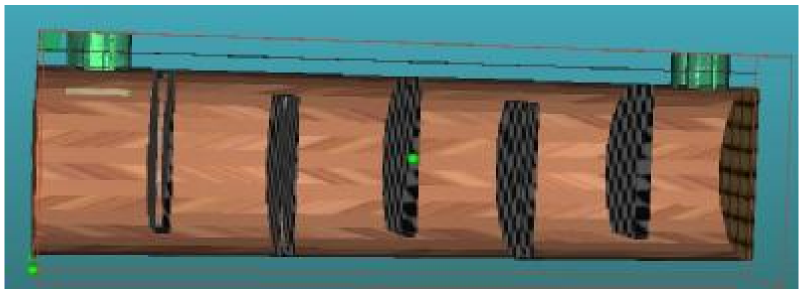
What then appears is shown on the right **à**

Note that it has the default three baffles.

If an even number is chosen, the outlet nozzle changes position, because the **relative positions** of baffles and nozzles obey built-in rules. See below for four and five baffles.







How to use SHELLFLO:
3. Viewing the ‘object tree’

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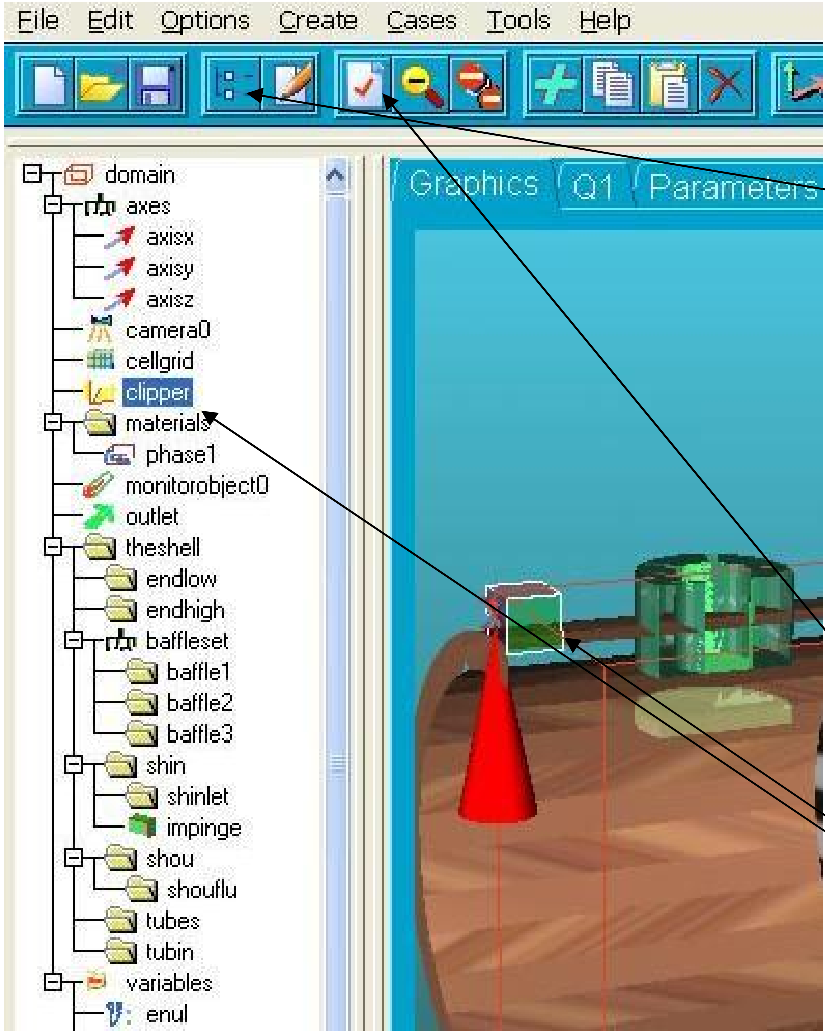


SHELLFLO’s objects are organised as a ‘**tree**’. Click its **icon** to display it.

The **object-name** meanings are easily guessed
(or changed by the user):

- shinlet = shell inlet
- impinge = impingement plate
- baffle1 = first baffle
- *etcetera*

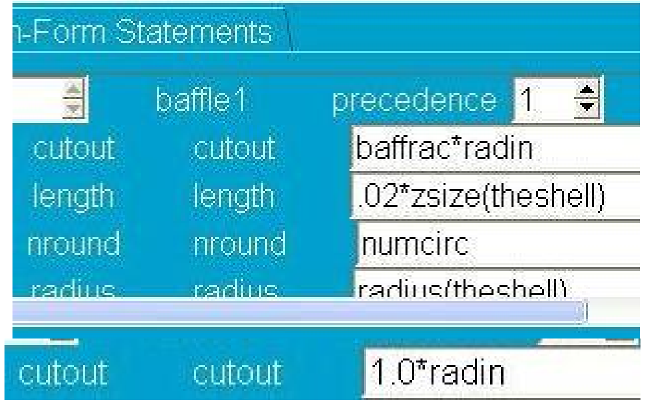
Objects ‘selected’ by a mouse click are high-lighted. Here the ‘**clipper**’ object is selected..

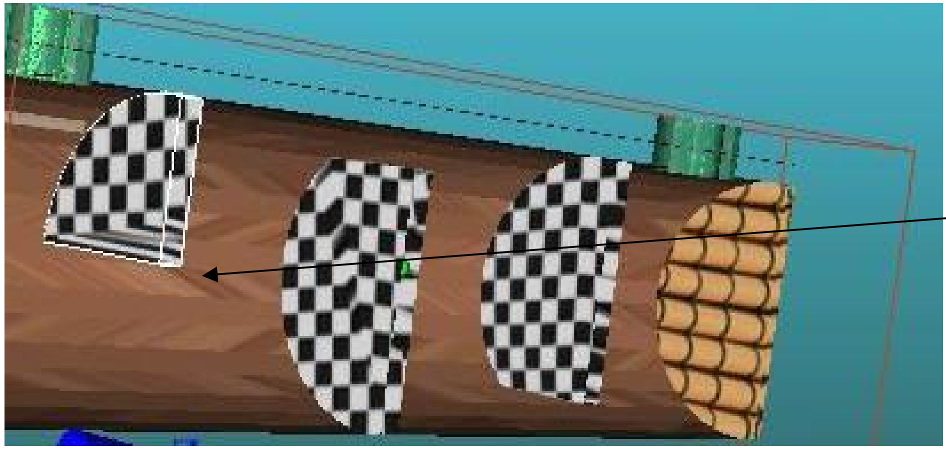
Click here to see the selected object’s **attributes.**

How to use SHELLFLO:
4. Changing baffle1's attributes

If 'baffle1' is selected and its attributes called for, the screen shows, as well as position and size, what is seen on the right.

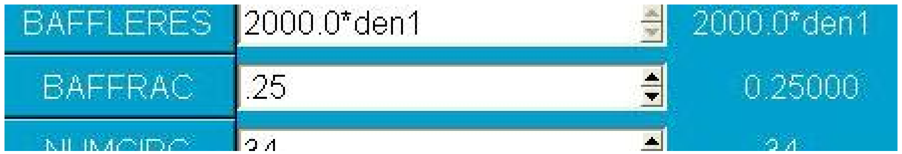
Let us change 'cutout' to this à





Then the shape of baffle1 changes instantly as seen here.

If instead we had changed the value of 'baffrac', all of them would have changed



SHELLFLO has a panel for ß this; and for much else.

How to use SHELLFLO:
5. Making a series of flow-simulating runs

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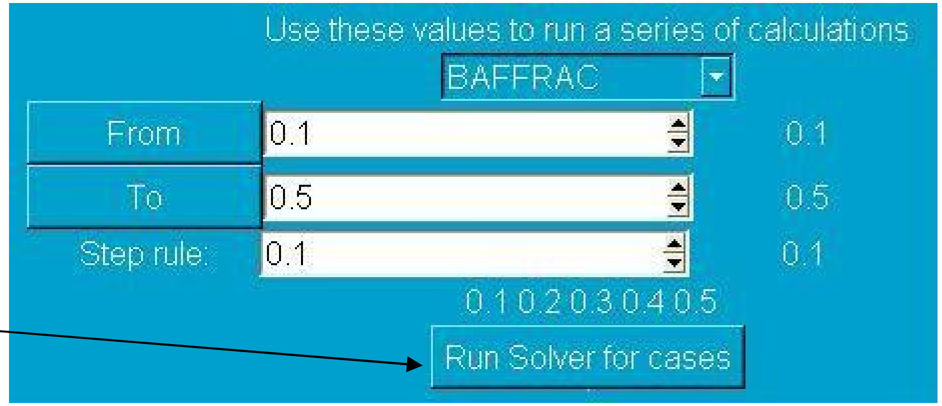
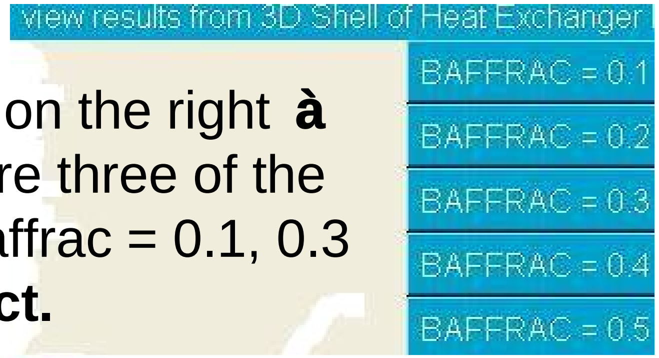
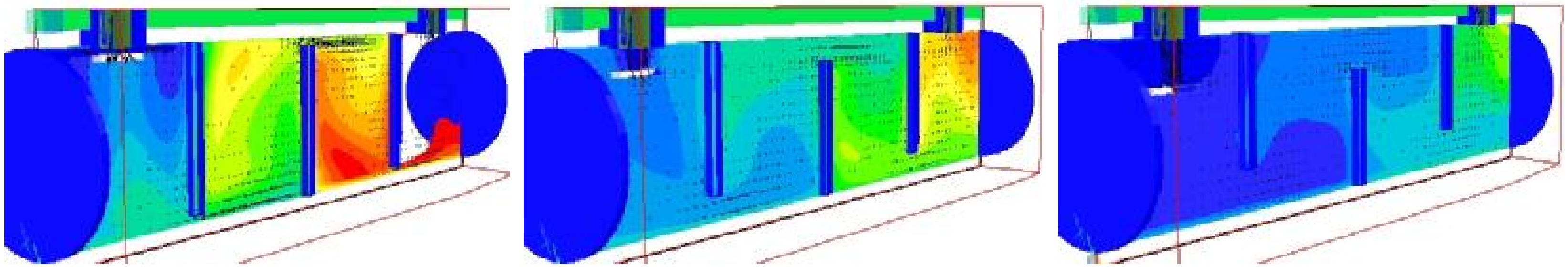
SHELLFLO

How will the performance depend on the '**baffrac**' value? It is easy to find out by defining a series of runs and then clicking **here.** The runs are then perfomed **automatically.**



After few minutes you will see the boxes on the right à Then click on the one you want. Below are three of the first-presented **temperature** fields, for baffrac = 0.1, 0.3 & 0.5 . Obviously **baffrac has a big effect.**





What SHELLFLO does: Summary

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SHELLFLO's main function is to allow the heat-exchanger designer to **explore** the influences of **geometrical changes**, and of **fluid-property variations**, on:

• **Hydrodynamic behaviour:** flow pattern, pressure drop, high- and low-velocity locations, tube-vibration likelihood, *etc*; and

• **Thermal behaviour:** temperature distributions, heat-transfer-coefficient variations, maximum and minimum **heat fluxes,** *etc*.

The user requires no specialist CFD expertise; but he should:

1. Familiarise himself with the **icons and text boxes** of the graphical user interface; and
2. Learn how to **explore** the printed-out and graphically displayed flow-simulation **results**.

The capabilities of SHELLFLO are defined by a PRELUDE script; they can be **increased** (or reduced) by **editing** that file.

SHELLFLO's capabilities: Final questions

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Has SHELLFLO been provided with **unnecessary** capabilities?
If so, what are they?

Does SHELLFLO lack any essential capabilities, *i.e.* ones which **must be supplied** before it can be of practical interest?
If so, what are they?

What not-yet-supplied features would be **desirable**? And in what order of priority? For example:

- **tube-header-**flow simulation?
- **time-**dependent behaviour?
- mechanical-**stress** prediction?
- more (all?) **TEMA** exchanger **types**? Which first?

Would you like to try it? To lease it? To buy it if the price were right?

What would **be** the **right price**?

Further information relevant to SHELLFLO

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- SHELLFLO is just one of many PRELUDE 'Gateways to PHOENICS'

- Another relevant to heat exchangers is TUBEBANK, which applies **fine-grid CFD** to flow and heat transfer within the spaces between the tubes.

- TUBEBANK uses a **two-dimensional** model of the flow, but it can include **fully-developed** flow in the third (parallel-to-tube) direction.
- This is more useful to researchers than designers; but it can be used to **augment** and **extrapolate beyond** the available empirical heat-transfer and pressure-drop data.

- It can thus represent **inclined** and **two-phase flow** behaviour, for which experimental data are absent.

Applying PHOENICS to Tube Banks using fine-grid CFD

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• PHOENICS **can** be used to simulate the flow in **3 dimensions**, but **computer times** and **storage** for modelling a **complete** heat exchanger could not be afforded for design.

• For realism, it is necessary to consider a bundle having several rows and columns; then so-called **'cyclic' boundary** conditions are applied, so as to simulate a very large bundle.

• 2D calculations can be used so as to provide the **volumetric** friction and heat-transfer parameters used in the **Space-Averaged CFD** method used by SHELLFLO.

• Material properties varying with temperature can be used.

The calculations which follow took less than 5 minutes on a medium- speed PC.

The TUBEBANK Gateway: the graphical user interface

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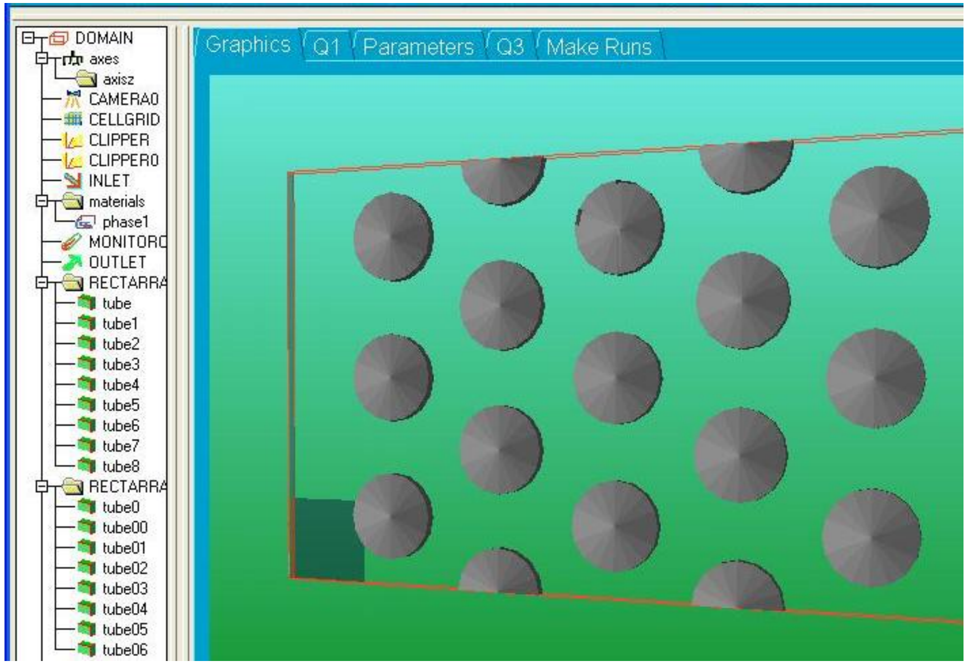
For users' convenience, all PRELUDE Gateways look much the same, *e.g.* with object tree on left.

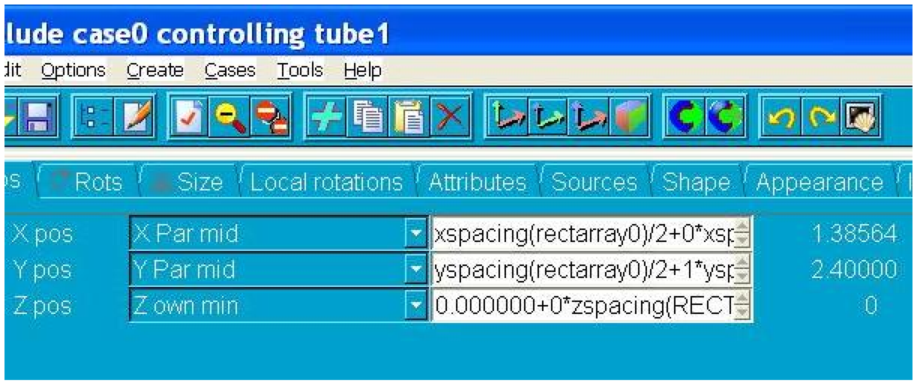
This has 2 rectangular arrays of tubes, to allow both **in-line** and **staggered.**

On the right is the attribute menu for tube 1.

Note that its position is expressed *via* a formula.

PRELUDE is **RELational.**





Tube-Bank Computations: Velocity & Pressure

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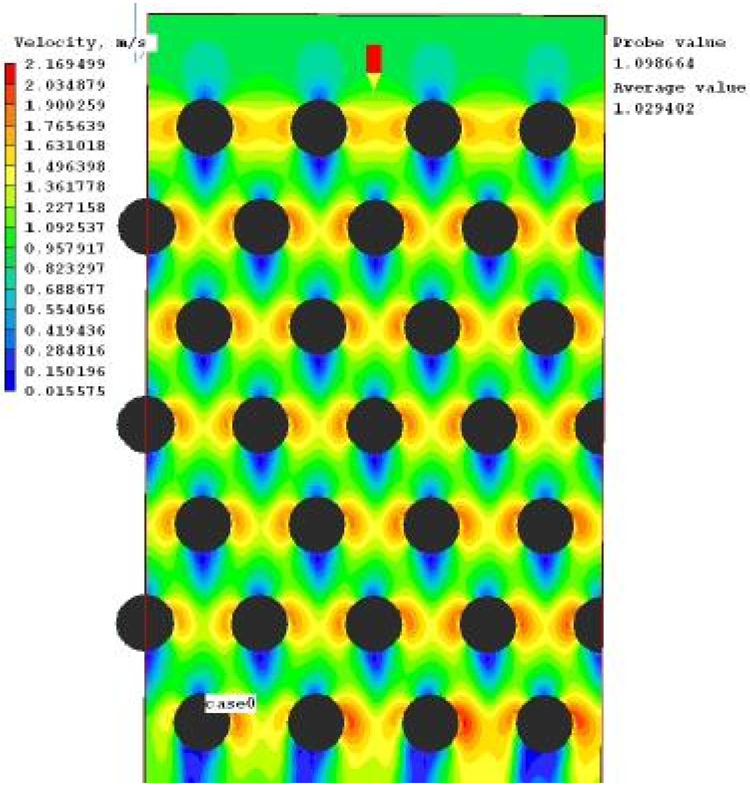
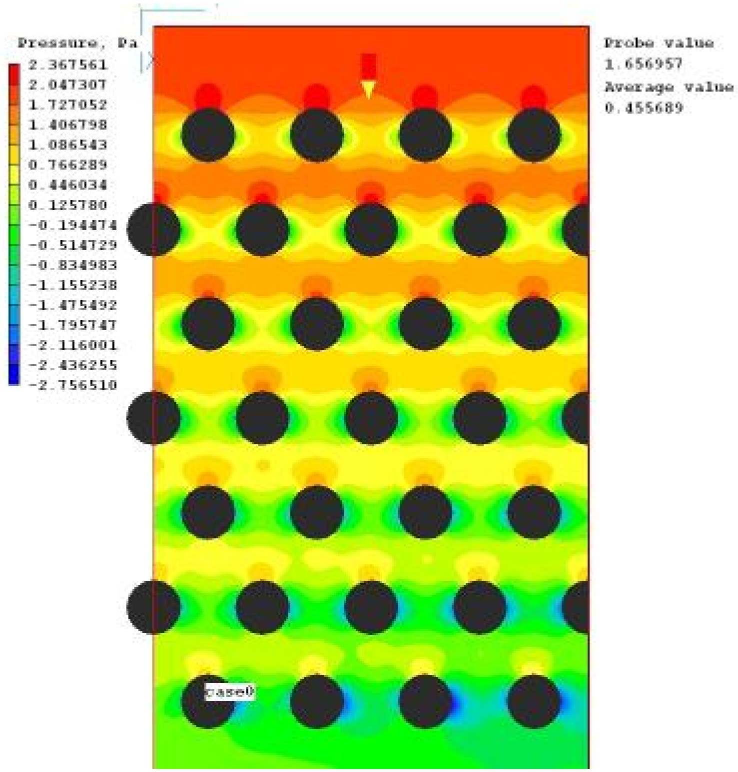
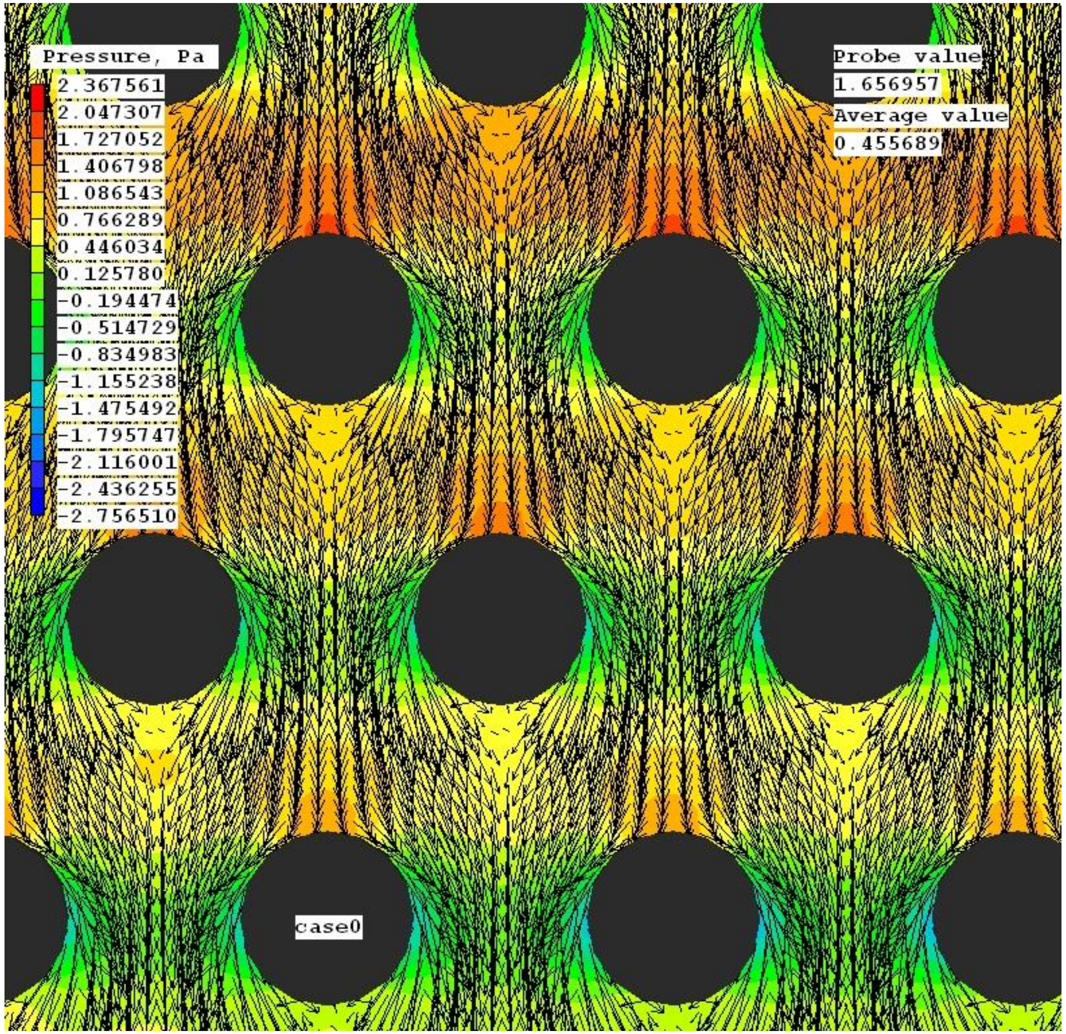


Absolute velocity



Pressure – note the pressure drop across tubes.

Velocity vectors



Note separation zones and Consequent recirculation

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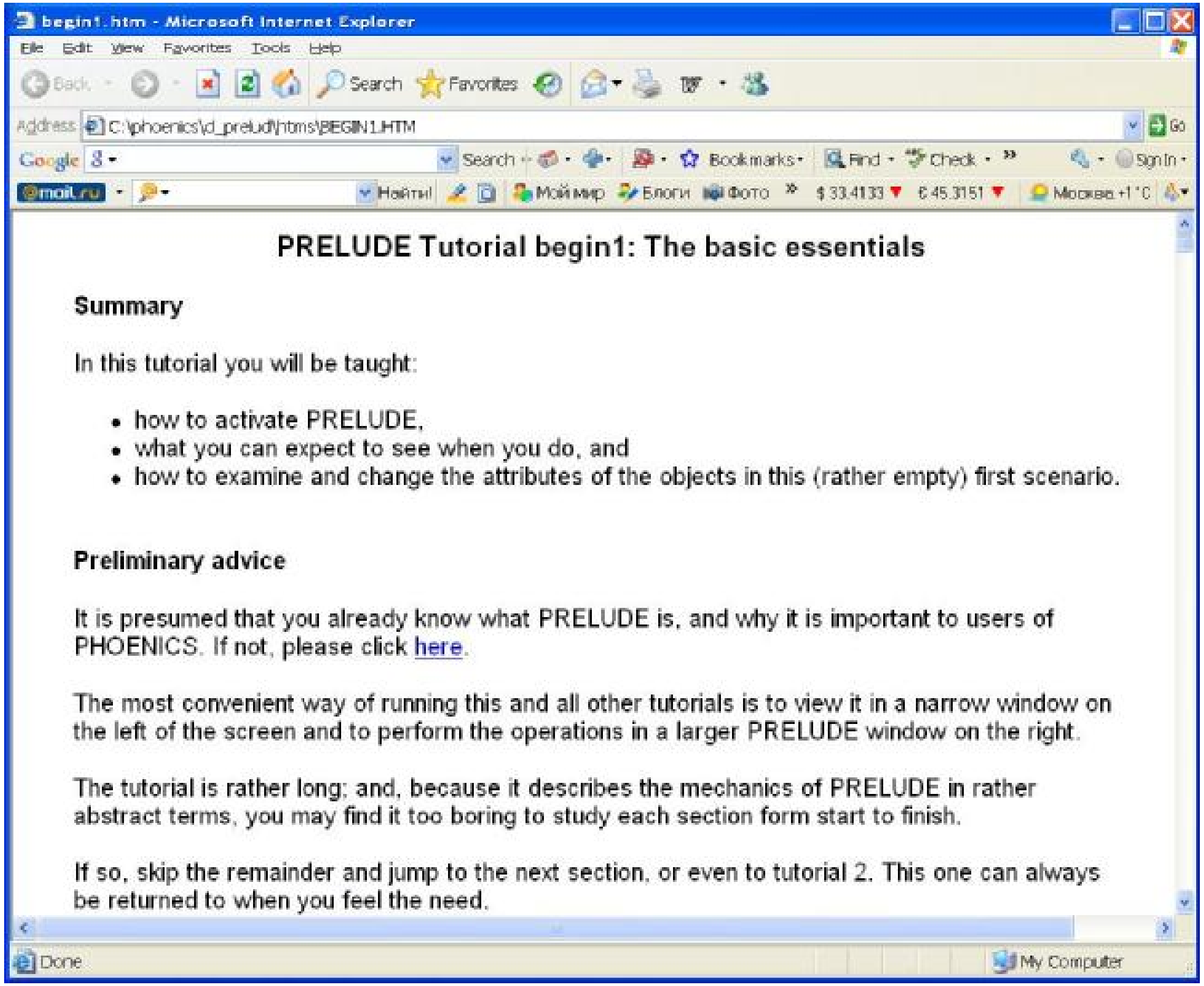
PRELUDE has an easy-to-use graphical interface; and tutorials are provided.

Clicking on the top-line 'help' button will call them in



PRELUDE Tutorial begin1: The basic essentials

Summary

In this tutorial you will be taught:

- how to activate PRELUDE,
- what you can expect to see when you do, and
- how to examine and change the attributes of the objects in this (rather empty) first scenario.

Preliminary advice

It is presumed that you already know what PRELUDE is, and why it is important to users of PHOENICS. If not, please click here.

The most convenient way of running this and all other tutorials is to view it in a narrow window on the left of the screen and to perform the operations in a larger PRELUDE window on the right.

The tutorial is rather long; and, because it describes the mechanics of PRELUDE in rather abstract terms, you may find it too boring to study each section form start to finish.

If so, skip the remainder and jump to the next section, or even to tutorial 2. This one can always be returned to when you feel the need.