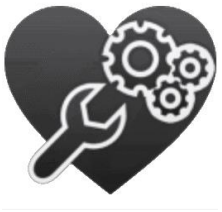
BioIRC solutions



CFDVasc manual

Main window of application is consisted from two parts:

- **toolbar** - which consist set of button for accessing variety of present functionalities
- **image area** – area in which is shown current image from image series with purpose of segmenting the same and manipulating the regions of interest (ex. Contour selecting, refinement, correction etc.)

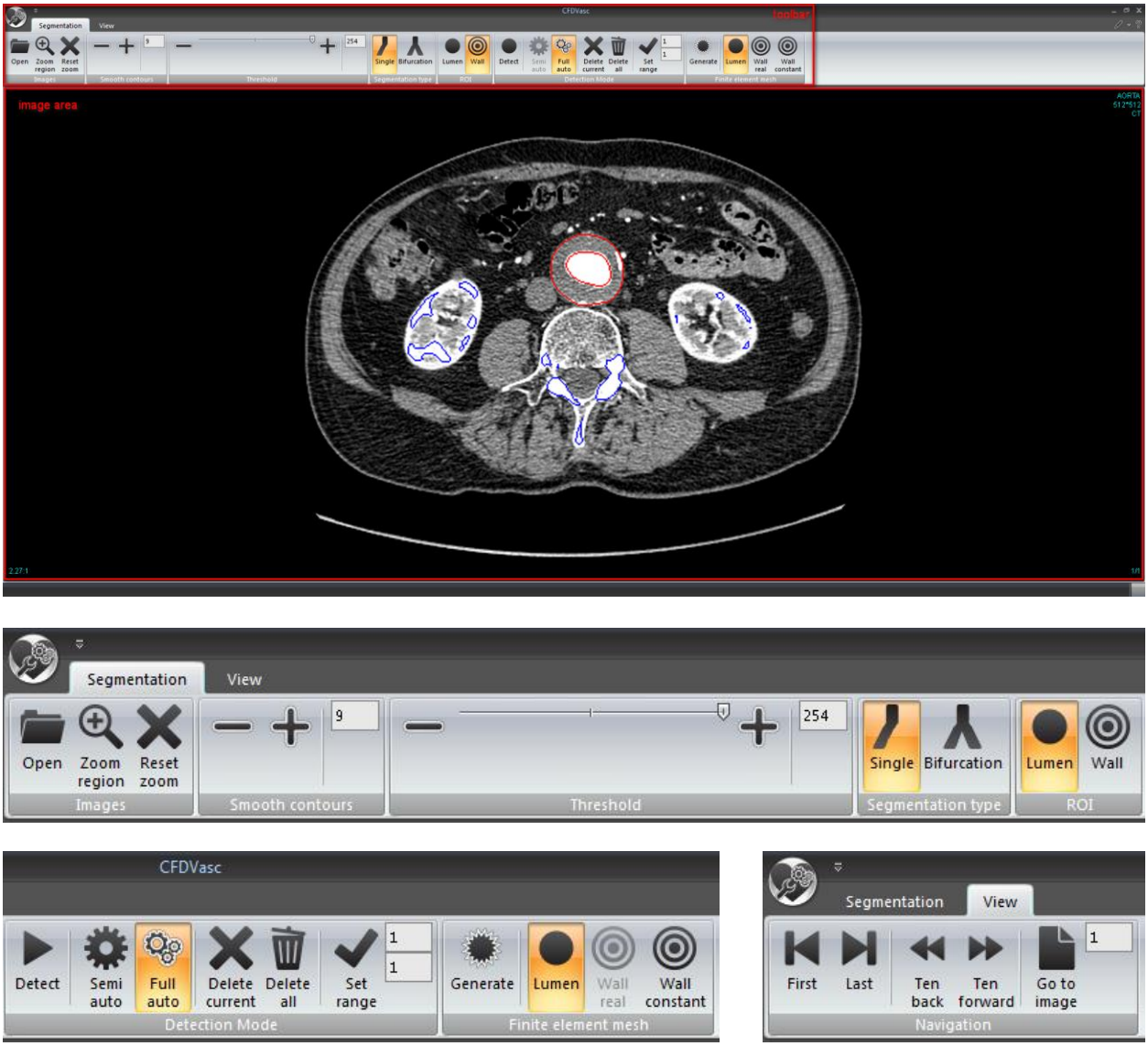


Figure 1 - Main window of the CFDVasc application and toolbar (Segmentation and View tab)

In toolbars are present following buttons:

- **"Open"** button – Initiate "File open" dialog for opening single or series of images by multi selection **Figure 2**.

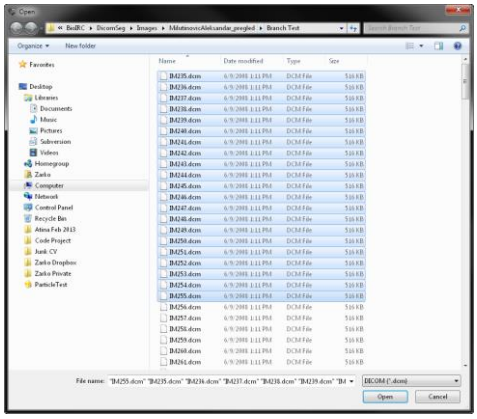


Figure 2 - Loading multiple images

After loading, images are shown on the screen with distinguished regions corresponding to the default threshold value of 254

- **"Zoom region"** button – is used for zooming in the specified region of interest. Region of interest is drawn by holding right mouse click and dragging mouse across of image part which should be zoomed **Figure 3**.

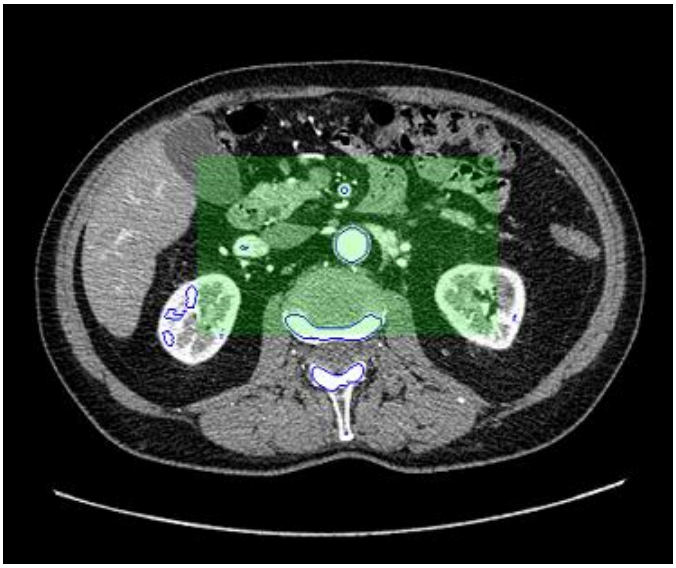


Figure 3 - Drawing region of interest

After releasing right mouse button selected region will be zoomed and centered at the image area window **Figure 4.**

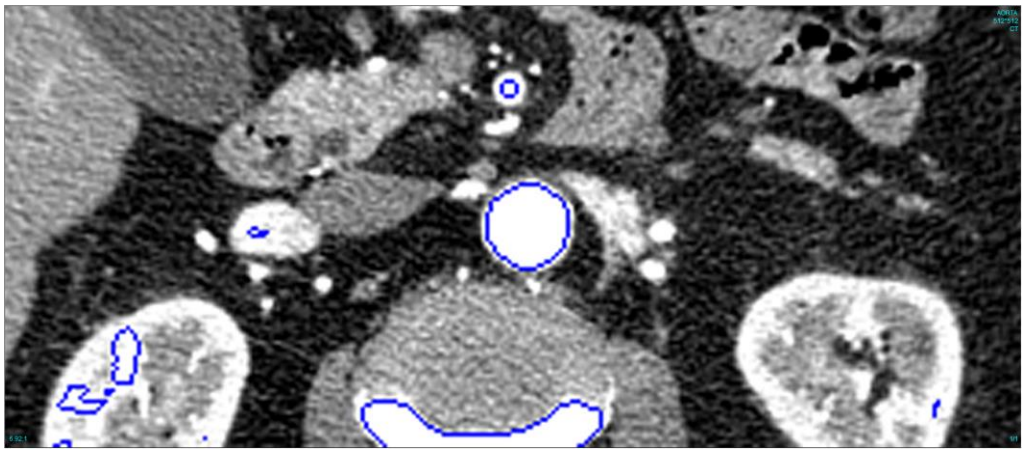


Figure 4 - Zoomed region of interest

- **"Reset zoom"** button removes current region of interest and draws whole image on screen **Figure 5**.

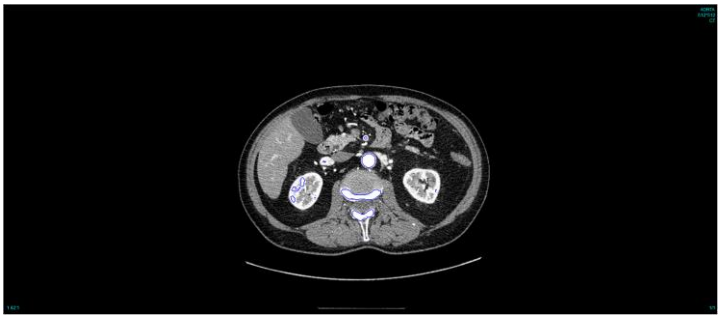


Figure 5 - Drawing whole image after resetting zoom region

- **Smooth contours buttons** - detected contours by threshold slider can be further refined by using this buttons **Figure 6**.

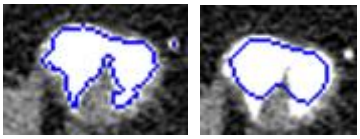
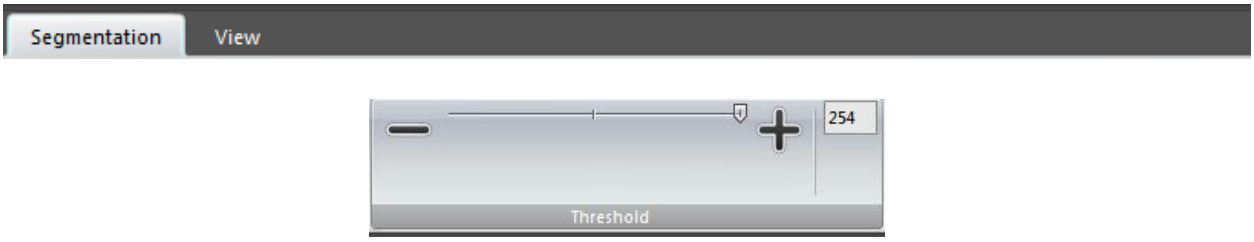


Figure 6 – Contour before smoothing and after smoothing



- Threshold slider control is used to set preferred threshold value in order to distinguish desired regions, on the DICOM images, which are bordered with blue colored contours **Figure 7**.

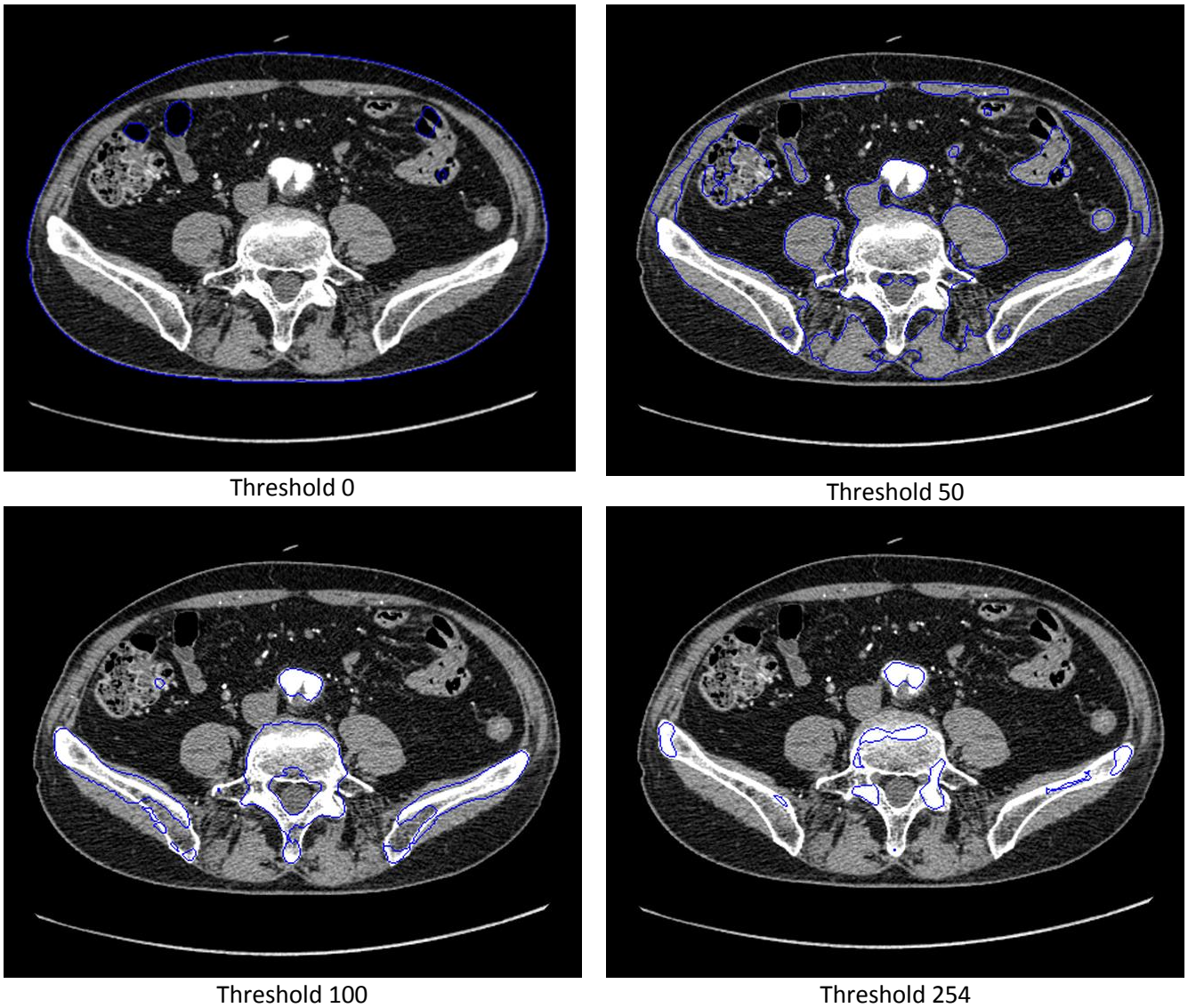
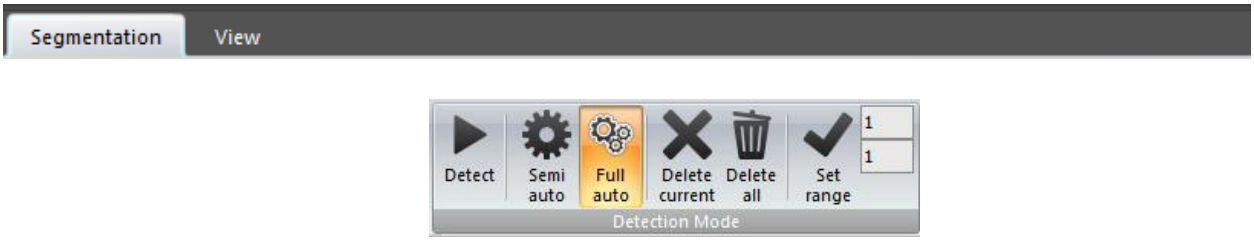


Figure 7 – Distinguished regions with different threshold values

After setting appropriate threshold value upcoming contour selection is done by moving mouse cursor to the preferred contour and left mouse click anywhere within the area of the contour including the contour edge.



- **"Detect" button** allows initiation of contours detection
- **"Semi – auto" button** enables mode in which user can control the segmentation by scrolling through images by mouse wheel. On current image contour detection is based on the initial one which user selected in first step.
- **"Full auto" button** enables the mode in which program automatically scroll images and detect contours on current one until detect button is clicked again.
- **"Delete current"** button allow deletion of detected contours on current image
- **"Delete all"** button allow deletion of all detected contour on all images in image stack
- **Set range** allow generating the finite element mesh using only images with detected contours that fall in specified range

- Segmentation type buttons are used to choose preferred type of geometry that will be reconstructed. Two types are available:

  Segmentation type "Single" button which should be checked in case of detecting the single blood vessel with no bifurcations present. After setting desired threshold factor upcoming is selection of one of shown contours by left mouse click. Selected contours are colored in red **Figure 8**.

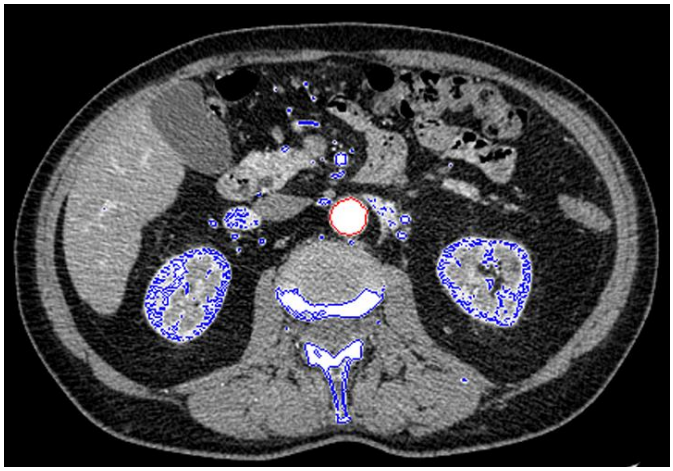


Figure 8 – Marked contour in single segmentation mode type

After initial contour is selected next step is detecting corresponding contours to initial one on the rest images. Detection can be performed in **semi-auto** and **full auto** mode.

In **Semi-auto** detection mode user should manually switch, scroll, images by mouse wheel and corresponding contour to initial one will be automatically selected in current shown image. In **Full auto** detection mode only initial contour have to be marked by the user and after executing detection, by Detect button, images will be switched automatically by descending order and corresponding contour to the initial one will be detected and marked on current image **Figure 9**.

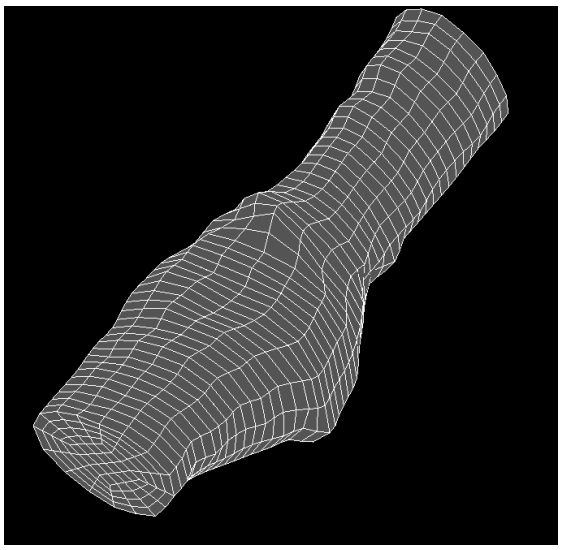


Figure 9 – Single vessel finite element model

Segmentation type "Bifurcation" button which should be checked in case of detecting blood vessel with two branches. In that case user should first select two bottom contours of the bifurcation branches by left mouse click **Figure 10**.

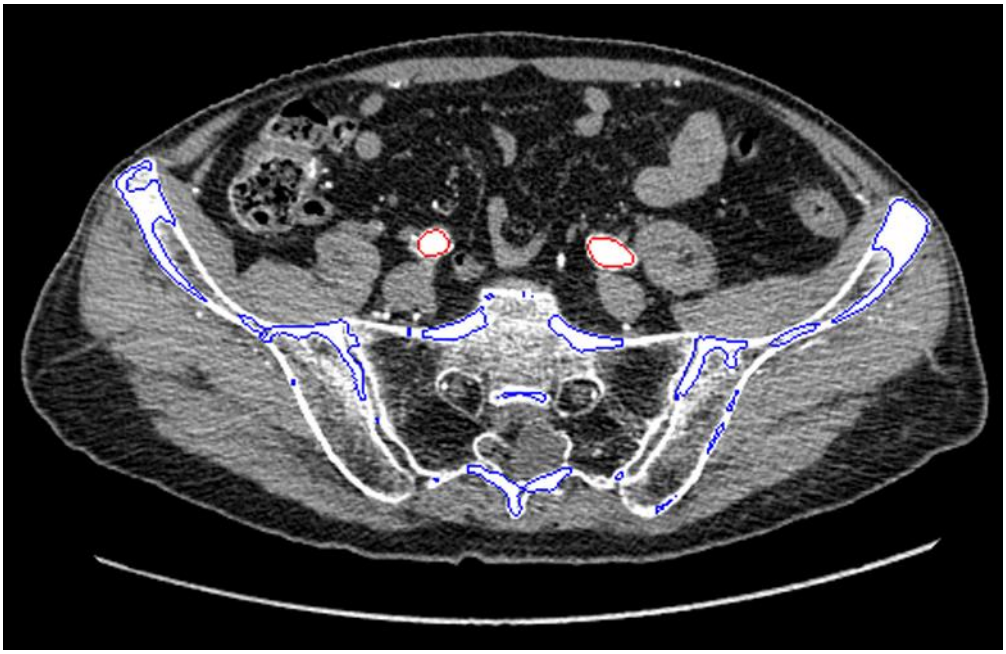


Figure 10 - Marked initial contours in bifurcation segmentation type

After detection is started images in this type of the segmentation can be scrolled only in ascending order via mouse wheel in semi-auto mode or automatically in full auto mode. In both cases, corresponding contours will be detected and marked on current, shown, image.

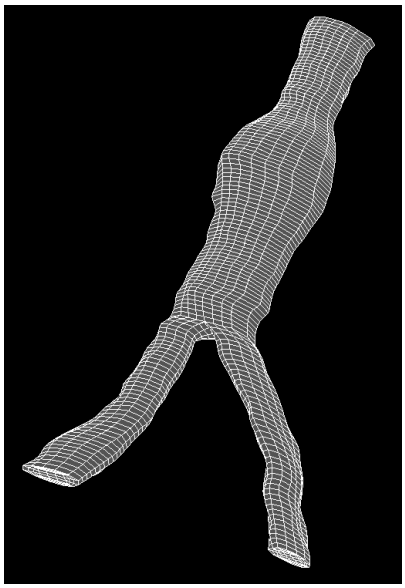


Figure 11 - Blood vessel bifurcation finite element model

- **ROI "Lumen"** button – allow detection of lumen region at images
  ROI "Wall" button – allow detection of wall region and should be checked only if previously lumen domain is detected

  Wall detection is available in both, single or bifurcation segmentation type mode. In order to perform wall detection previously detected lumen contour must exists. After lumen detection is finished, as user preferred, in order to start wall detection just Wall button should be checked. After clicking on button detect, in detection mode region on toolbar, wall detection is started by showing first image in image series on which lumen contour is detected. Wall detection is performed by gradually expanding previously detected lumen contour toward the wall boundaries iteratively. After detection is finished, on current image, program will automatically go to the next image with detected lumen and same procedure will be repeated until wall detection is finished on all images with lumen contours, **Figure 12**, or if user stops the detection.

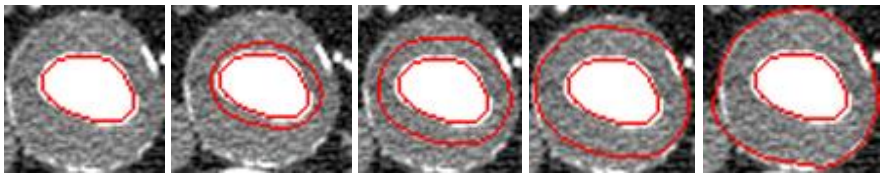
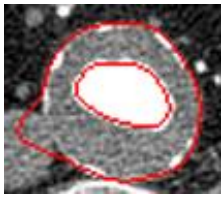


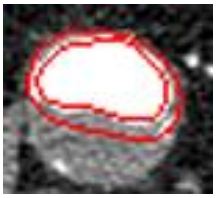
Figure 12 - Gradual expansion of previously detected lumen contour toward the wall boundaries

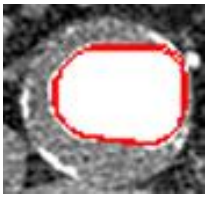
After detection is done user should go through all images again where wall detection was conducted and perform verification on detected contours in order to determine if additional, manual, corrections are needed.

Currently few type of situations request manual contour correction:

- **Contour leaking** – when contour go out the borders of the wall
- **Premature expansion termination** – when contour stop in early phase of expansion
- **Contour freezing** – when contour stops immediately after expansion is started


Contour leaking


Premature termination


Freezing

Three types of manual correction on wall contours are available:

Partial native correction – where user should position the mouse cursor in region of contour that should be corrected. After positioning wheeling **backward** will cause contour **expanding** in that region **Figure 13**, and wheeling **forward** will cause contour **contracting Figure 14** . Contour will expand until reach the boundaries on the image. This kind of correction depends of the image topology.

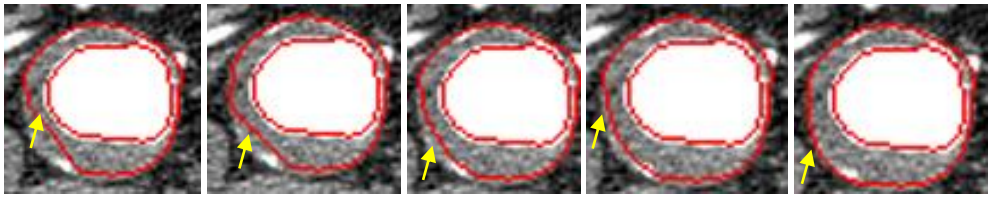


Figure 13 - Expanding deformed contour in area of mouse cursor by wheeling backward

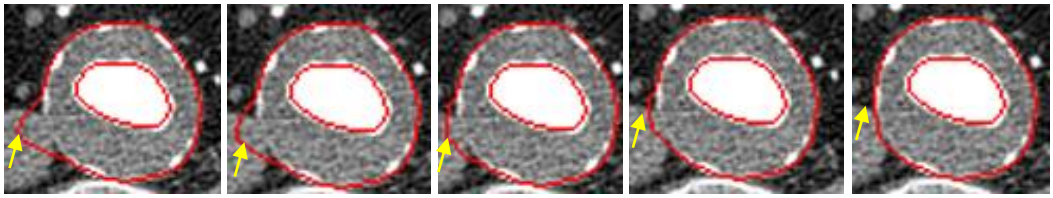


Figure 14 - Contracting deformed contour in area of mouse cursor by wheeling forward

Partial forced correction - Contour will expand until reach boundaries of the wall. Further on wheeling backward will not have any effect. If expanding is necessary after contour reached boundaries holding **SHIFT** and wheeling **backward** will force contour to continue expanding out of wall boundaries **Figure 15**.

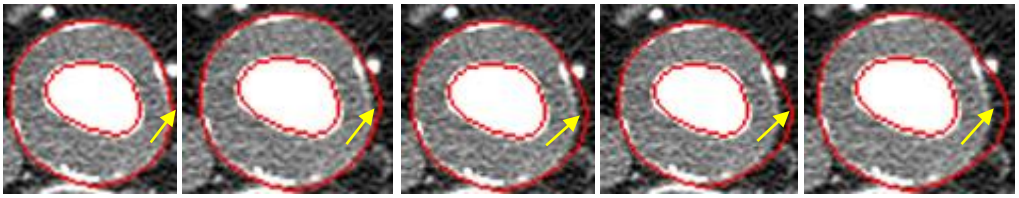


Figure 15 - Expanding contour in area of mouse cursor by wheeling backward and holding SHIFT key at the same time

Global native correction - In some situations, such as premature stopping, it is needed to expand whole contour manually. Not only some regions near the cursor of the same. This kind of correction is actually emulation of contour expansion in automatic phase of detection. Wheeling **backward** and holding **CTRL** key will cause expanding whole contour until boundaries are reached **Figure 16**. Further corrections can be partial. Correction of this type of contour can be done also with partial correction but this type of correction is more comfortable because expanding in all directions at the same time.

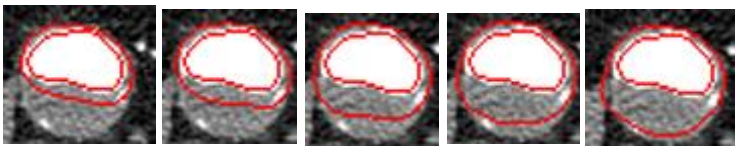


Figure 16 - Expanding whole contour by wheeling backward and holding CTRL key at the same time

Rarely happens that contour do not expand at all (freezing contour) **Figure 17**. In that case contour can be corrected using, previously explained, manual corrections or can be simply removed by deleting it using the "**Delete current"** button or key **Delete** on keyboard.

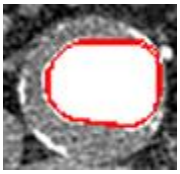


Figure 17 - Freezing contours must be removed or corrected in order to get appropriate 3D model for finite element simulations

When detecting wall for bifurcation type models two close contours after bifurcation can overlap each other what require manual correction. Because both contours are in area of mouse pointer both will react on mouse scrolling on manual correction. In order to isolate some contour which should not be corrected user can select contour which should underlay effects of corrections by left mouse click. Further on second contour will remain unchanged while selected contour (colored in green), can be modified.

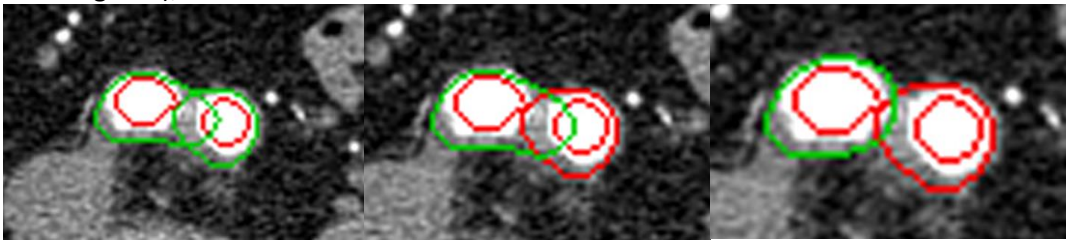


Figure 18 - Modifying right contour just after bifurcation

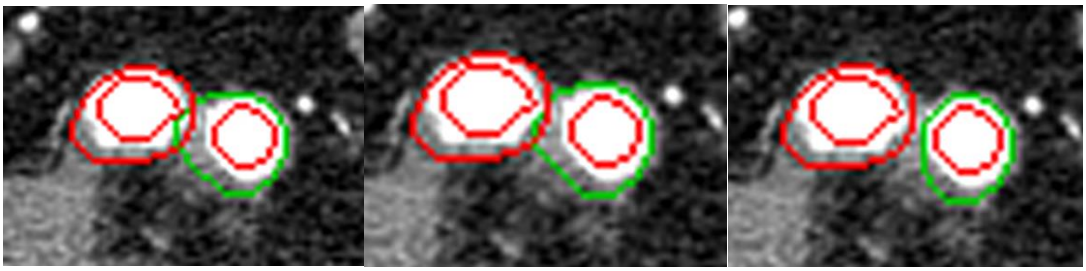
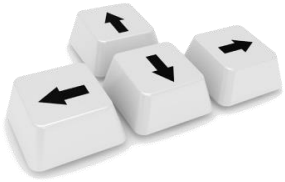


Figure 19 - Modifying left contour just after bifurcation

In wall detection mode (ROI Wall checked) mouse scrolling is dedicated for contour correction so in order to move forward through images use arrow keys right and up or left and down for moving backward.



After marking initial contours and detecting rest of the contours last step is generating finite element mesh model.

- **Generate button** generates 3D finite element mesh in external FEM Viewer application
- **FEM Lumen button** which should be checked if user wants to generate finite element mesh representing only lumen of blood vessel.
- **FEM Wall real button** which should be checked if user wants to generate finite element mesh representing lumen and wall of blood vessel. In this case detection of wall must be performed.
- **FEM Wall constant button** allow generation of the lumen and wall region even if the wall detection is not performed. Lumen region must be previously detected and generated wall is with constant thickness across whole lumen domain.

Lumen FEM button is used in situations when only blood flow simulations are needed. In those cases only finite element mesh representing lumen of the blood vessel is generated from detected contours. Available results are **velocity**, **pressure** and **shear stress** distribution across the model **Figure 20**.

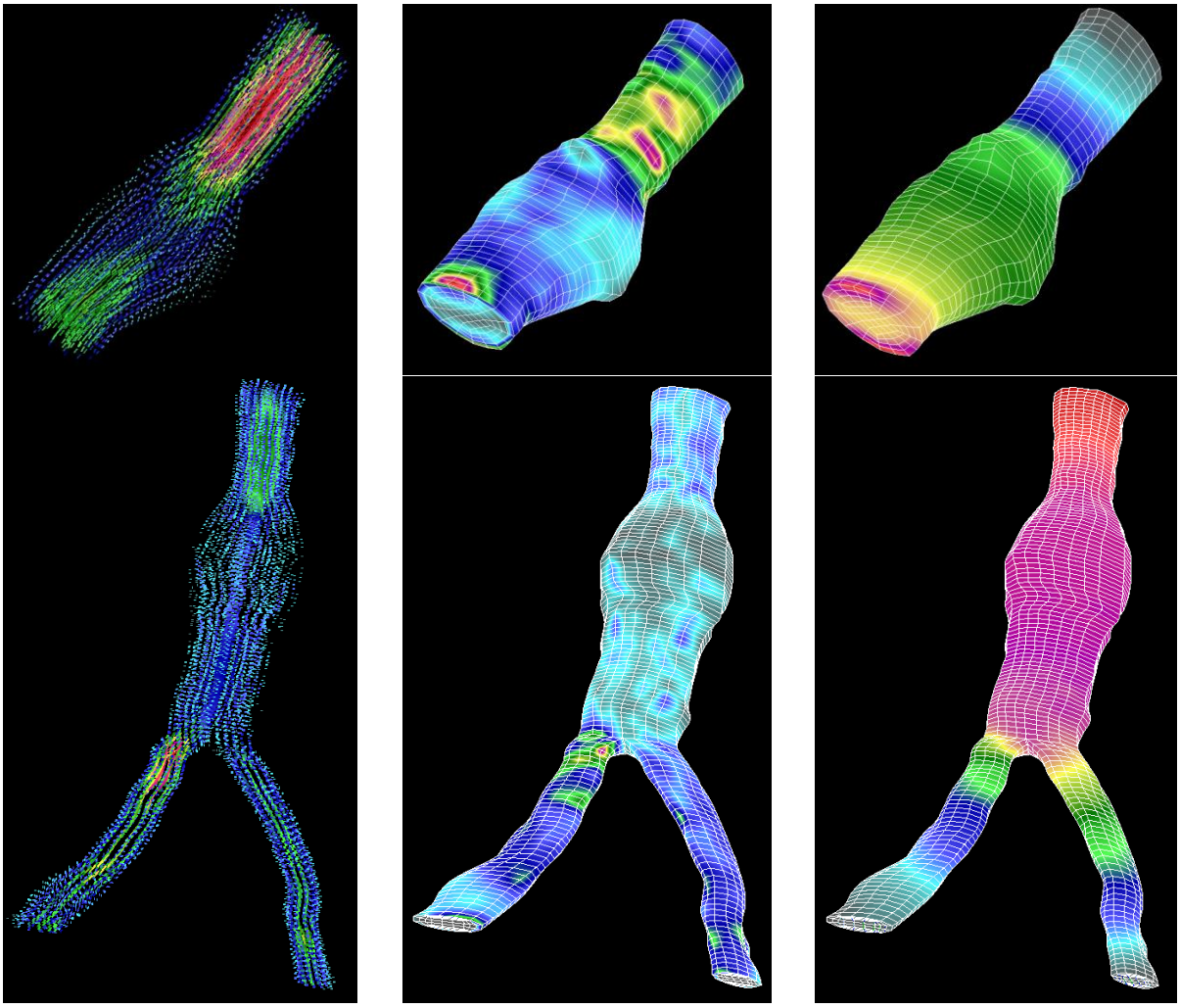
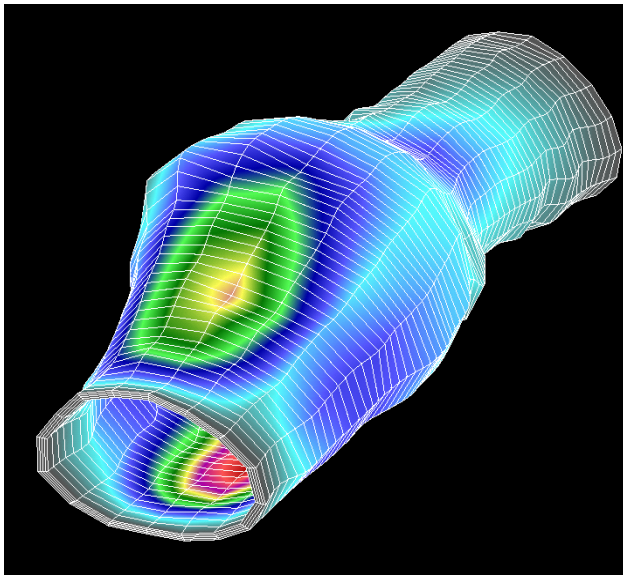
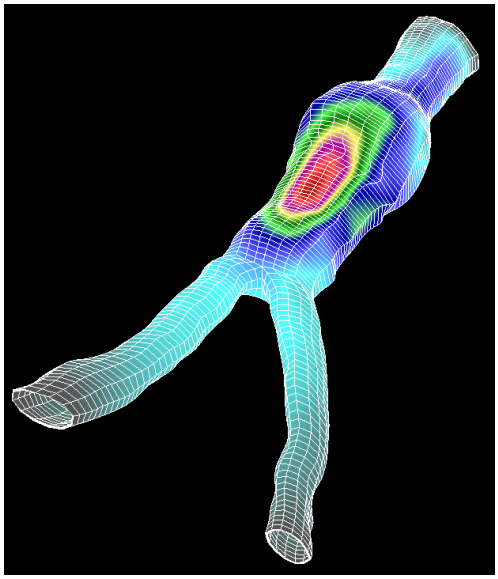


Figure 20 – Lumen meshes of single and bifurcation type model with velocities vectors, pressure and shear stress distribution respectively are shown

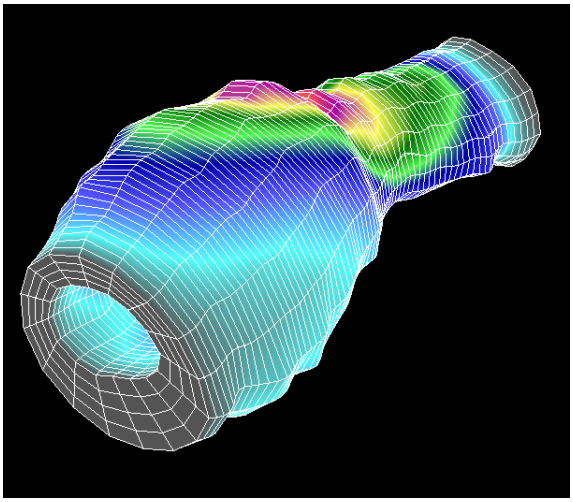
- **Wall real and Wall constant** FEM button is used with the combination with lumen FEM button and only in situations when simulation of the interaction between lumen and wall of blood vessel is needed. In case of checking wall button it is possible to perform fluid structure interaction simulation when both lumen and wall mesh is generated. In FSI simulations are available velocity, pressure and shear stress distribution on lumen mesh. On wall mesh stress and displacement distribution are available **Figure 22**. With "Wall real" wall is generated according to contours detected in wall detection procedure. In case that wall is not detected it still can be generated but with constant thickness across whole model. Lumen contours detection must be previously performed. For bifurcation segmentation type it is only available adding wall with constant thickness.



Constant wall single segmentation type

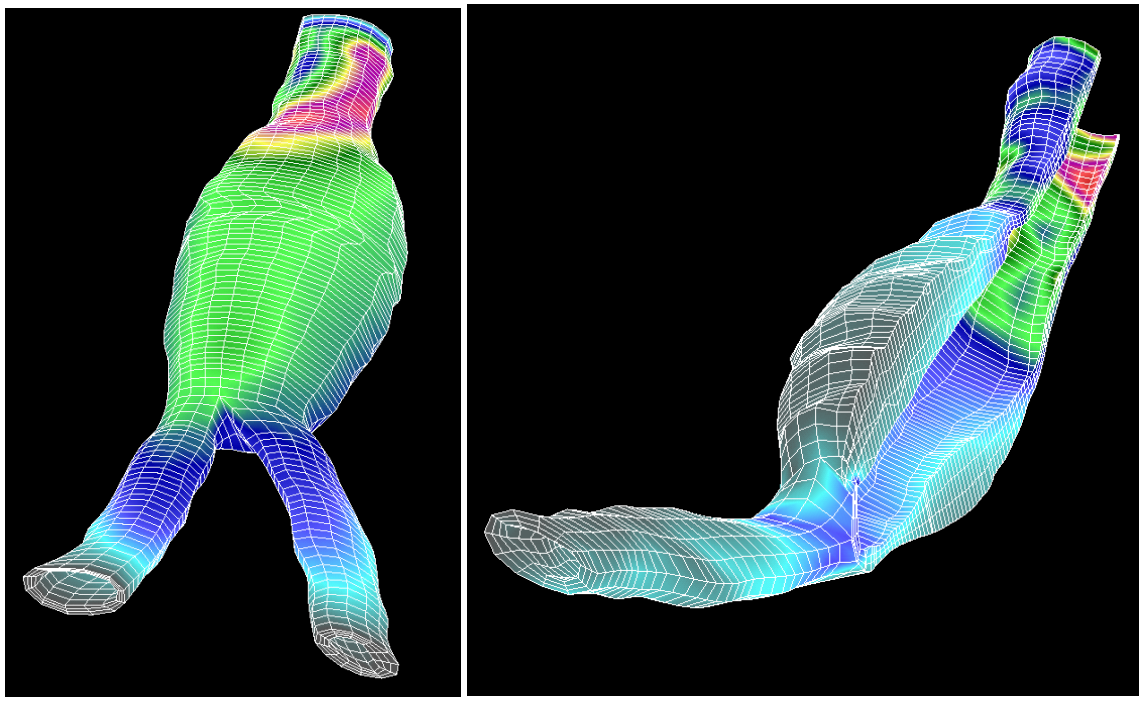


Constant wall bifurcation segmentation type



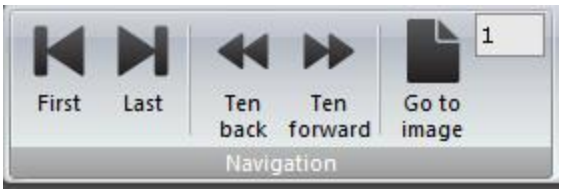
Real wall single segmentation type

Figure 21 – Constant and real wall meshes with displacement distribution shown



Real wall bifurcation segmentation type

Figure 22 – Constant and real wall meshes with stress distribution shown



- **Buttons "First" and "Last**" are used to show first or last image in image stack. Images regularly are switched by the mouse wheeling. If huge number of images are loaded in the application these two buttons can be found as very useful by freeing user of trouble by mouse wheeling through the bunch of images. On keyboard buttons **Home** and **End** respectively are employed for performing same functionality.
- **"Ten back" and "Ten forward"** buttons – allow jumping ten images forward or ten images backward in image stack. Purpose of these buttons are faster moving through the images when serious amount of images are loaded.
- **"Go to image"** button – allows user to jump to the image with specified number in the edit box

After clicking on the button Generate from the toolbar menu, on the CFDVasc, FEM View application, **Figure 23**, for generating, viewing finite element meshes, executing simulations and presenting the simulation results is started.

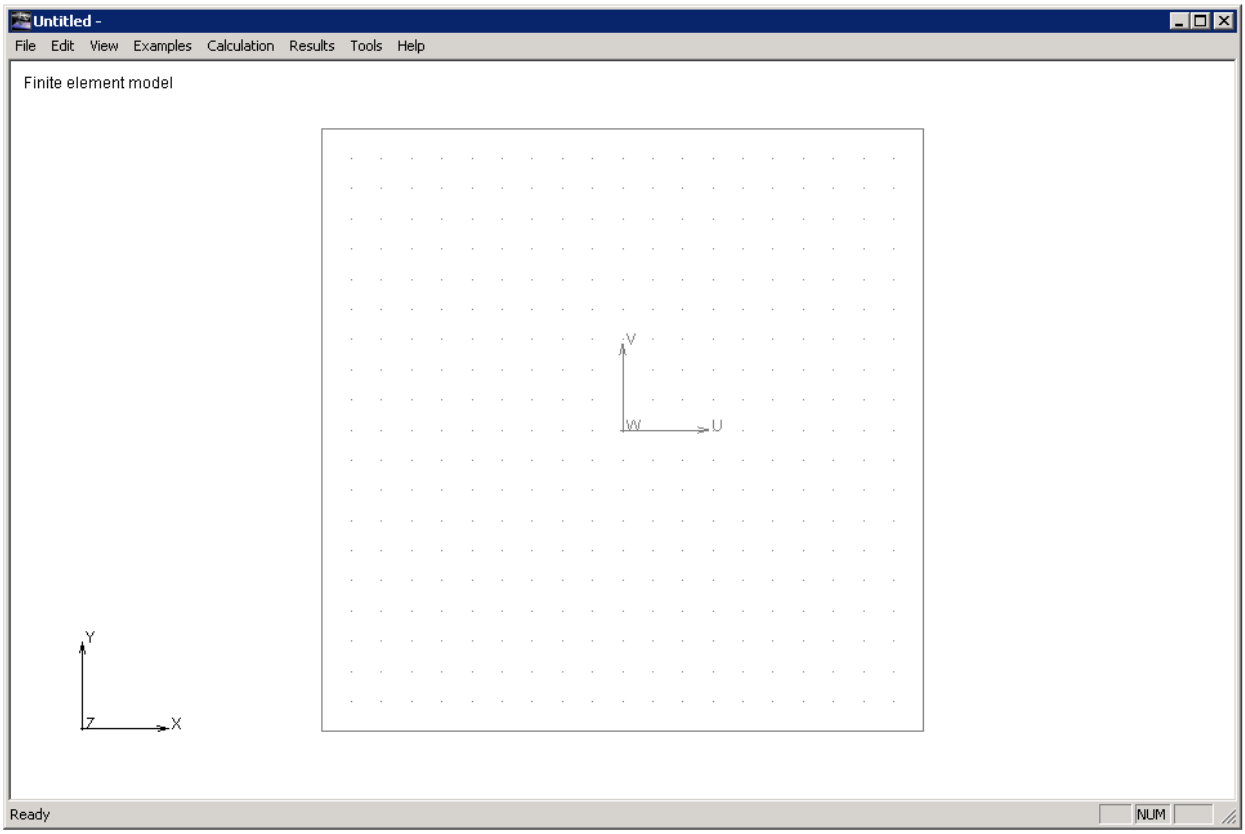


Figure 23 – FEM View Main window

On the top of the window is the main menu for accessing general functionalities of the software. In the file menu user can operate with files, import model with results or export images of the actual model **Figure 24**.

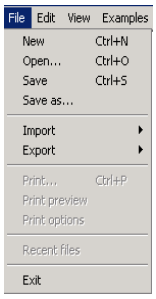


Figure 24 – File menu

In view menu user can choose viewpoint or the way how he want to operate with model. zoom, pan, rotate etc. **Figure 25**

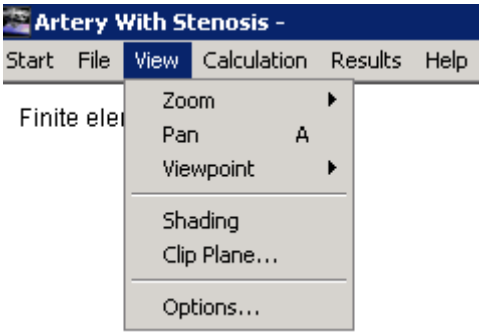


Figure 25 – View menu

In calculation menu user can start calculation or choose number of time steps and other options **Figure 26**.

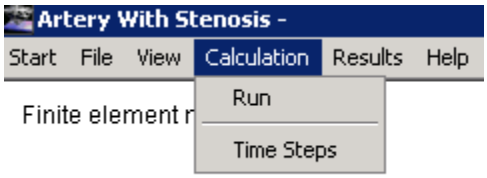


Figure 26 – Calculation menu

In the Results menu user can show result and choose different options of results which will be shown, **Figure 27**

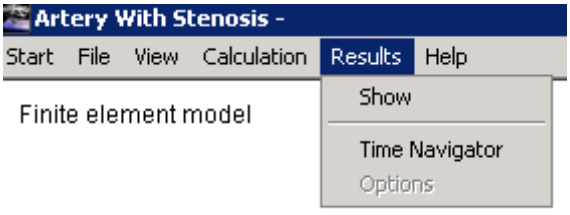


Figure 27 – Results menu

On the left side of the main window is the side bar, **Figure 28**, where are the buttons Generate for generating the model and applying modified model parameters, Calculate for starting the calculation process with solver, Results group box where user can view results of realized calculation by checking the Show check button. Options button opens menu for changing type of results that will be shown and other result properties. In Step edit box user can play animation in case of non-stationary (transient) simulations.

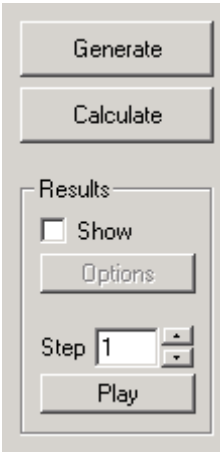


Figure 28 – Side bar

After setting up the parameters of the model user can see their effects by starting calculation on calculate button click on the side bar. Window shown on **Figure 29** indicates that PAKF started calculation.

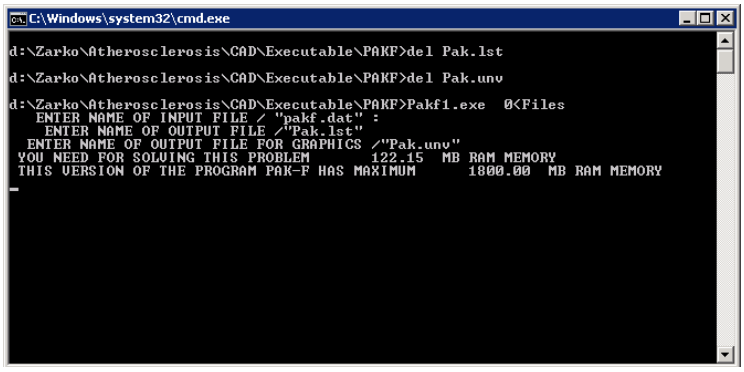


Figure 29 – PAKF started calculation

After completed calculation application reads the results and returns the overview of the simulation results **Figure 30.**

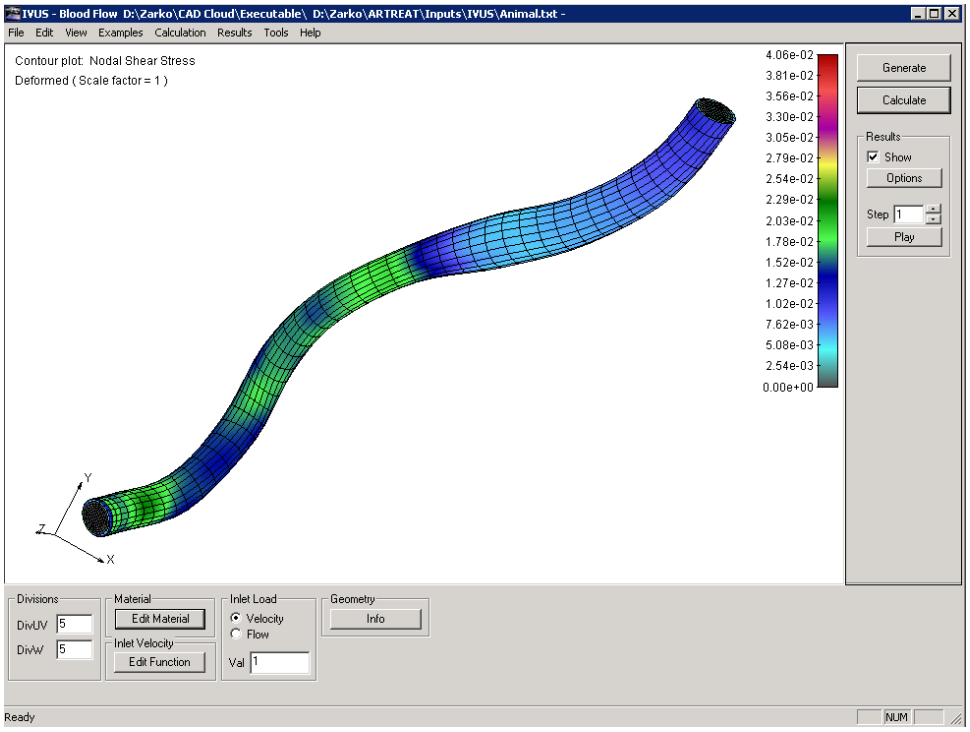


Figure 30 – First results

By default first results that will be shown for 2D model are nodal velocities. User can change result overview by clicking the Options button on side bar **Figure 31.**

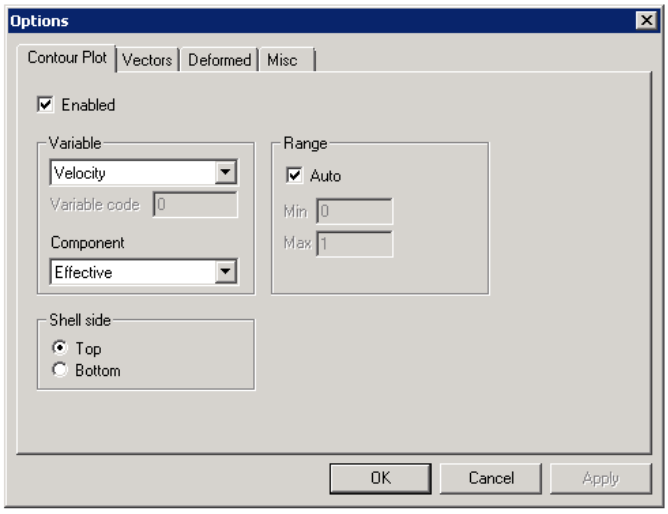


Figure 31 – Options –> Contour plot

User can change variable which is showed by clicking Variable drop down box where is the list of variable that can be showed **Figure 32**.

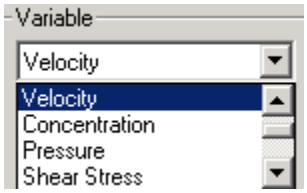


Figure 32 – Picking up the results

For the Velocity in Component drop down list Effective velocity is showed by default but user can choose components in other three directions **Figure 33.**

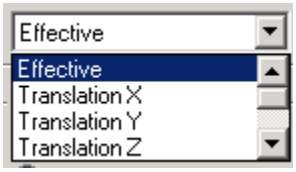


Figure 33 – Picking up the components

In the vectors tab **Figure 34** user can see velocity vector field by choosing the variable in the Vector drop down list and checking the Enabled check button in Vectors tab and unchecking it on the Contour Plot tab.

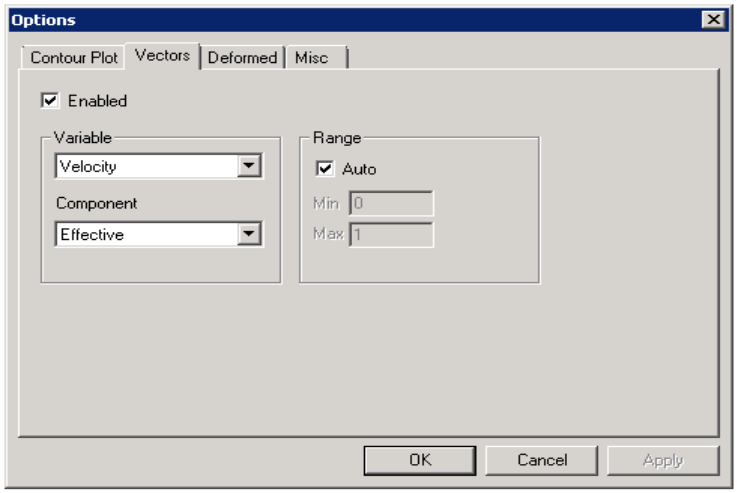


Figure 34 – Picking up the components

After clicking the OK button user will get overview of velocity vector field. On **Figure 35** are shown velocity vectors.

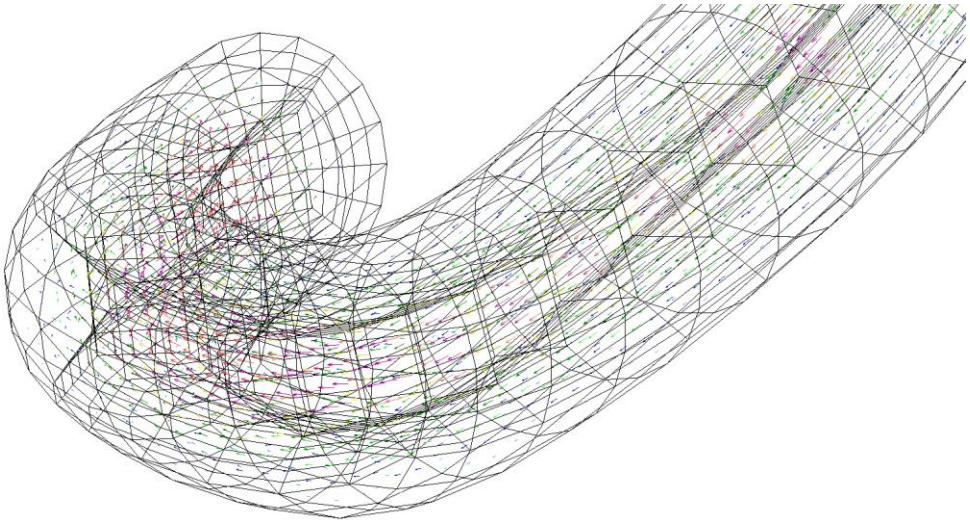


Figure 35 – Velocity vector field

For better overview of the results when mesh density is high user can turn of the mesh in Misc tab by unchecking the Show mesh check button **Figure 36**.

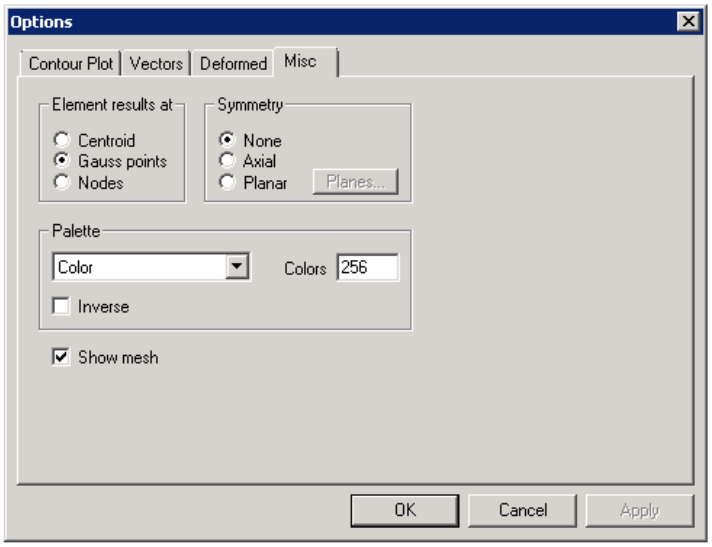


Figure 36 – Misc tab

In horizontal bar user can change mesh division in Divisions group, Material and Velocity function in Material and Inlet Velocity groups **Figure 37**.

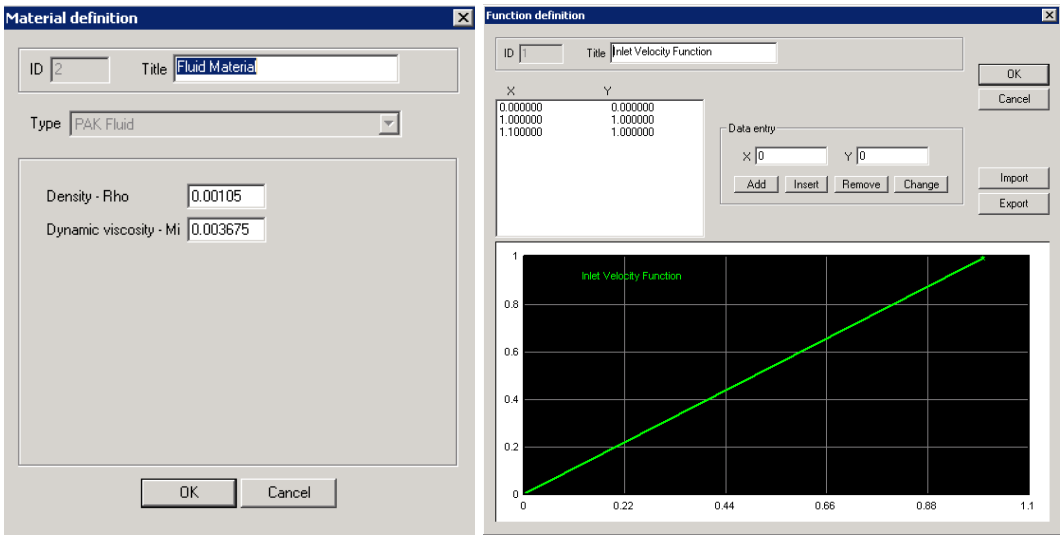


Figure 37 - Material and Function definition