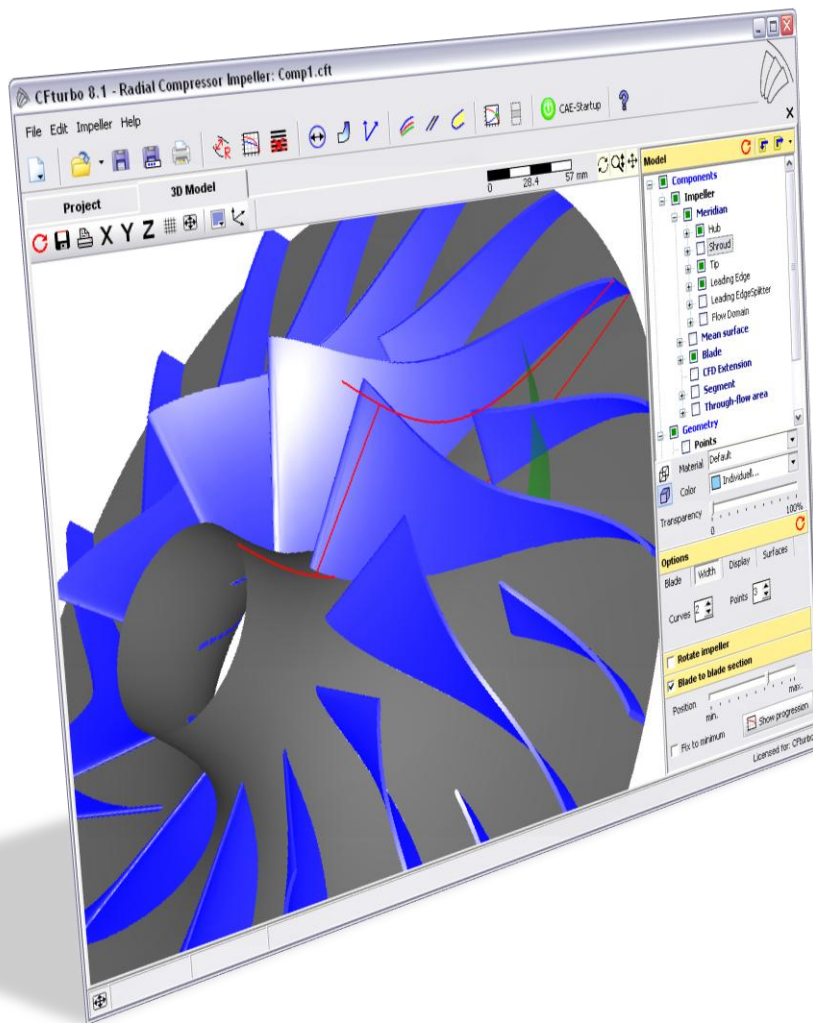




Instruction on the reverse design of impeller and volute geometries of compressors with CFturbo



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1 Preliminary

1.1 Assumption of best point and fluid properties

Empirical functions are implemented in CFturbo that allow the calculation of parameters on the basis of the specific speed for instance. Therefore the opportunity is given to set up parameters in a way that a promising design will be created. Here promising may stay for the fact that a good efficiency will be gained with the particular design.

The consideration of the empirical correlations may also be advantageous while reversely redesign a given geometry of an impeller. Therefore the following parameters should be given:

- fluid properties
- Best point mass flow
- Best point speed
- Best point pressure ratio

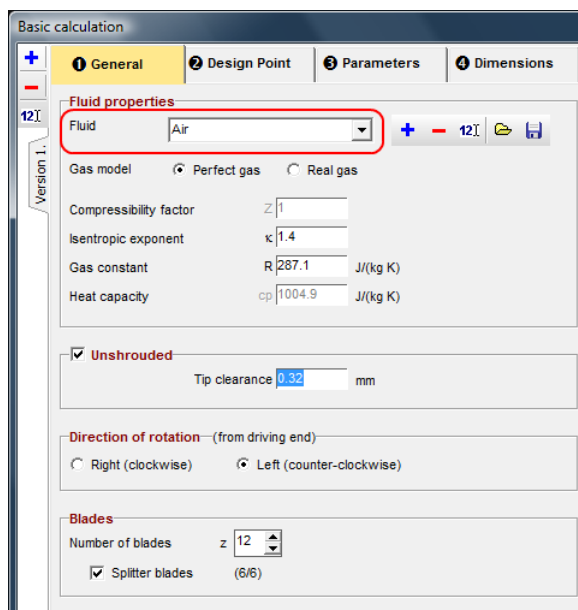


Figure 1

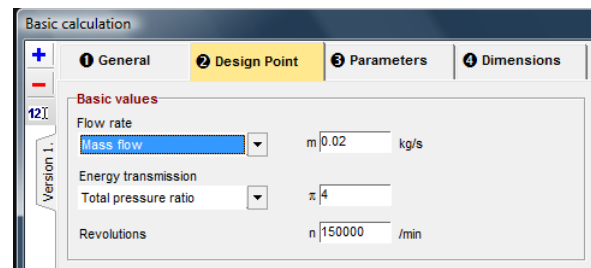


Figure 2

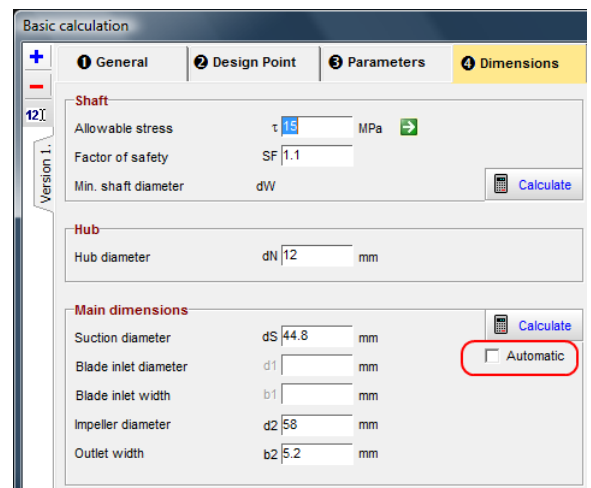


Figure 3

In case of pumps or blowers there is not a fluid property panel. Then only the density of the fluid has to be given.

1.2 Setup of the main dimensions of the impeller

The main dimensions, that are hub and shroud diameter (d_N , d_S) as well as outlet width (d_2 , b_2), have to be taken out of the geometry of the given impeller and have to be input in Dialog "Basic calculation" tab 4:

The mode "automatic" is to be deactivated. Beyond the mentioned parameter, further dimensions have to be taken from the original geometry and have to be typed in (see Figure 1):

- the size of the tip
- direction of rotation
- number of blades as well as splitter blades

2 Geometric design of the impeller

2.1 Generation of reference geometries

The original geometry of the impeller should be visible in CFturbo while conducting the reverse engineering. Therefore a visual comparison is possible. To this end reference data of the impeller have to be created, that are hub and blades:

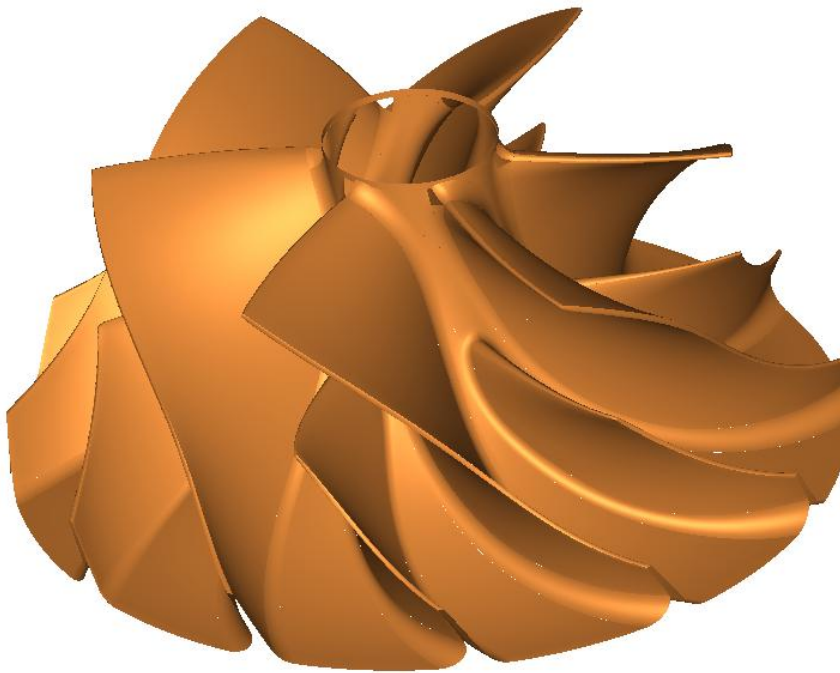


Figure 4

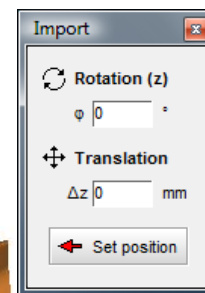


Figure 5

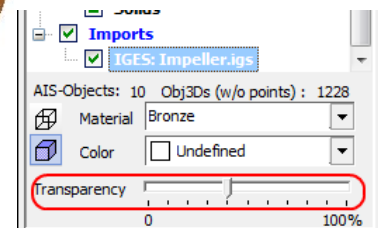


Figure 6

Geometries can be loaded into the current design in neutral formats like IGES, STEP and STL. The extracted impeller should be saved in one of these formats. STL shall be only the second choice because this needs comparatively more memory. The impeller has to be aligned in x- and y-direction in a way as demanded by CFturbo. Currently in CFturbo the displacement of imported geometries is possible only in z-direction and the rotation is only possible around z-axis (Figure 5).

It is advantageous to display the imported geometry of the impeller transparently. This can be done by selecting the imported impeller (model tree branch "Imports") via left click with the mouse. Subsequently the value of transparency can be changed (e.g. to 40%, see Figure 6).

2.2 Determination of the meridional shape

The meridional cut in the second design step should be based on the co-ordinate z and r (axial length, radius). Therefore these data have to be extracted from the original geometry. Figure 7 shows the impeller geometry and a plane that contains the rotational axis. From surfaces, built by rotation of leading edge of main and splitter blades, intersection lines with the axial plane can be created.

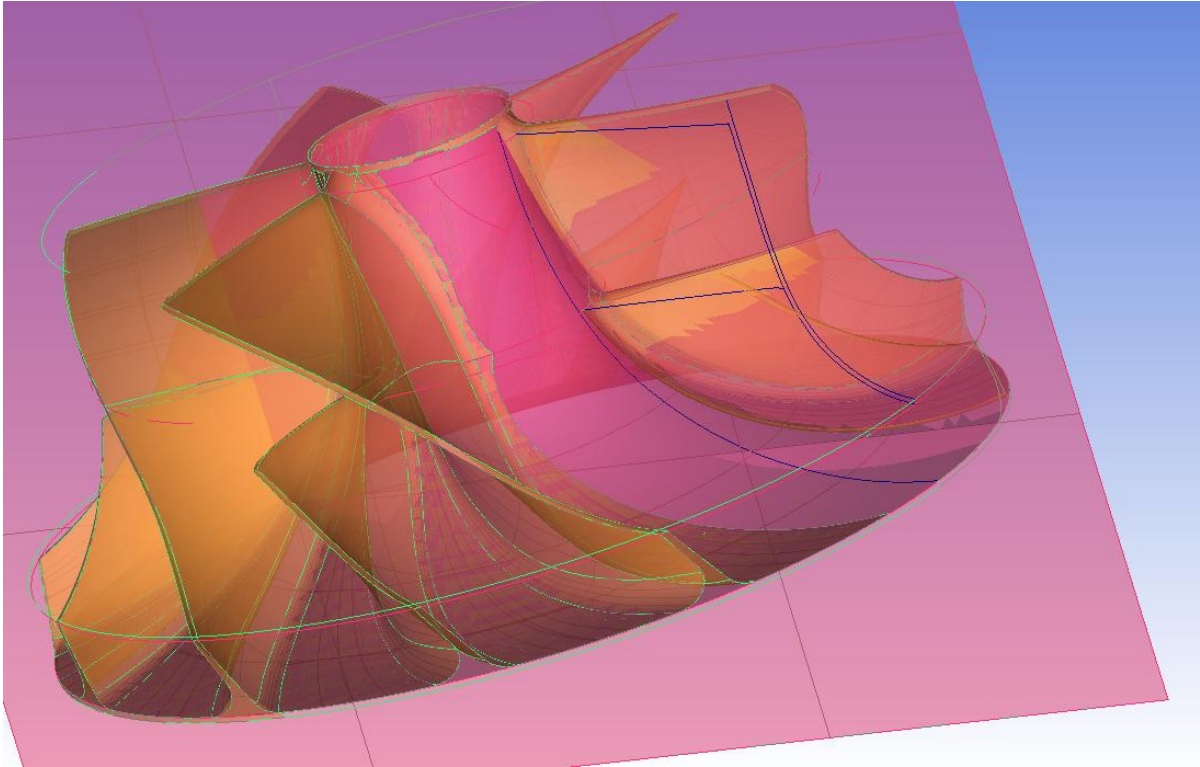
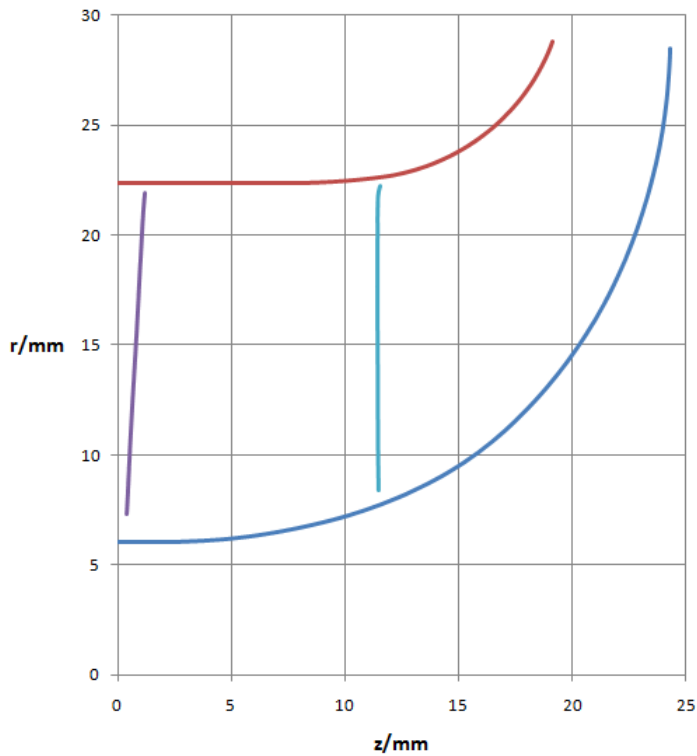


Figure 7

The intersection of hub and shroud with the co-axial plane contains the (hub and shroud) co-ordinates in z and r. The following curves are the result (Figure 8). Their co-ordinates should be saved in a text-file to be loaded into CFturbo. The data have to be given in the unities that are used by CFturbo with current design (here e.g. in mm), a z-r-pair per row:



Example: Hub.txt:

```

0          6.031548139
0.379575416 6.033787969
0.75914152  6.031430792
1.13870576  6.028328091
1.518281177 6.026141811
1.897860318 6.027228199
...
    
```

Figure 8

After the first call of the design step for the creation of the meridional contour (Meridional contour), a meridional cut will be built in accordance to the default co-relations of Cfturbo and according the main dimension earlier set up. Now the z-r-co-ordinates of hub etc. should be loaded for comparison. This is done by a right click in the display area and by the subsequent selection of the context menu item "Load extra polyline".

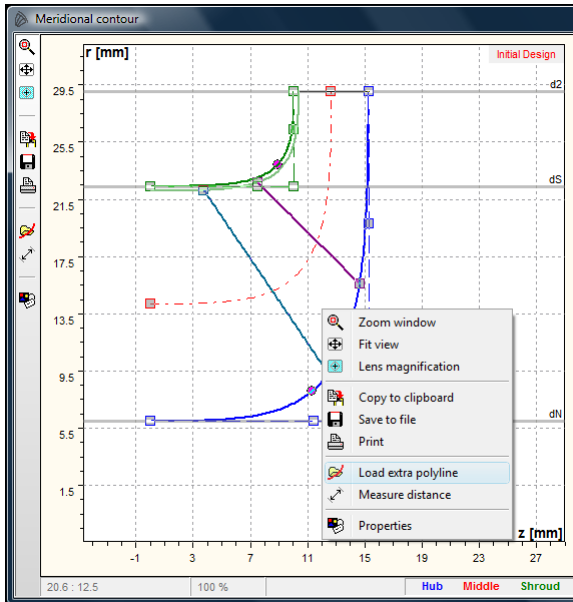


Figure 9

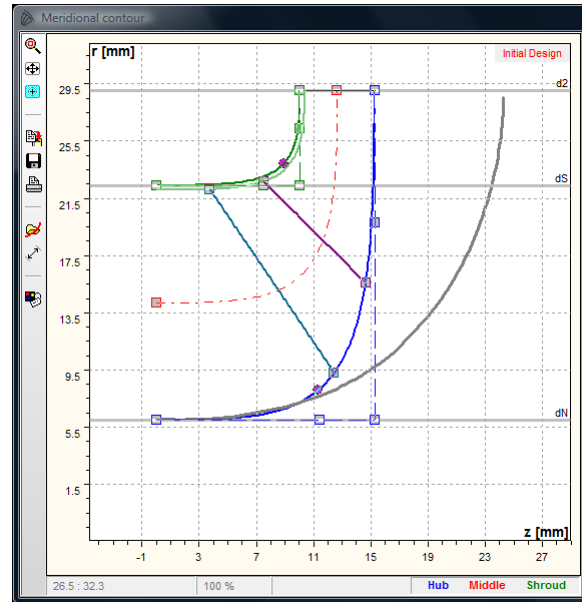


Figure 10

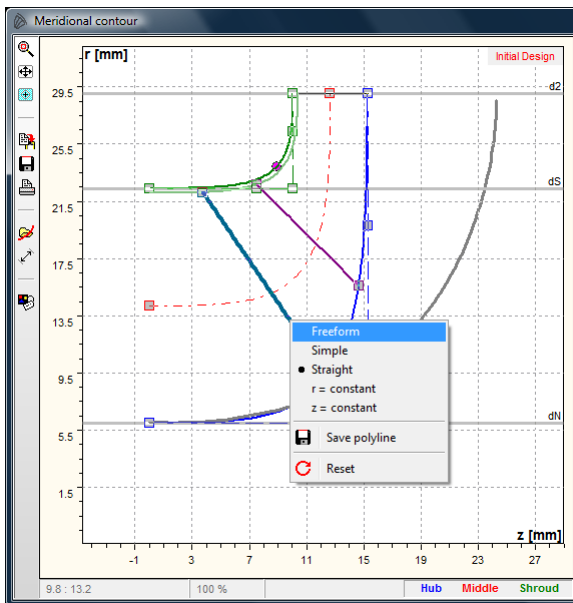


Figure 11

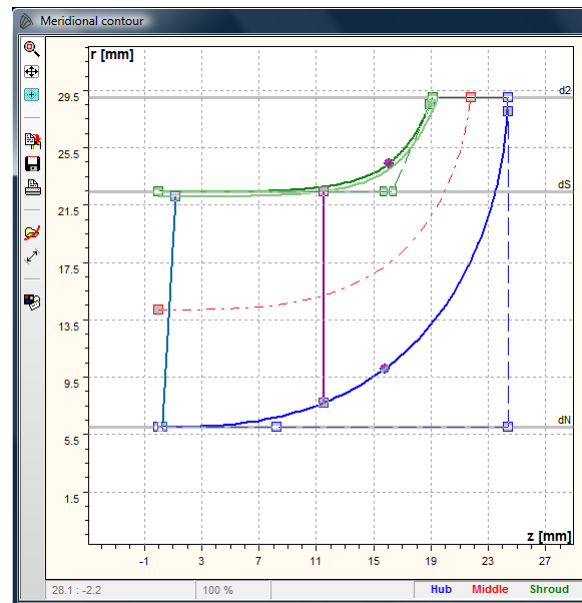


Figure 12

As an example for that a loaded hub line (grey) is displayed in Figure 10. The blue hub Bézier curve has to be altered now in a way that it gets almost congruent with the grey line. Due to the degree of the Bézier curve (here 4.) there will not be 100% congruence in most of the cases, but good approximations are possible. The most top Bézier point of the hub and shroud cannot be shifted in the axial direction, since this would change the outlet width. That is why the most top Bézier point of the middle (dotted) Bézier curve must be used to change the extension of the meridional shape.

As shown for the hub, all other curve of the meridional cut have to adjusted to the reference geometry.

Default for the leading edge is a straight form. In case the leading edge of the reference impeller is not straight, its form has to be changed in the meridional contour dialog. This has to be done by right clicking on the curve and choosing the proper option in the appearing context menu (Figure 11).

The option "Freeform" yields a 4. degree Bézier curve. With this type of curve the user has the greatest freedom while designing. However, option "Straight" might be sufficient for most of the contours of the leading edges. After appropriate modifications of the curves the meridional contour given in Figure 12 was created for the actual example.

2.3 Blade properties

2.3.1 Extraction of geometrical dimensions

It is a strong advantage if the geometric variables can be extracted from the basis geometry in a way, that they can be used directly in CFturbo. Such variables are e.g. radii, axial length, meridional and tangential co-ordinates as well as blade angles along mean lines, with whose help mean surfaces of the blades can be designed.

Such a line is e.g. the mean line at the tip of the blade. In case the line's x,y,z-co-ordinates are known, the following variables can be easily derived from it:

variable	formula
axial length	z
radius	$r = \sqrt{x^2 + y^2}$
meridional coordinate	$m = \int_{trailing\ edge}^{leading\ edge} \frac{dr + dz}{r}$
tangential coordinate	$t = arctan\left(\frac{y}{x}\right) - t_{leading\ edge\ hub}$
blade angle	$\beta = arctan\left(\frac{dm}{dt}\right)$

Table 1

To be loadable in CFturbo those data have to be provided in text files, see chapter 2.2, that contain rows of co-ordinate pairs.

2.3.2 Determination of the blade angles at leading and trailing edge

Within this design step a number of spans, which are used to design at, have to be determined as well as the blade leading and trailing edge angles at those spans. Beyond it a first estimation of the blade thickness at hub and shroud has to be given. These values may be adjusted iteratively later on in the process of the reverse design. Therefore for the time being the thickness definition can be carried out on the basis of CFturbo's defaults. The calculation of the blade angles on this basis will be achieved by the soft button "Calculate β_B (Main)" (Figure 14). When the data have been extracted as described in the prior chapter, blade angles can be taken directly from there.

In case of 3D-blading, the option "Free form 3D" has to be chosen in the section "Blade setup". It is convenient to design on a small number of spans (blade mean lines), because this will limit the number of parameters to be adjusted. Therefore with 3D-blading one should try to carry on with the design on the basis of 3 spans.

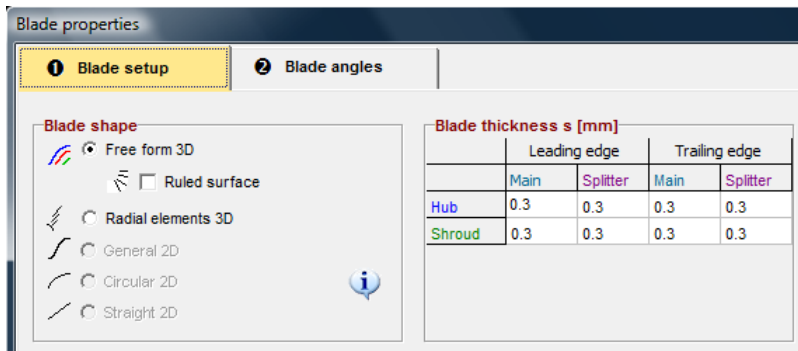


Figure 13

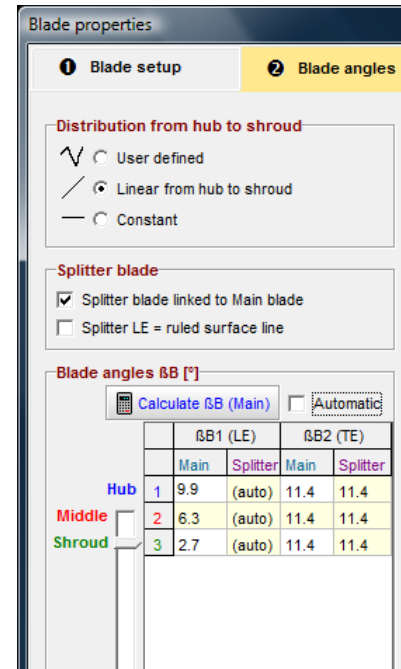


Figure 14

2.4 Mean lines

2.4.1 Mean lines of the main blades

In the initial design mean lines can be also generated on the basis of the default design of Cfturbo. To this end the dialog "Design blade mean lines" should be opened and ended per OK. The herewith produced mean surface is now discernable. It will not lay in the centre of the blade of the reference impeller geometry initially, which will make a rotation to the right position necessary (Figure 5). In case the tool box (Import) for setting the position of imported geometries is not visible, it can be opened by right-clicking on the name of the imported impeller (model tree, branch "Imports") and choosing "Set position" in the appearing context menu. Advantageous is a rotation, that brings the first point of the hub mean line (i.e. the point at the leading edge) on the centre of a blade of the imported impeller (Figure 15).

If, as described in the preceding chapter, extracted m-t-data and β -t-data for the different spans or sections are existent in the form of text files, these should be loaded per "Load extra polyline" into the appropriate diagrams. Subsequently the Bézier curves have to be adjusted in a way, that they are approximately congruent with loaded m-t-lines. The procedure is similar to the design of the meridional contour, Figure 10...12. If extracted blade angles are existing, the appropriate values of leading and trailing edge should be typed in the design dialog "Blade properties" (Figure 14).

In case m-t-data are not given, the tangential position of the points of the leading edge at the other sections - the leading edge of the hub section has already been adapted by the rotation of the imported geometry - have to be adjusted to the reference geometry. This is to be done by the

specification of the angle ϕ_0 . If a linear distribution of the angles at the mean lines of the leading edge is to much of a constraint, it should be switched to "User defined". Then the angle of every mean line is adjustable individually.

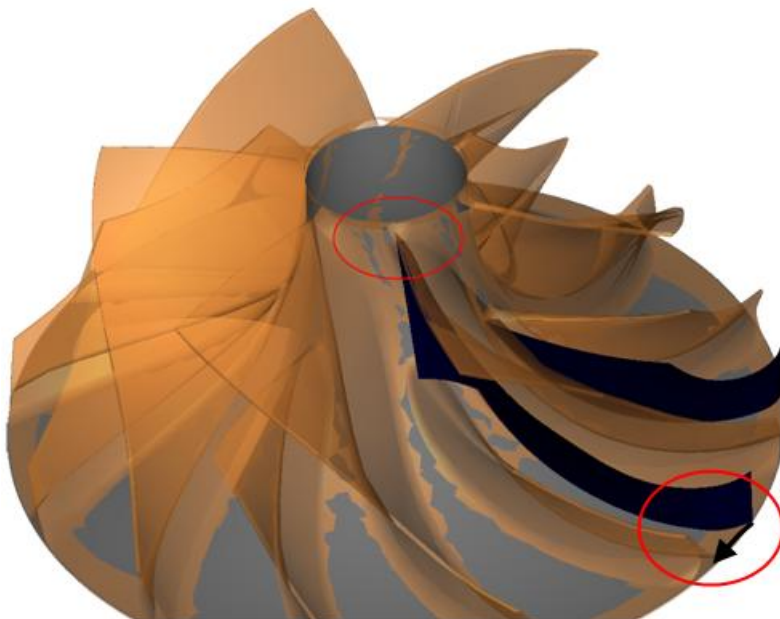


Figure 15

Constraints						
j	dm [-]		Leading edge		Wrap angle	
	Main	Splitter	Main	Splitter	Main	Splitter
			rel. [%]	rel. [%]	rel. [%]	rel. [%]
1	3.581	1.809	0.0	50.0	60.0	50.0
2	1.633	0.917	0.0	50.0	60.0	50.0
3	0.910	0.446	0.0	50.0	60.0	50.0

Leading edge points		Mean lines	
<input checked="" type="checkbox"/>	User defined	<input checked="" type="checkbox"/>	Coupled linear
<input type="checkbox"/>	Linear		
<input type="checkbox"/>	Constant		

Figure 16

After setting the tangential position of the leading edge, the trailing edge can be placed. This is to be done by an iterative change of the wrap angle $\Delta\phi$ in the dialog "Design blade mean lines". With more than 2 mean lines all angles $\Delta\phi$ should be coupled linearly. If in the further design this turns out to be a restriction, then the option "Coupled linear" must be deactivated, such that the adjustment of every angles is possible (Figure 16).

In the current version of Cfturbo every change in the design step "Mean lines" has to be checked in the 3D-view. This demands always the closing of the dialog per OK and in case of a correction the reopening of the dialog.

The blade angles at leading and trailing edge will only then fit with those of the imported impeller, if correct m-t-data have been used for the design of the mean lines. The same applies for the distribution of the blade angles along the mean lines. In case these data were not available the blade angles at leading and trailing edge have to be set in the design step "Blade properties" (Figure 14). When these are adjusted and subsequently checked in the 3D-view, then the blade angle distribution has to be corrected in the dialog of the design step "Design blade mean lines". For that purpose the inner Bézier points of the mean line have to shifted in a an appropriate way.

Probably the correction of the blade angles at leading and trailing edge as well as the correction of the distribution of the lade angles have to be performed alternately. Also, it might be, that the position of leading and trailing edge at the mean lines have to be adjusted again.

2.4.2 Mean lines of the splitter blades

The standard during the design of splitter blades is to tread them like shorten copies of the main blades (Figure 17). If this option was chosen, a separate design is not possible. If in the further design process it turns out that the splitter blades cannot be composed in the standard way, the option "Splitter blade linked to main blade" has to be deactivated. Adjacently the design of the mean

surface of the splitter blades has to be carried out in the same way as for the main blades (design step "Design blade mean lines", second tab), see preceding chapter.

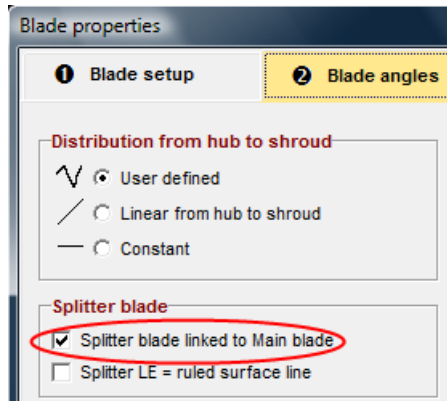


Figure 17

3 Blade profiles

3.1 Blade thickness

If the blade thickness is known at leading and trailing edge as well as at the top edge of the blade (i.e. at the shroud) and if the thickness is constant along these edges, then the blade thickness design at the top edge is finished with an exact as possible input of the blade thickness (Figure 13).

Generally the blade will be thicker at the blade root as at the top edge and will not have a symmetric thickness distribution at pressure and suction side measured at mean line. Beyond it the blade will be cambered stronger at the leading edge as in the vicinity of the trailing edge. Therefore the following adjustments should be carried out in the design step "Blade profiles":

- Design mode: Freeform (thickness distribution via Bézier curve)
- Increase of the number of the Bézier points (e.g. to 4)
- If necessary invalidation of the symmetry of pressure and suction side (SS-PS-Coupling: None)

In case it is not feasible to design the blade with the default number of Bézier points, further Bézier points can be added by right-clicking at the Bézier curve (Figure 19). This might be necessary especially at the blade's nose, if this is strongly shaped.

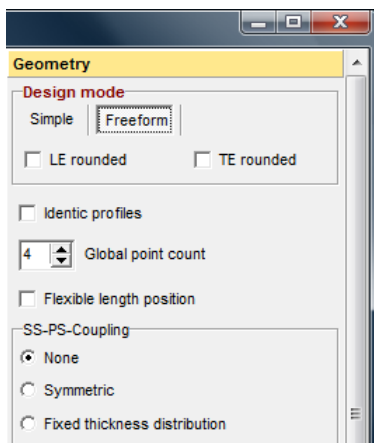


Figure 18

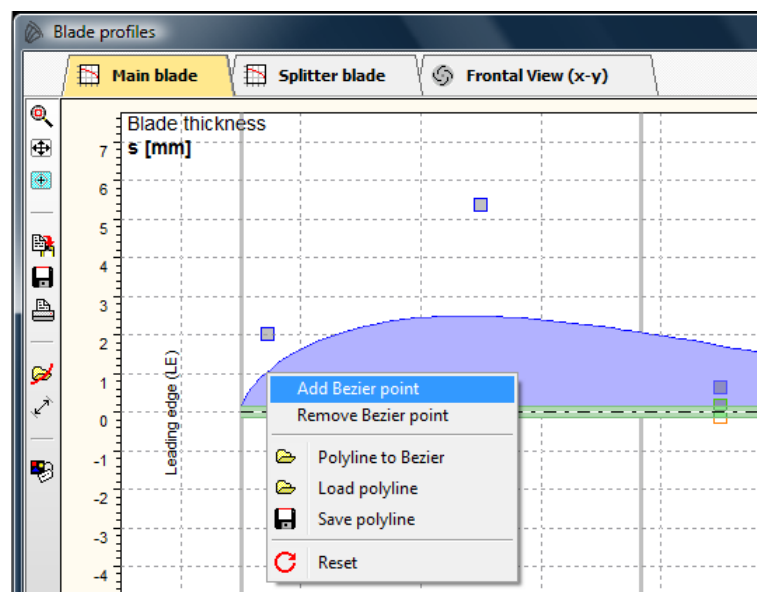


Figure 19

If Bézier points, whose position is to be changed with the help of the mouse, lay on each other, then a tool box appears, in which one can choose the eligible Bézier point. Beyond it Bézier points can also be adjusted by the direct input of their coordinates. Thereto the appropriate edit box has to be opened with a right-click at the Bézier point.

Ideally the Bézier curve has to be approximated to a loaded polyline as shown in design of the meridional contour. This polyline must have x-y-pairs, that hold a non-dimensional blade length (at the appropriate section, i.e. hub or shroud) and an associated blade thickness that has to be added to the mean surface. If these data are not available, the values of the blade thickness of main and

splitter blades have to be adjusted in the given way. The check of these adjustments must be done in the 3D-view.

3.2 Round leading edge

In the design step "Blade edges" three different modes are provided: "Simple", "Ellipse" und "Bézier". The last option again gives so most comprehensive opportunities for the design and should be chosen, unless leading and trailing edges shall be trimmed. The adaption of the Bézier curve with the help of the movement of the Bézier points has again to be checked visually in the 3D-view. Therefore the dialog must be closed with OK and has to be reopened, if the result was satisfactory.

3.3 CFD-Extension

If the design shall be used together with Cfturbo's ICEM-Interface furthermore, a small outlet extension should be defined, since this will be used for generation of the rotor-stator-interfaces. It is sufficient to check the appropriate checkbox to this end. The size of the extension will be determined with the help of the size of the impeller (Figure 20).

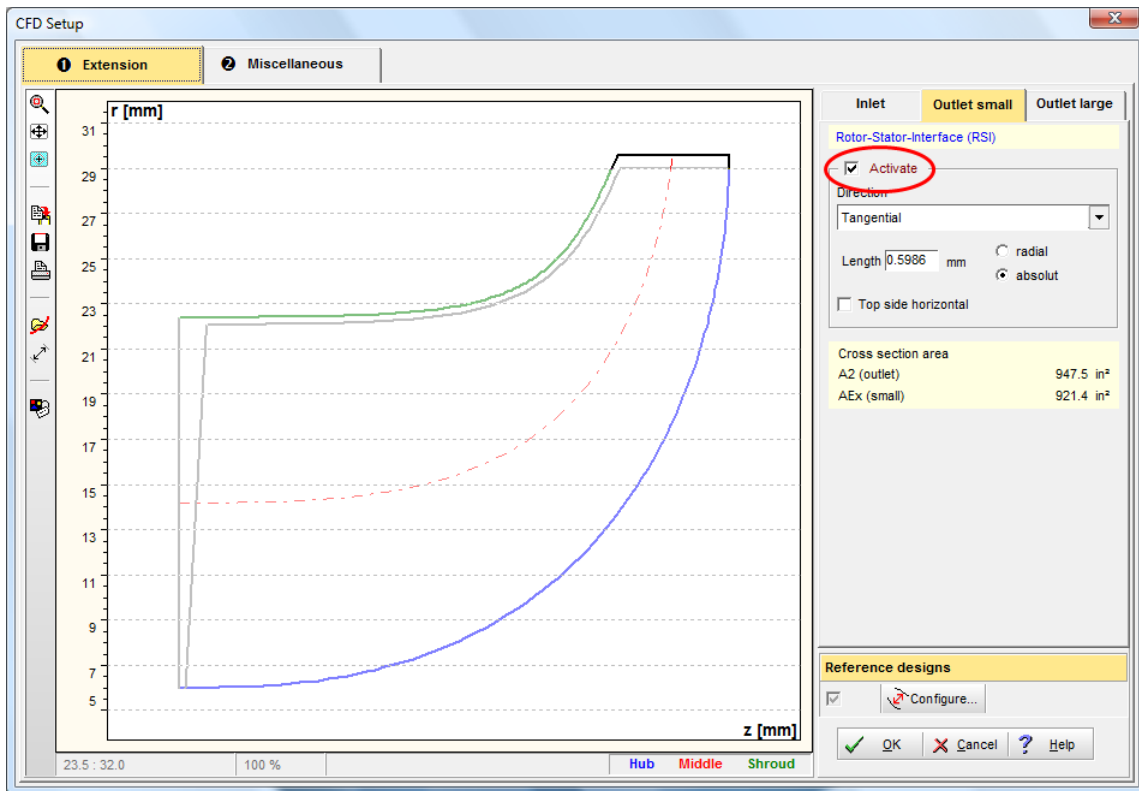


Figure 20

4 Volute

It is recommended to load separate parts of the reference geometry of the volute in accordance to the respective design step as separate comparing parts into CFturbo. Herewith a visual comparison in every design step is possible, without interference of parts, that are currently not of interest. For the generation of these individual parts, i.e. vaneless radial diffuser and pinch type diffuser, spiral and outlet diffuser, see chapter 2.1.

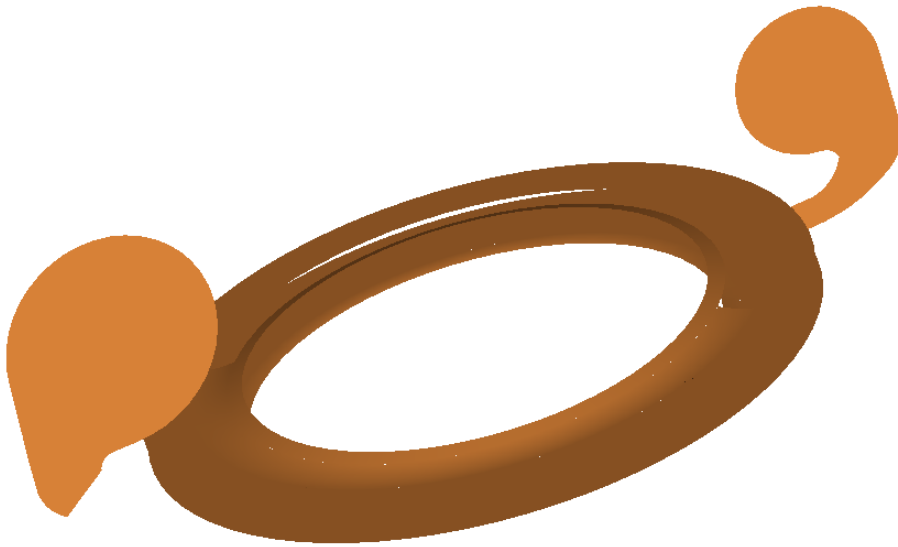


Figure 21

Exemplary two coaxial sections of the spiral as well as the contour of the radial diffuser are displayed in Figure 21.

4.1 Inlet definition

4.1.1 Impeller

As a starting point in any case the cft-file of the associated impeller should be used. Thereto after starting the design the appropriate soft button (Figure 22) is to be pushed and the proper file is to be chosen. The result is, that all edit boxes of the first tab are filled with the correct values (Figure 23).

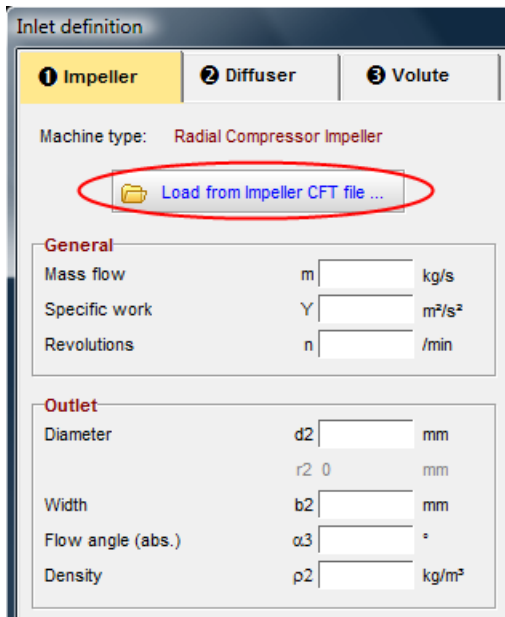


Figure 22

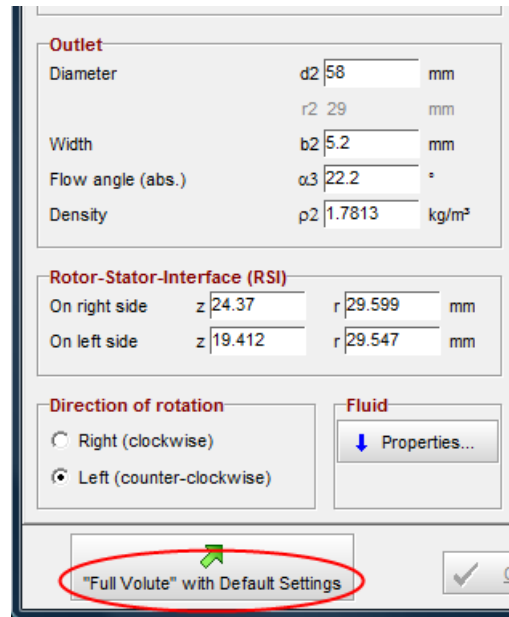


Figure 23

Via "Full Volute with Default Settings" now an initial design of the volute can be carried out, that is of course to be modified afterwards.

4.1.2 Diffuser

The second tab Diffuser has to be filled with the geometric parameters of the vaneless diffuser and the pinch type diffuser. Because these parts have a rotational symmetry, the respective parameters can be easily extracted from the reference data.

After the finishing of the first design step Inlet Definition a 3D-geometry will not yet being produced, which means that a visual comparison with reference geometry is not yet possible. Therefore in the further design process of the volute it might be necessary to come back to the diffuser design, in order to do some modifications of the geometric parameters.

4.1.3 Spiral

In the third tab Volute the inlet values of the spiral geometry have to be set. The inlet diameter d_4 is not possible to be changed here, since it is a result of a formula containing already given parameters:

$$d_4 = d_{pinchin} + 2 \cdot (h_{pinch} + h_{vaneless}) .$$

In case of asymmetric internal volutes (see chapter 4.2) the outer radius r_5 , that is to say the biggest radial dimension, will be determined with the inlet width of the spiral:

$$r_5 = \frac{d_4}{2} + b_4 .$$

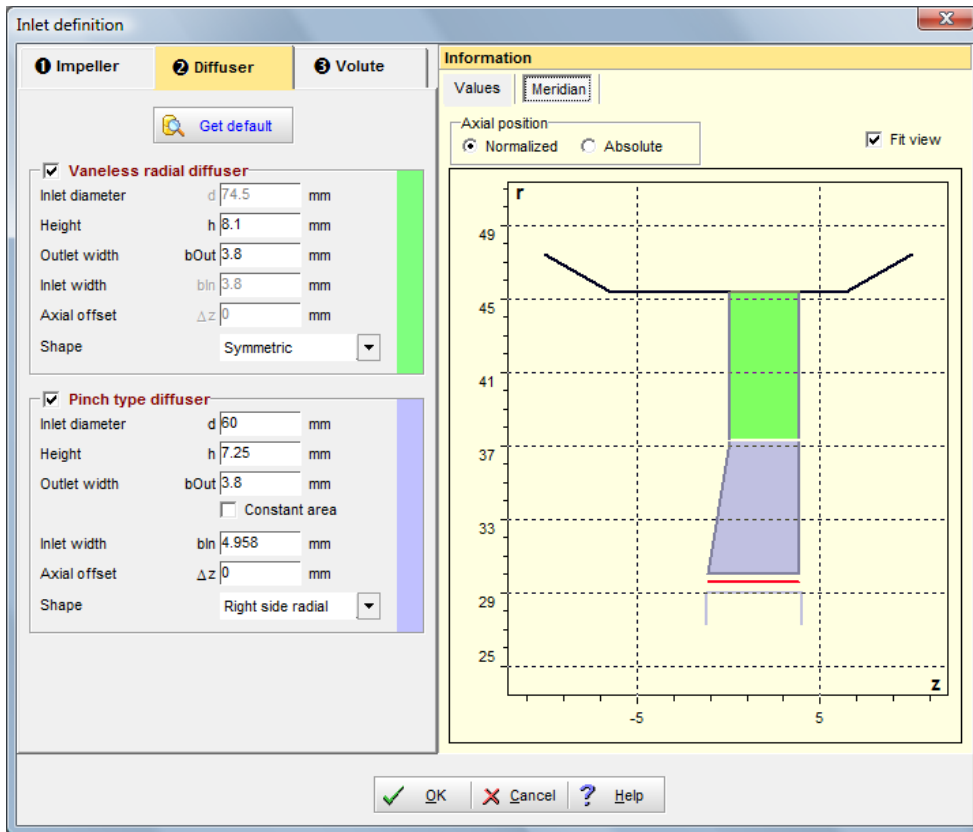


Figure 24

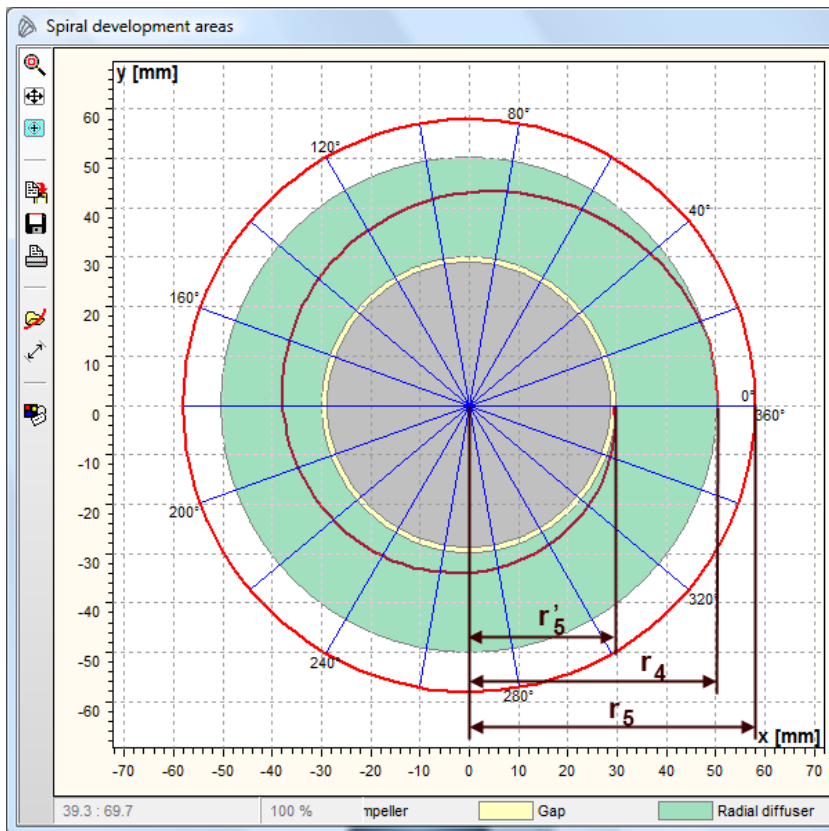


Figure 25

4.2 Cross section shape

In the dialog "Cross section" the cross section design of the Spiral is to be chosen. Afterwards the principle cross section shape will be displayed, where a radial extension is assumed (for radial scaling use arrows right above the diagram). When the appropriate cross section shape was chosen, some geometric parameters are editable.

For instance, the choosing of a round asymmetric shape yields the opportunity to design spirals that are have an internal location, which means they are bended towards the axis. These shapes are utilized for turbo charger compressors. There are more design options concerning the shape of the inner and outer bend as well as the geometric parameter "Neck width" (side distance from volute inlet to actual volute cross sections) and "Ratio" (semi axis ratio for quarter bend).

The change of these parameters will not be visible in volute design at once, since only after finishing the next design step "Spiral development areas" the 3D-geometry will be discernable. The following applies again: in the further design parameters have to be adjusted to the desired geometry.

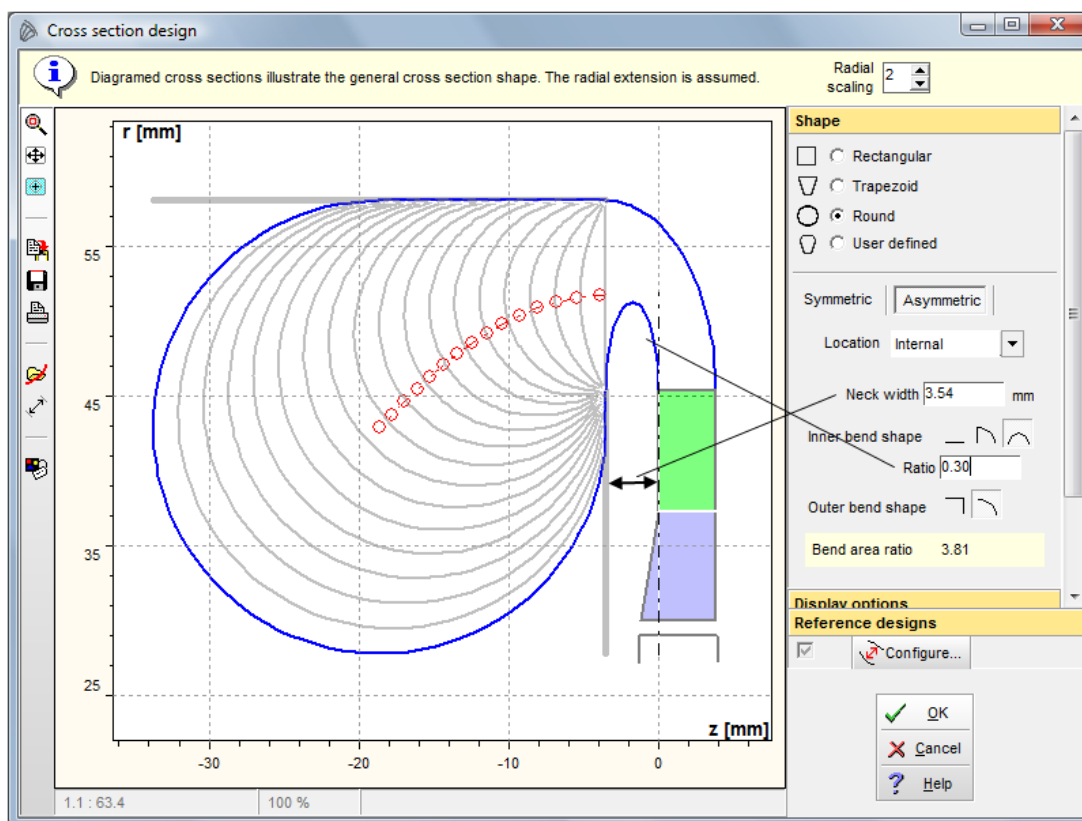


Figure 26

4.3 Spiral geometry

In the dialog "Spiral development areas" the actual spiral geometry will be set up and calculated respectively. Here important parameters are radii, heights, widths a.s.o. If a nonlinear distribution of radii or cross section areas along the perimeter of the spiral is necessary, this can be set with "Set progression".

In case of internal asymmetric spirals the big radius in the diagram of the radius progression (Figure 28) is in accordance to the radius, that is made by the inner side of the spiral with the z-axis at the

smallest wrap angle (Figure 25). At the location of the biggest wrap angle, the round cross section of the spiral has a diameter of $d_s = r_s - r'_s$.

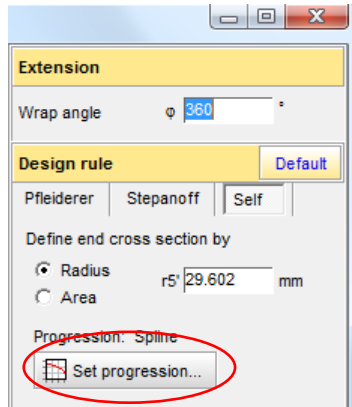


Figure 27

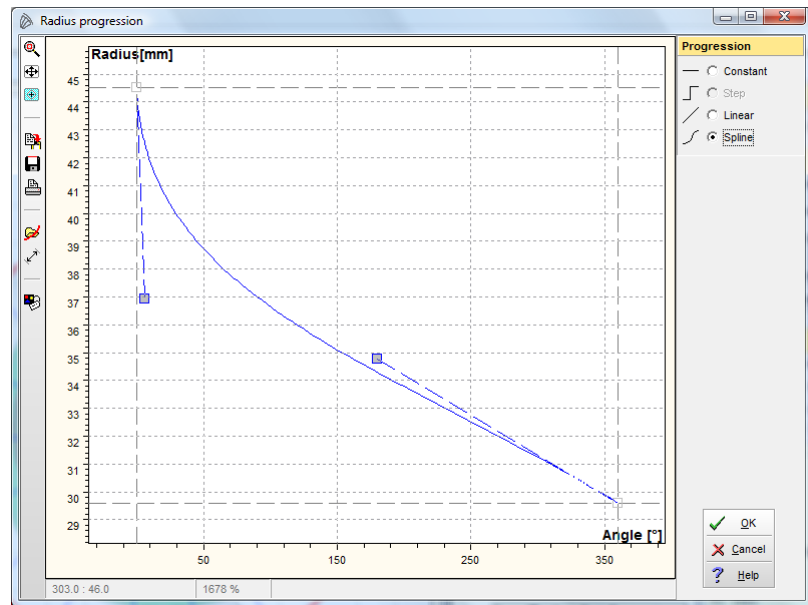


Figure 28

Again, it is necessary to make a parameter change and finish the dialog with OK. Then the altered geometry must be compared to the reference geometry visually.

4.4 Diffuser geometry

The last design step's content is the design of the diffuser at the outlet of the spiral ("Diffuser geometry"). The shape ("Direction") of the diffuser is to be chosen and dependent on this shape some geometric parameters have to be given. It is recommended to import a reference geometry of the diffuser in order to check the influence of the parameter changes after pressing "OK".

5 Summary

The redesign of impellers with CFturbo works best in case 2D-data are available, that can be loaded directly into the respective design steps where they can be used as a basis for the fitting of the Bézier curves. Currently these 2D-data must be generated outside CFturbo, see e.g. chapter 2.2.

The checking of the geometric design must be carried out in the 3D-view visually. It might be, that parameters in a design step are to be changed and the respective dialog has to be closed via OK. Only then the updated geometry can be analyzed. This must be done iteratively until the desired effect is achieved.

The blade shaping is currently performed in CFturbo on two spans, which are hub and shroud. If free form 3D blades shall be redesigned, this might not give enough freedom for the design. For milled compressor impellers probably the switch to the option "ruled surface" (Figure 13) is an opportunity to match the given reference geometry in the design process.

Bézier curves, that are used in CFturbo for the design, have a maximum degree of 4. This can be possibly not enough to for the matching of highly curved geometries. Beyond it, they are currently not used in every design step, where 2D-parts are to be created or changed. One example is the design of the radial diffuser that is currently only feasible with straight lines.

The outer and inner bend at the transition from the radial diffuser to the spiral (Figure 26) is currently made of the section of an ellipsis. Again, this is possibly not sufficient for all shapes of bends, in order to match the reference geometry exactly.