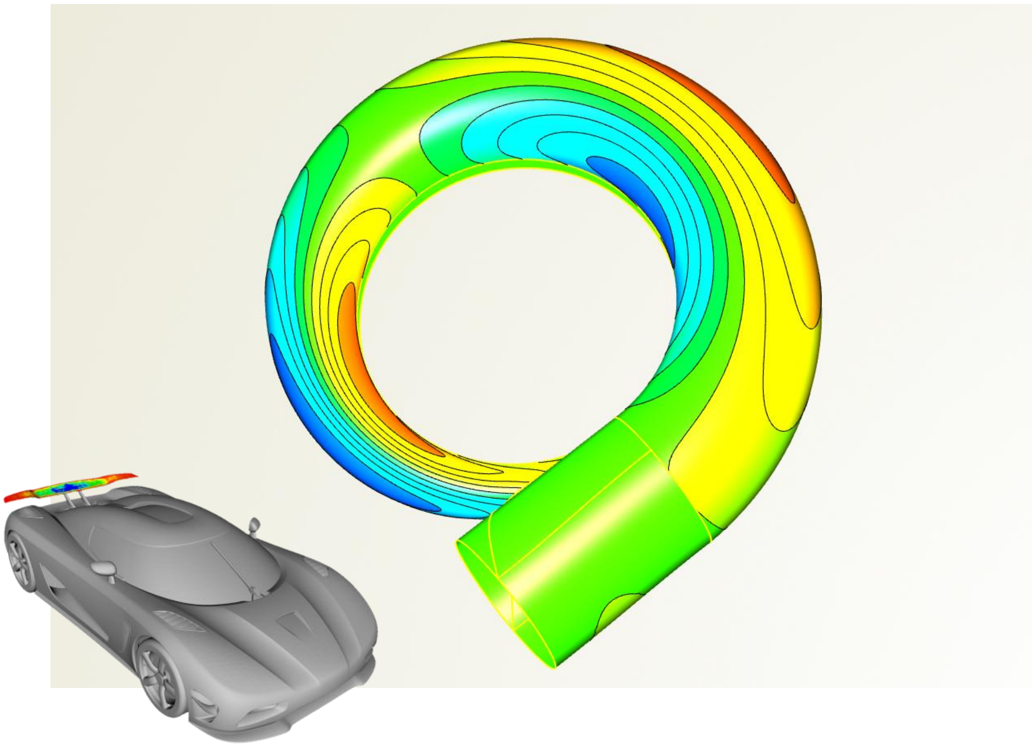
Learn More

Sensitivity Computation

Parametric models of complex geometries are typically controlled by up to 100 parameters, making it difficult for the designer to select the most suitable and relevant parameters for an optimization task, especially if the model was set up by someone else. The *sensitivity computation* allows for a very efficient optimization of complex models in connection with adjoint CFD solvers. It gives you the most important CAD model parameters with regard to a specific objective. More details will be given in this document.

Users without access to adjoint CFD solvers can also benefit from the sensitivity computation: It can conveniently be used to compute and plot the design velocities – the movement of the model surface due to changes of the parameter values. The design velocities visualize the effects of the parameters on the model, which helps to understand the parametric model in a visual way, see the following picture for an example:



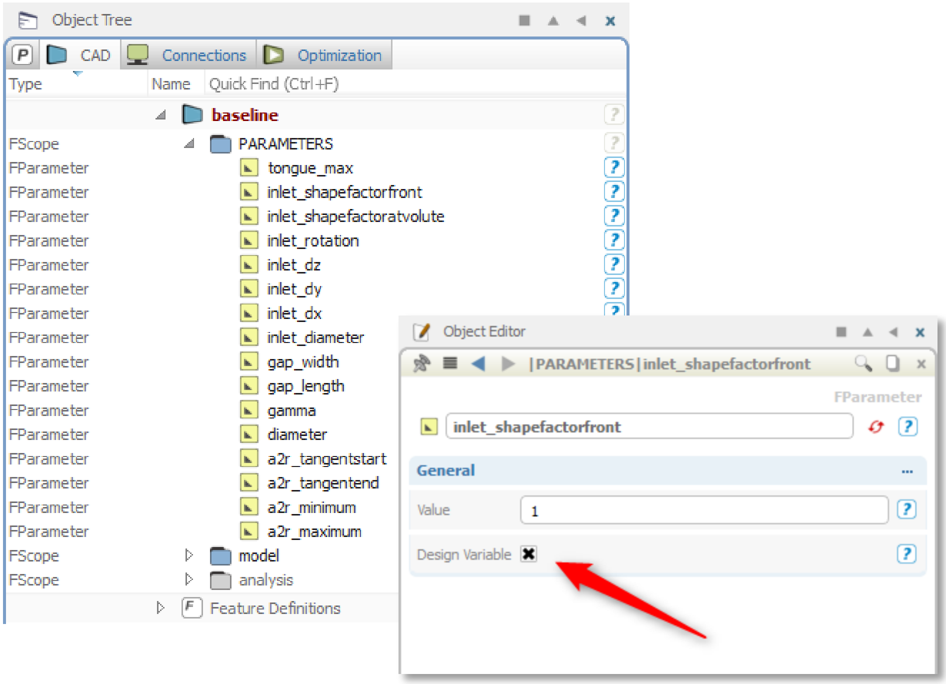
In this brief tutorial, the design velocities are demonstrated first. For this purpose, you can use any parametric model which contains some parameters or design variables. In a second step, adjoint CFD information is involved and multiplied with the design velocities in order to receive the most influential CAD variables of the model, considering a specific objective.

1

Design Variables

Make sure that your model contains design variables that control the shape of your geometry.

► If you only used parameters so far, then switch your selection of parameters to design variables (the icon turns from light blue to yellow).



✓ Remember: parameters can contain discrete values or expressions (e.g. "sqrt(a+b)"). In contrast, design variables can only hold discrete values. And unlike parameters, the value of design variables can be controlled by design engines or, as we will see in the further steps, by certain computations for automation purposes.

If a parameter that held an expression is switched to being a design variable, the expression is detached and the current value is used for the design variable.

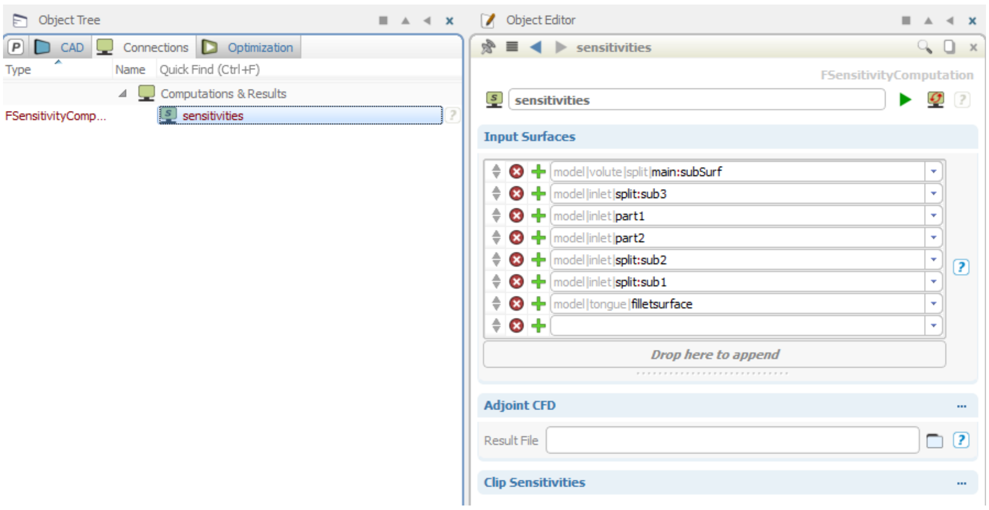
2

Sensitivity Computation

If your model is ready and contains design variables, you can continue with creating a sensitivity computation:

- Choose *menu > connections > sensitivities*.
- Drag & drop (or paste) the surfaces you want to involve into the list editor that is called “Input Surfaces”.

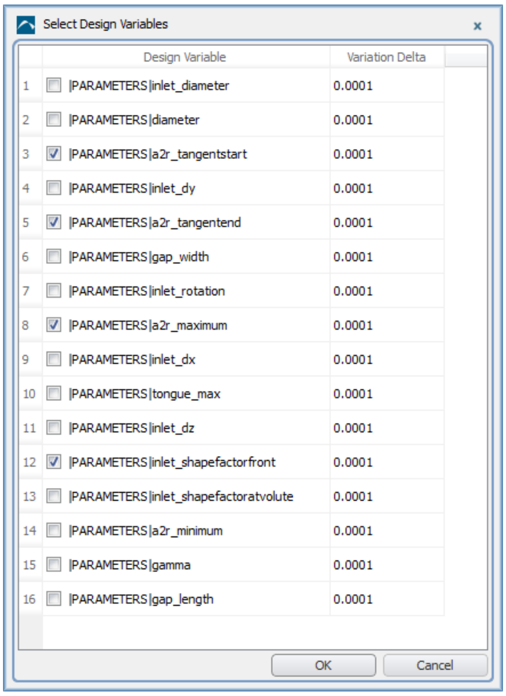
✓ If you have several surfaces, you can drag them at once onto the area “Drop here to append”.



3 Choose Variables and Run

Let's run the computation and configure the variables. The computation automatically lists all design variables that are suppliers to the selected surfaces. You can activate or deactivate variables in this list.

- Press the run button ▶ at the top of the object editor, next to the name of the computation.
- The upcoming dialog (see screenshot) shows all the variables that are connected to the given input surfaces. Select the variables you are interested in and for which the calculation should be started.
- Press OK for running the computation.



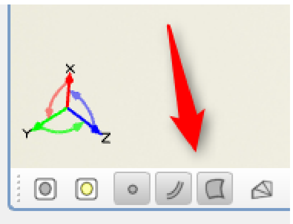
✓ For the determining the design velocities, the values of the design variables are perturbed in positive and negative direction by the amount specified in "Variation Delta". The geometry is updated, the normal displacement of the surface tessellation elements is measured and the gradient of surface movement due to change of the variable value is numerically computed for each tessellation element.

To adapt the perturbation to the range of the design variable, "Variation Delta" can be individually set for each variable. The exact value is not so important, but it should be a couple of orders of magnitude smaller than the variable's range.

4 Visualization of Design Velocities

After the computation run, a mesh and a default contour plot is available below of the sensitivity computation node (see the picture). We want to visualize where each variable has the strongest effects on the surfaces:

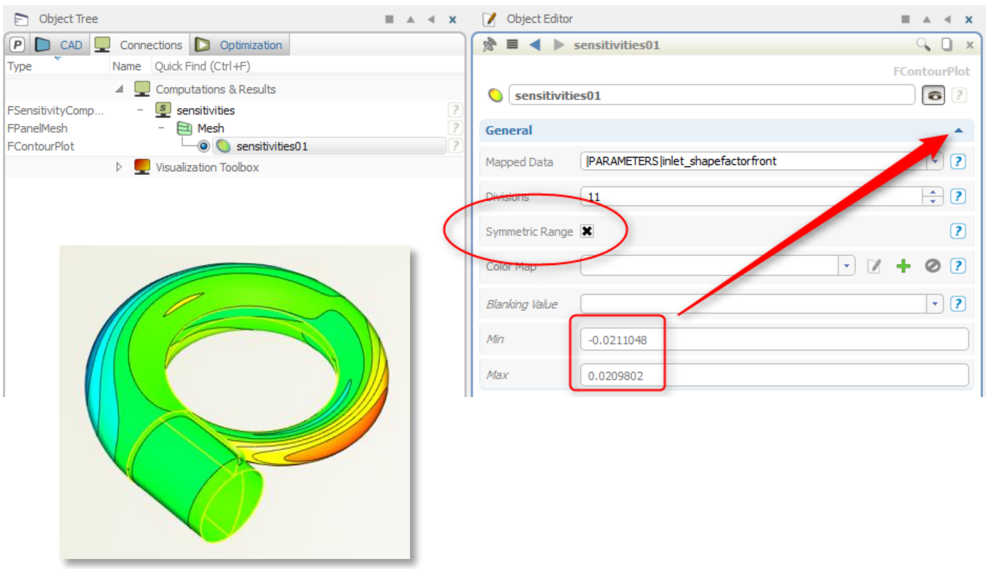
- Select the contour plot and choose a variable at the attribute "Mapped Data".
- Switch on "Symmetric Range".
- Filter surfaces at the 3D view in order to exclusively visualize the results. Otherwise, the generated mesh and the surfaces coincide which makes it hard to look at the results.



✓ For contour plots, the option "Symmetric Range" can be used for the default color mapping (see the category "General" of the contour plot "sensitivities01"). This means that the larger absolute value is automatically applied as the lower and upper bound, considering the sign again. Here is an example: [-0.0211048, 0.0211048].

Why symmetric mapping? Applying the symmetric range makes the visualization of the results more intuitive, the blue regions mean a change in negative surface normal direction, whereas the red regions mean a change in positive direction.

The min- and max-values can be optionally shown as well, see the screenshot below.



5 Involving Adjoint CFD Results

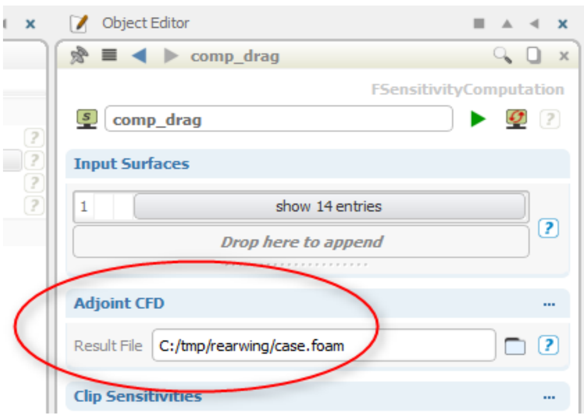
In addition to the calculation of design velocities shown in the previous steps, these velocities can internally be multiplied with the adjoint shape sensitivities – the change in objective function due to a normal movement of the surface elements of the CFD grid. As a first step, the adjoint sensitivities are automatically interpolated onto the surface tessellation (i.e. onto each triangle). We are interested in the objective change ∂J with regard to the change of a specific CAD design variable α_i. This can be calculated using the chain rule:

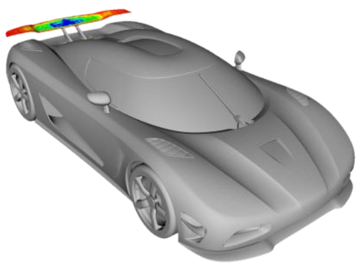
$$\frac{\partial J}{\partial \alpha_i} = \sum_{k=0}^{m} \frac{\partial J}{\partial n_k} \frac{\partial n_k}{\partial \alpha_i} \frac{A_k}{A_{average}}$$

Here, ∂n_k is the movement in normal direction of a triangle element k, so $\frac{\partial J}{\partial n_k}$ is the adjoint shape sensitivity from the CFD run, while $\frac{\partial n_k}{\partial \alpha_i}$ is the design velocity. For each triangle, the calculation is additionally weighted with the relative local area of the triangle.

Based on this information, we can now continue in our tutorial. As an example, let's have a look at a rear wing geometry of a sports car for which adjoint information was calculated before:

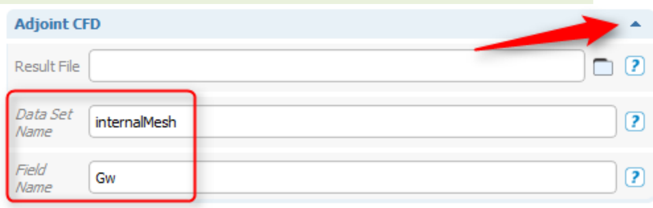
▶ After step 2 of this tutorial, additionally enter your adjoint solution:





✓ Usually, the geometric model was exported before (for instance, using STL), so as to calculate the adjoint sensitivities in a first step. For this purpose, external CFD software is used. Note that currently *.foam and *.case (Ensight) files are supported.

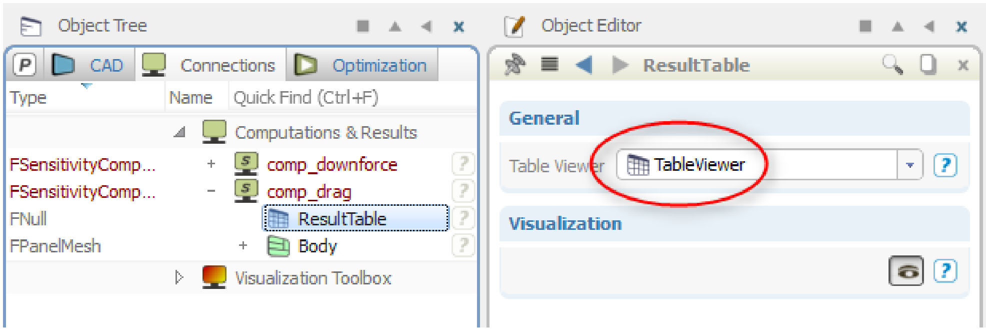
For *.case files, see also the *data set* and *field name* attributes that need to be set.



6 Assessment

See step 3 and 4 again for running the computation and for visualization of the results. Now, the values $\frac{\partial J}{\partial \alpha_i}$ are additionally shown in a table:

- Make sure that the result table is shown in the table viewer.
- By checking for the largest absolute values in the table, you can find out your most important CAD variables (the ones that have the strongest effect on your objective J).



baseline: Sensitivities

	Sensitivity	Variation Delta
aoa_Center	5.75649	0.0001
aoa_Outer	0.0925556	0.0001
aoa_Tip	-0.0502847	0.0001
camberPos_PressCenter	5.69464	0.0001
camberPos_PressTip	-7.64858	0.0001
camber_PressCenter	45.6081	0.0001
camber_PressTip	0.989046	0.0001
thickness_PressCenter	-247.23	0.0001
thickness_PressTip	-10.3726	0.0001
stepPosition_yShift	92.8336	0.0001
camberPos_SucCenter	-12.0784	0.0001
camberPos_SucInner	-11.8784	0.0001
camberPos_SucTip	-1.40639	0.0001
camber_SucCenter	13.1993	
camber_SucInner	10.9808	
camber_SucTip	-0.139731	
thickness_SucCenter	73.9607	
thickness_SucInner	63.8199	
thickness_SucTip	10.0784