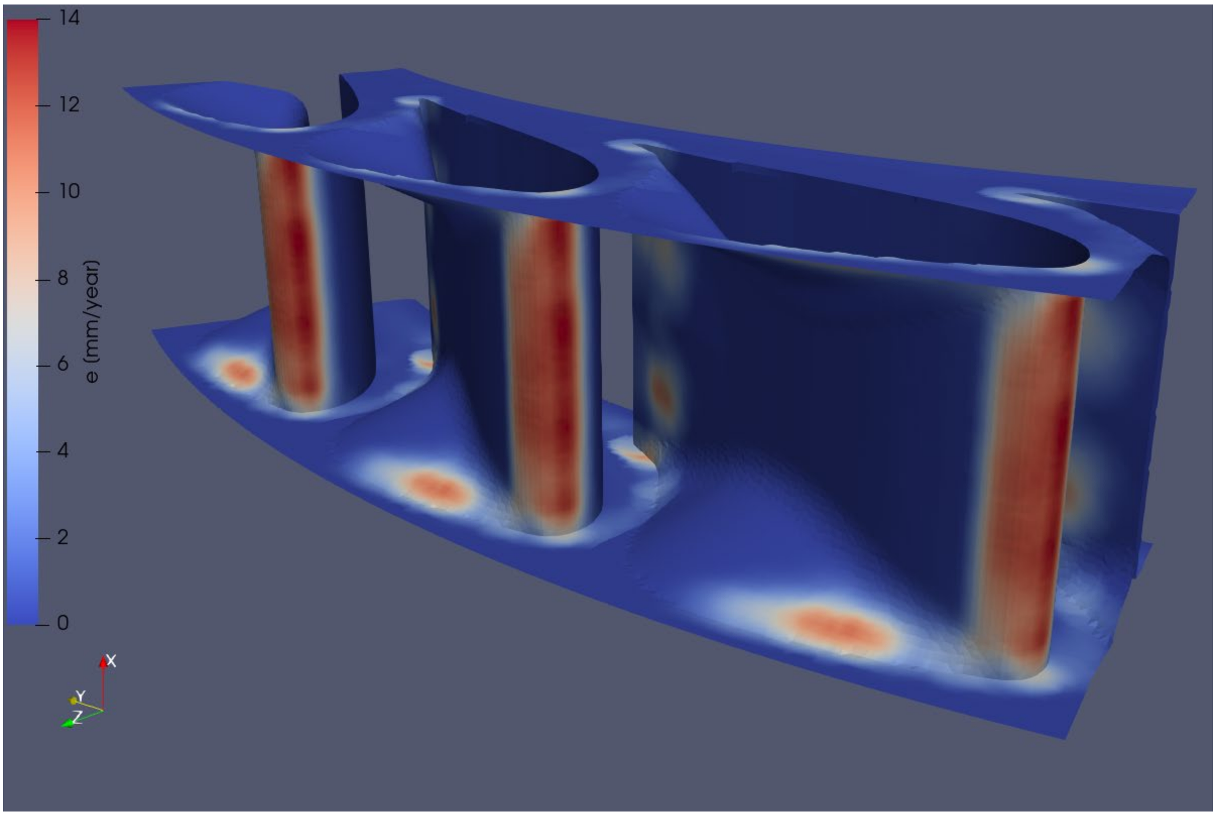
Physics based Level-set morph: Erosion of a Francis Turbine Guide Vane

For BOXER version 3.15.0

BOXERsolutions Ltd.
Suite 1
200 Cambridge Science Park
Milton Road
Cambridge
CB4 0GZ
info@boxersolutions.com
www.boxersolutions.com
+44 (0)1223 628771

Erosion of a Francis Turbine Guide Vane

This example demonstrates the BOXERgeom physics-based level-set morphing capabilities for generating the degraded geometry of a hydro-turbine component due to sand erosion. The initial geometry is a ring of guide vanes from the Francis Turbine test rig that is housed in the Waterpower Laboratory at the Norwegian University of Science and Technology. Erosion rates on the geometry surfaces were sourced from CFD calculations that utilise Discrete Phase Modelling and the Finnie erosion model. Flow field results were obtained at operating conditions for the turbine's best efficiency point (12,000 LPM) and particle transport conditions represented sand flow rates on the Bhilangna river in the Himalayas during monsoon season (12-million tons/year). The steps to generate the erosion rates are not included here as the tutorial focusses on the capabilities of BOXERgeom. The erosion rates are stored in an ASCII-encoded, column-format file, which drives the geometry degradation.



We used the test-case provided by NTNU – Norwegian University of Science and Technology under the Francis-99 workshop series: https://www.ntnu.edu/nvks/francis-99

Prerequisites

This tutorial assumes that the user is familiar with the general method of the BOXERmesh GUI, and the operation of the various specifier panels. If this is not the case, then please begin a BOXERmesh tutorial.

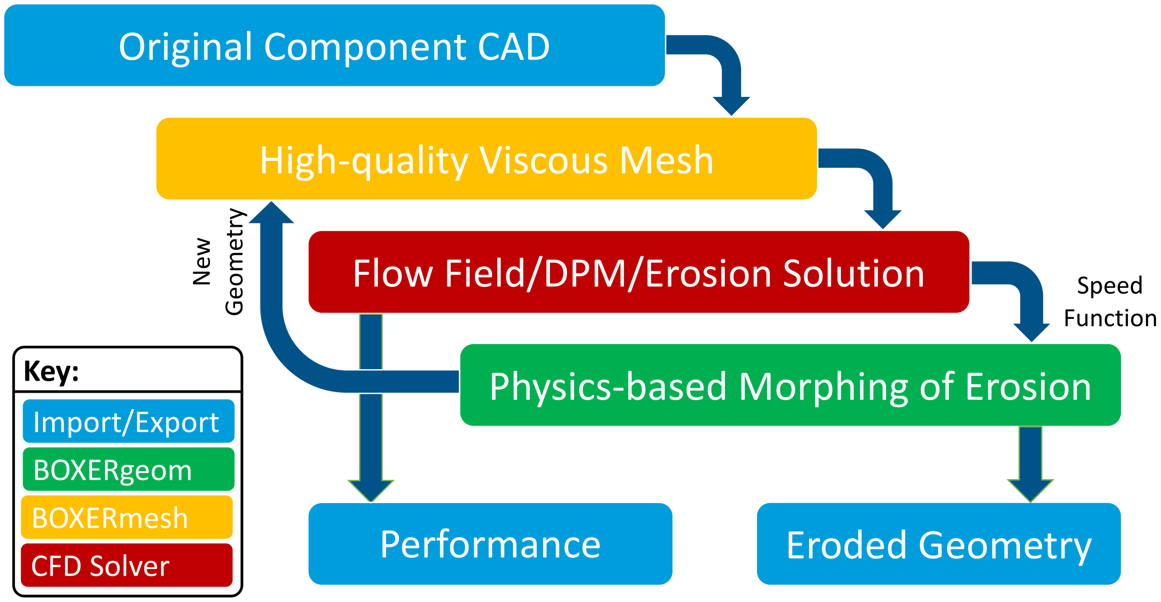
The following files are required to complete the tutorial:

- `francis_turbine_guide.btf`
- `erosion_guide_vane.dat`

Implementation within a Workflow

The following diagram illustrates an example workflow that can be implemented to model component erosion with the tools that are available in BOXERgeom and BOXERmesh. The process can be fully- or semi-automated thanks to the Lua-scripting capabilities in BOXER. The link between BOXERgeom and BOXERmesh is seamless and fully parallel, which minimised the turnaround time of the workflow process.

This example uses CFD modelling to determine erosion rates on the turbine components, but other methods may be used, such as direct measurements of in-service parts.

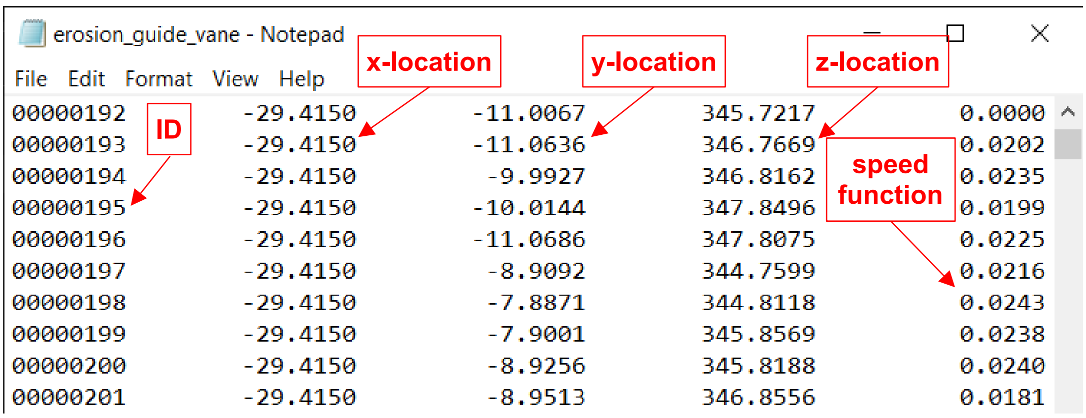


Speed Function File Format

The speed function (in this case `erosion_guide_vane.dat`), which drives the physics-based morphing in BOXERgeom is expected to be an ASCII-encoded, column-format file (either space or tab delimited). The five columns are a unique ID, x-, y-, z-location, and the speed function value (in this case erosion rate; eroded volume per surface area per second – $m^3/m^2/s$ or m/s). Note that these values do not need to be defined at each point in the level-set explicitly. BOXERgeom will interpolate the values from the speed function file to the component surface based on the closest point.

In this example, the erosion was post-processed from the CFD solver into the correct format using the capabilities that are available in Paraview v5.7 (Kitware, New York, USA). In your own cases, surface data will also need to be converted into speed function files, but this is outside the scope of this tutorial.

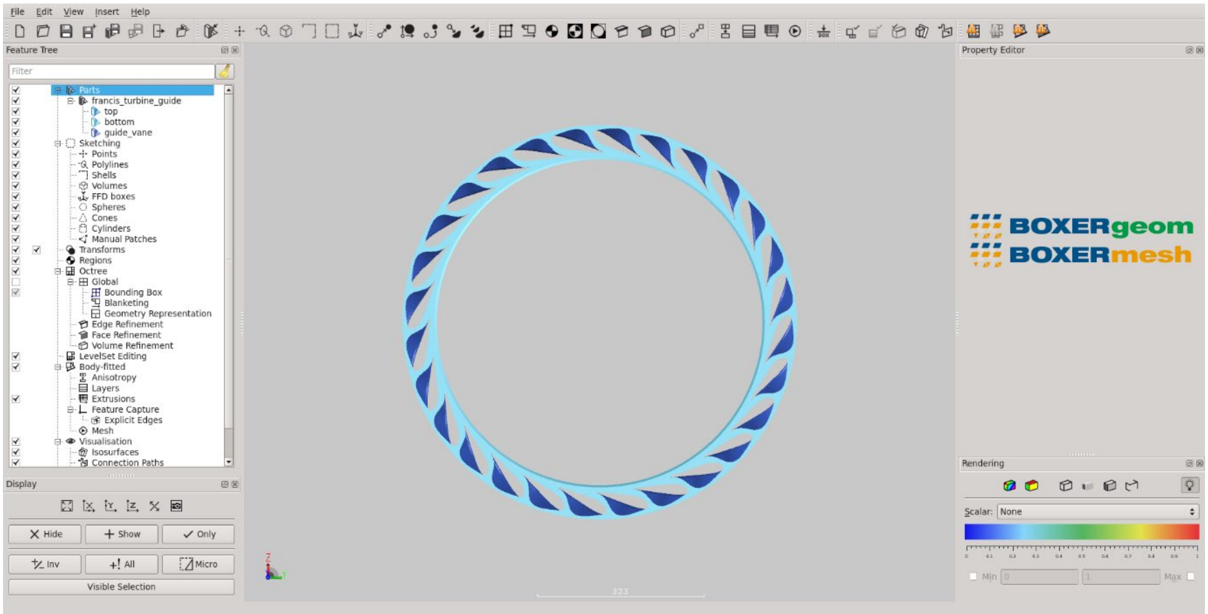
An example of the speed function file used in this tutorial, with the columns annotated, is given below:

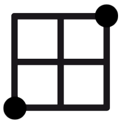


00000192	-29.4150	-11.0067	345.7217	0.0000
00000193	-29.4150	-11.0636	346.7669	0.0202
00000194	-29.4150	-9.9927	346.8162	0.0235
00000195	-29.4150	-10.0144	347.8496	0.0199
00000196	-29.4150	-11.0686	347.8075	0.0225
00000197	-29.4150	-8.9092	344.7599	0.0216
00000198	-29.4150	-7.8871	344.8118	0.0243
00000199	-29.4150	-7.9001	345.8569	0.0238
00000200	-29.4150	-8.9256	345.8188	0.0240
00000201	-29.4150	-8.9513	346.8556	0.0181

Importing the geometry 

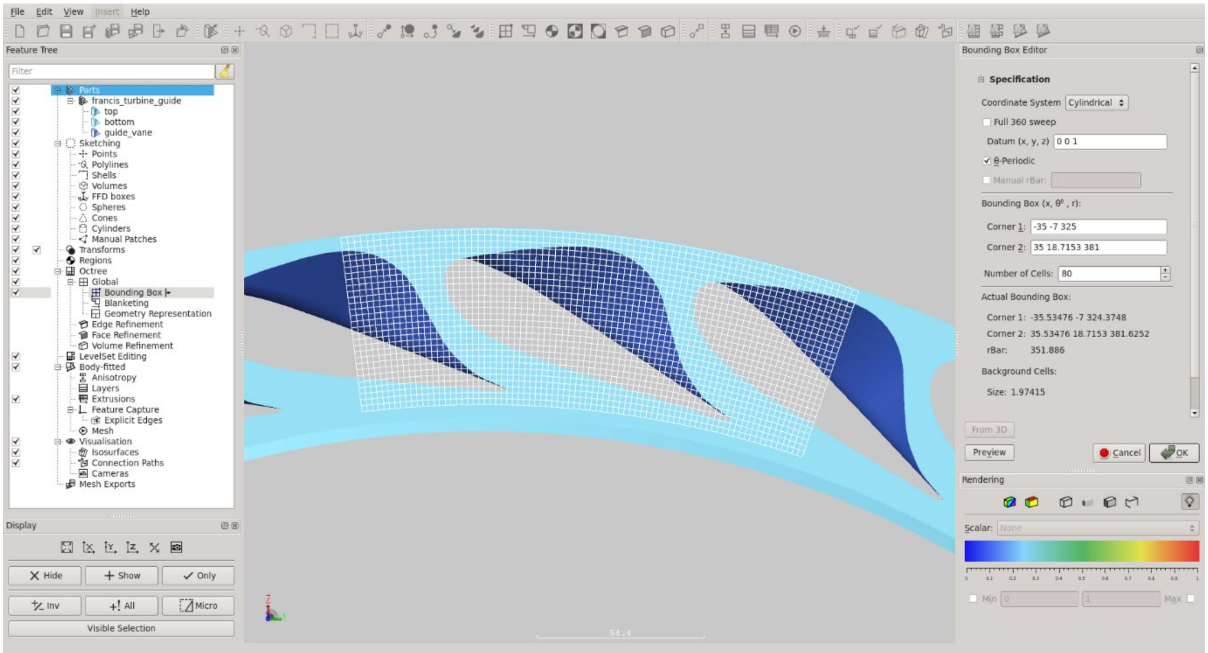
- `File > Import Part` from the menu bar, OR
- Click the “Import Part” toolbar button, OR
- Use the keyboard shortcut Ctrl-G
- Open `francis_turbine_guide.btf` from the file browser



Setting up the octree 

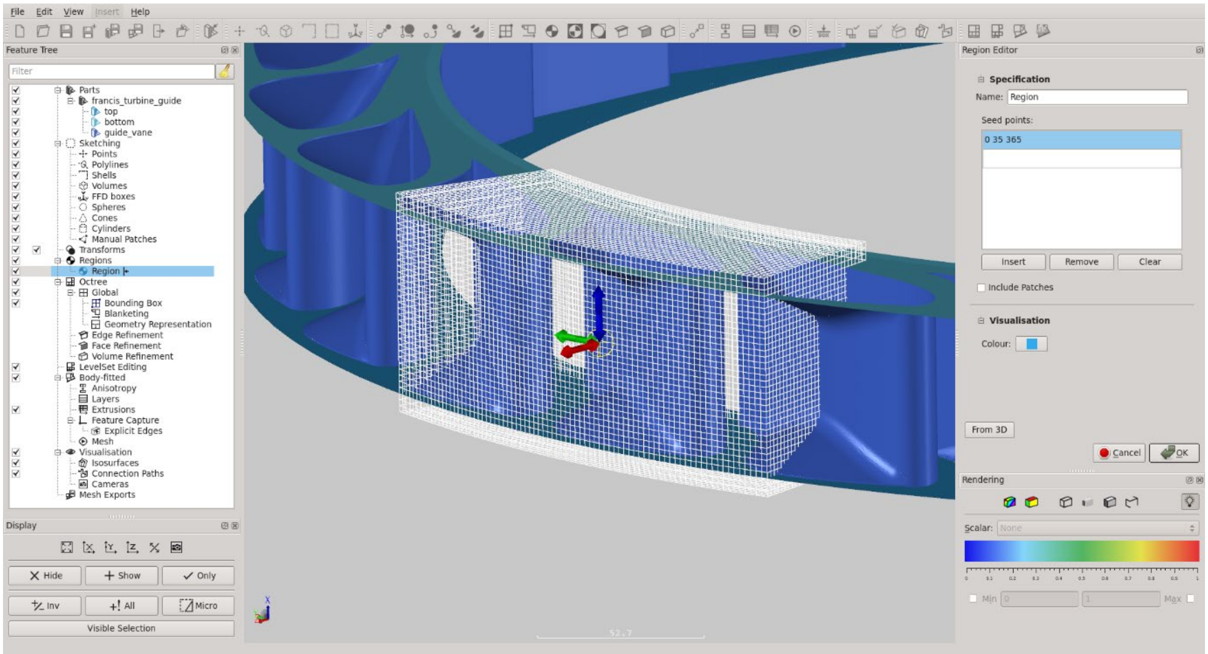
The physics-based level-set morphing operates in the same domain (bounding box) and with the same resolution as the octree mesh. Due to the circular shape of the guide vane ring, we can utilise the cylindrical bounding box capabilities that are available in BOXER. To reduce processing times, we will define the bounding box to cover only two of the 28 guide vanes and centre it on a singular guide vane that will be eroded. The number of cells is set to achieve a cell size of approximately 2, which is sufficient to model the degraded geometry surfaces – the mesh resolution can be increase for high fidelity CFD models.

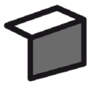
- Set Coordinate System to: Cylindrical
- Set Corner 1 to: (-35 -7 325)
- Set Corner 2 to: (35 18.7153 381)
- Set Number of Cells to 80



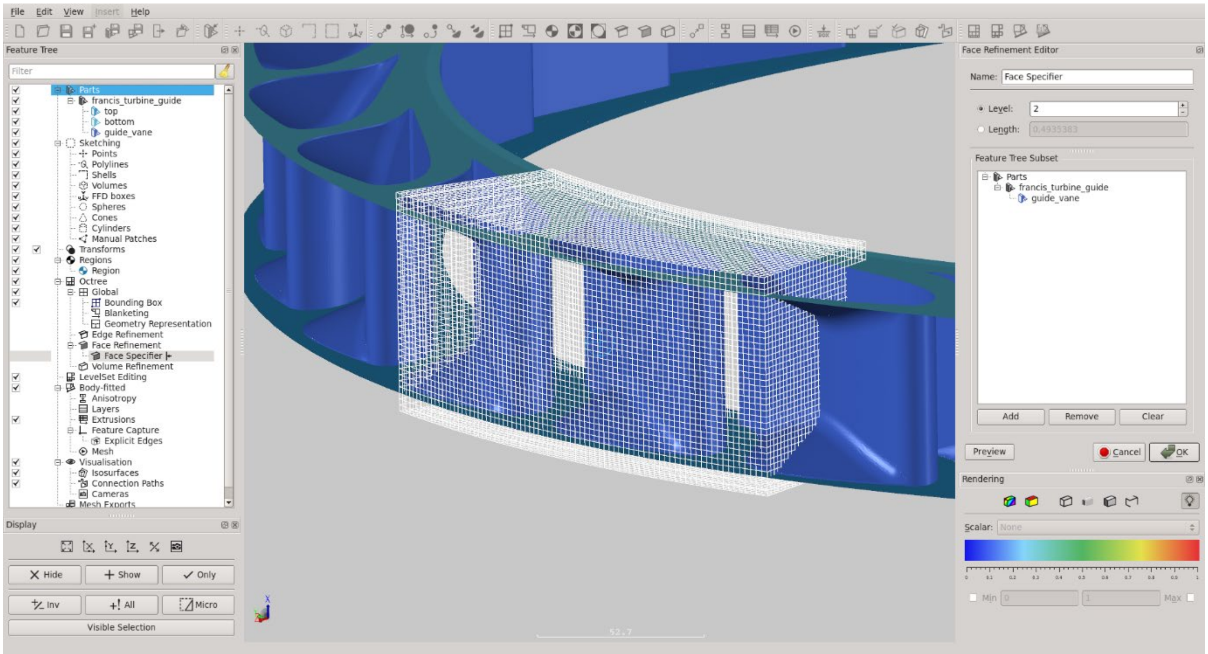
Defining the fluid region

- Create a Region and set its seed point coordinates to be (0 35 365)



Setting a face refinement on specific patches 

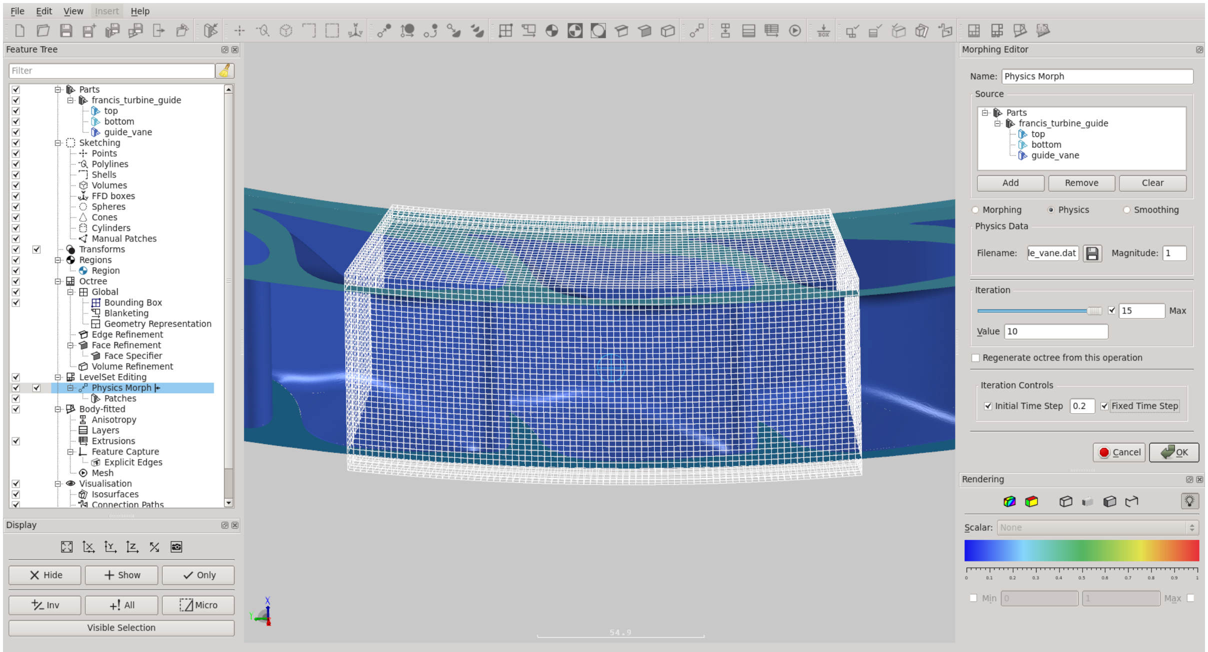
- Create a Face Refinement Specifier on patch "guide_vane" at octree level 2



Creating a physics-based level-set morph specification

This step demonstrates the main objective of this tutorial – to set up a physics-based level-set morph to model component degradation from sand erosion. The upper limit on the number of iterations is set to 15 to control the maximum amount of erosion on the guide vane geometry. We also use a fixed time step for the level-set operation, so that the distance the geometry morphs is consistent between each iteration. Initially, we look at the resultant geometry at Iteration 10, before increasing the amount of erosion in the next step.

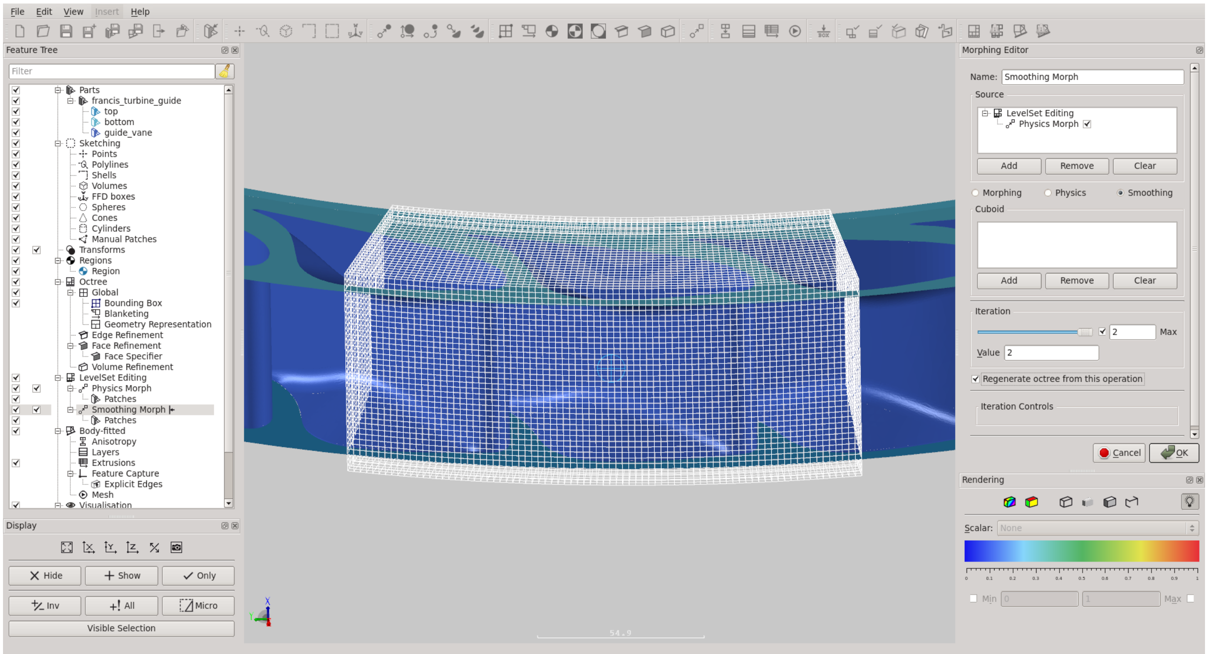
- `Insert > Level-set editing > Morphing` from the menu bar, OR
- Click the "Create new level set editing morphing specifier" toolbar button
- Set Name to `Physics Morph`
- Select the Physics radio button
- Drag-drop `francis_turbine_guide` from the Feature Tree to `Source` field in the Editor
- Open the External Data file browser to select a surface based scalar file
    - Select `erosion_guide_vane.dat` as the data file
- Under Iteration:
    - Tick the checkbox and set Max to 15
    - Set Value to 10
- Under Iteration Controls:
    - Tick the Initial Time Step checkbox, set the time step to 0.2, and tick the Fixed Time Step box



Creating a smoothing level-set morph specification 

The output surface from the physics-based level-set morphing operation can often be irregular due to the input and deformation of the surface. Therefore, the smoothing morph capabilities can be used to generate a more regular surface for the eroded surface. In this example, two smoothing iterations are sufficient to reduce the surface irregularities to an acceptable level.

- `Insert > Level-set editing > Morphing` from the menu bar, OR
- Click the “Create new level set editing morphing specifier” toolbar button
- Set Name to `Smoothing Morph`
- Select the Smoothing radio button
- Drag-drop `Physics Morph` from the Feature Tree to `Source` field in the Editor
- Under Iteration:
    - Tick the checkbox and set Max to 2
    - Set Value to 2
- Tick the “Regenerate octree from this operation” checkbox



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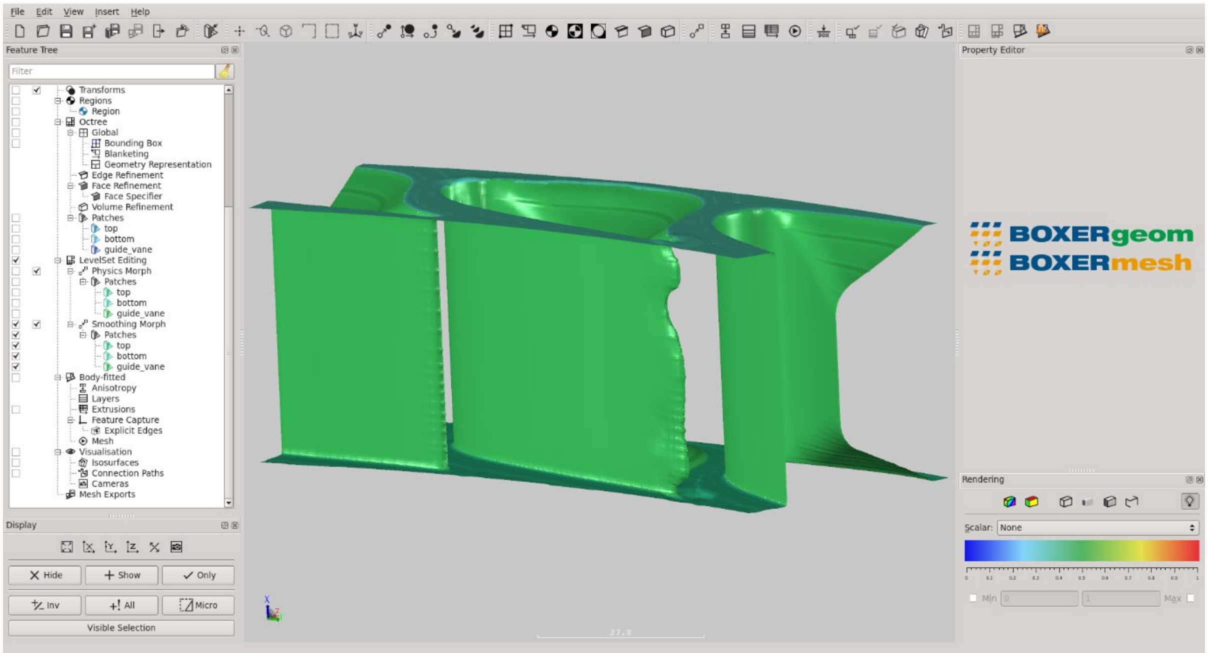
Generating the Physics Based Level-set morph

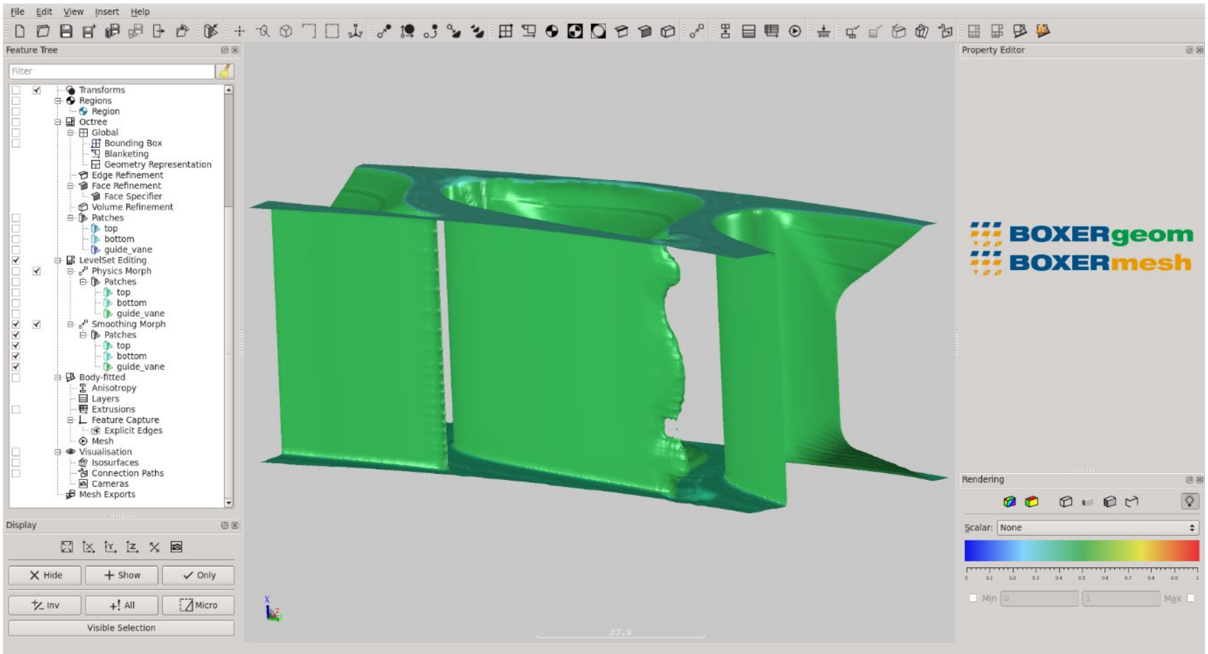
- Press the “Generate Level-set” button on the toolbar (*the button goes orange to indicate that BOXERgeom is busy*)
- When the Level-set calculation is complete, the Generate Level-set button goes grey, and its action is disabled to indicate that the Level-set is up to date
    - The operation takes approximately 25 minutes on 6 CPUs
- The Level-set surface appears in the scene at slider position 10 for the physics morph and 2 iterations of geometry smoothing
- In the Feature Tree, under Smoothing Morph, select the `top`, `bottom`, and `guide_vane` patches, then right-click and select Only
- Select the `top`, `bottom`, and `guide_vane` patches again, then right-click and select Show Faces



Regenerating the Level-set morph at a new slider position

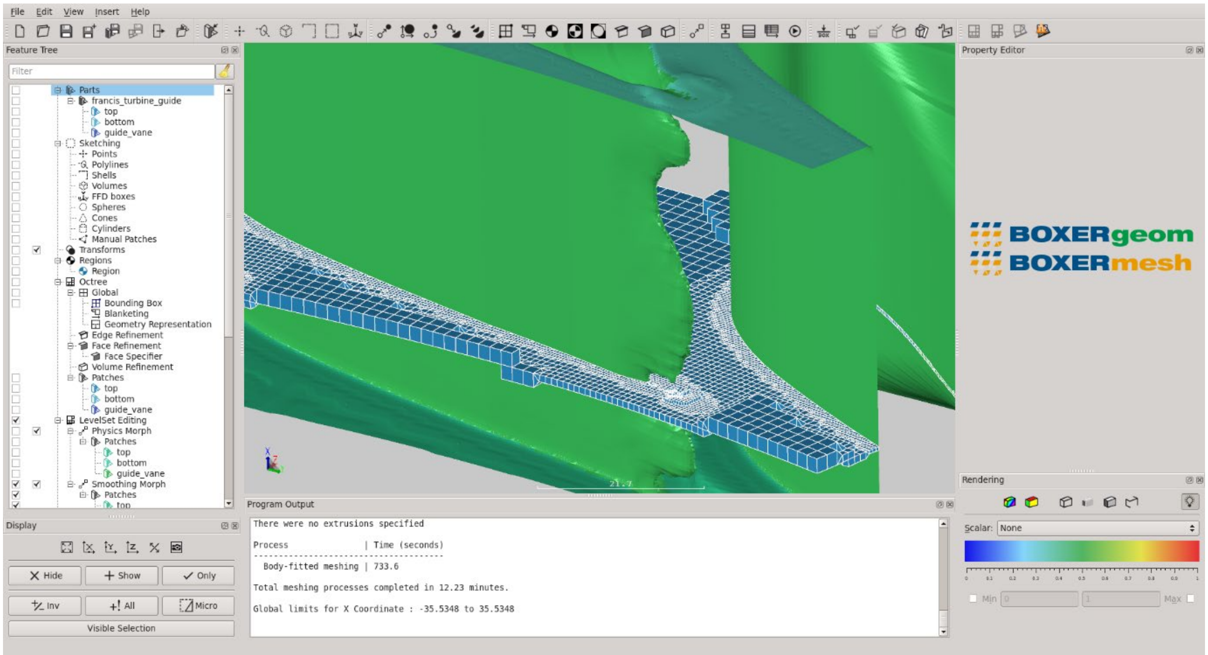
Here we demonstrate the effect that changing the specification of an upstream level-set operation has on downstream operations. In this tutorial, the smoothing morph is dependent on the physic-based morph, so changes to the physics-based morph cause the smoothing morph to out of date. For example, the smooth morph currently represents the smoothed surface of the eroded geometry at Iteration 10. Moving the slider value for the physics-based morph to show a different state of erosion means the smoothing morph must be recalculated, as its input has changed. The time to complete this operation will be less than the previous step, as the physics-based morph does not need to be recalculated because its input (the original geometry) has not changed.

- In the Feature Tree, right-click Physics Morph and select Edit Properties
- Click-and-drag the Iteration slider to its maximum position (Value: 15)
    - The LevelSet Editing branch in the Feature Tree shows a warning triangle to indicate that the operation is now out of date
    - This slider position corresponds to approximately a year's worth of erosion based on the operating conditions in the CFD model
- Click the "Generate Level-set" button on the toolbar
    - As only the smoothing morph needs to be updated, the operation takes less time than before (approximately 4 minutes on 6 CPUs)



Generating a mesh 

- Press the ‘Generate Inviscid Mesh’ button
    - This operation takes approximately 15 minutes on 6 CPUs
    - BOXERmesh generates a volumetric body-fitted mesh around the Level-set shape at slider value 15 in the normal way.
    - This mesh can have layers added/be extruded/be exported for analysis in the normal way



Exporting the mesh

Finally, we export the mesh to be run in a CFD solver. In this example, we export to BOX-format file, but the process is similar for other file formats. This demonstrates how an iterative process of: geometry → flow → degradation → mesh → flow → repeat. For example a mesh at three months' degradation can be exported and solved to determine how the eroded geometry affects erosion rates, and so on.

- Go to `Insert > Mesh Export` and select `BOX` to open the BOX Mesh Export Editor dialog. Alternatively, click the `Create new BOX mesh export specification icon` on the toolbar.
- Leave the name as default `BOX Mesh Export`.
- Click on the disc icon to open a file browser. Navigate to the working directory, enter the filename `guide_vane` and check the `Automatically Save with File-Extension (*.box)` tick box. Click `Save`.
- Ensure the `Enabled` tick box is checked.
- Drag the region that contains the mesh (`Region`) from the Feature Tree and drop it in the `Exported Regions Subset` in the BOX Mesh Export Editor.
- Click `OK` to exit.
- Click on the `Save all body-fitted mesh exports` button in the toolbar, or
- `File > Save all mesh exports` from the menu bar.