Extraction of Acoustic Cavity Modes

Actran Student Edition Tutorial

Workshop description

Introduction

- This workshop introduces the modal extraction analysis for acoustic cavity and proposes an application case on a simple cavity

- The objectives of this workshop are the following :
  - Get introduced to acoustic cavities and resonance
  - Get introduced to the modal extraction analysis

- Software version
  - Actran 2021.1 Student Edition

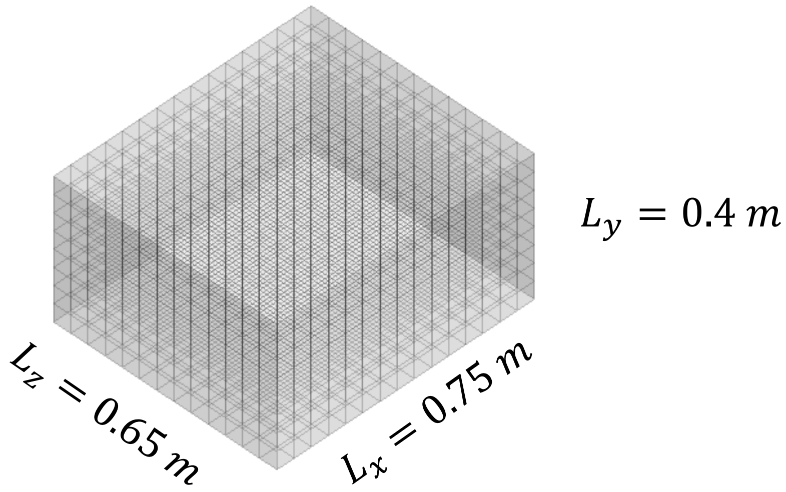
Workshop description

Finite fluid component

- The cavity is assumed rigid at its boundary, only the acoustic part is modeled
  - A **finite fluid** component is defined
- Modal extraction is only suitable for real system (no imaginary part) so the model cannot include damping mechanisms

Analytical solution

- Let us consider a plate with the following properties:
  - Size: $L_x = 0.75\,m$, $L_y = 0.4\,m$, $L_z = 0.65\,m$
  - Fluid properties:
    - Speed of sound $c = 340\,m/s$
    - Density $\rho = 1.225\,kg/m^3$



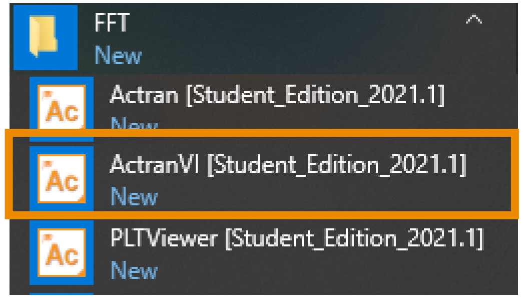
- For rectangular cavities, analytical eigen-frequencies can be calculated using the equation below

$$f_{ijm} = \frac{c}{2}\sqrt{\left(\frac{i}{L_x}\right)^2 + \left(\frac{j}{L_y}\right)^2 + \left(\frac{m}{L_z}\right)^2}$$

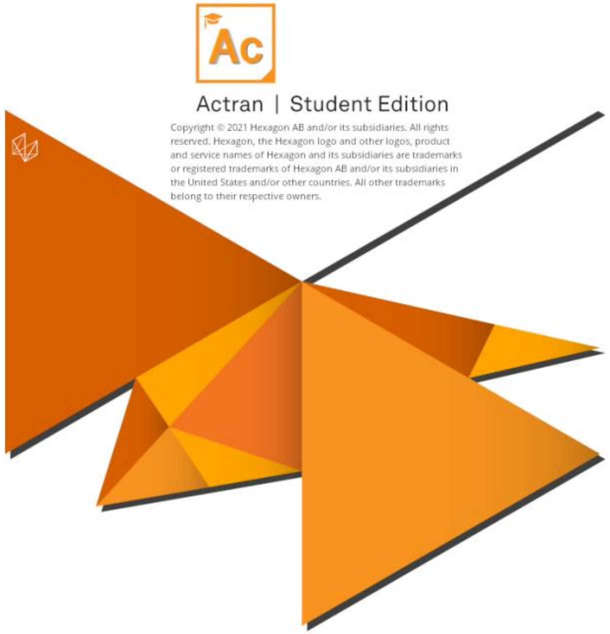
Workshop pre-processing

Start ActranVI

- Start ActranVI:
  - Shortcut is available through the Windows Start Menu



(Windows Start Menu)



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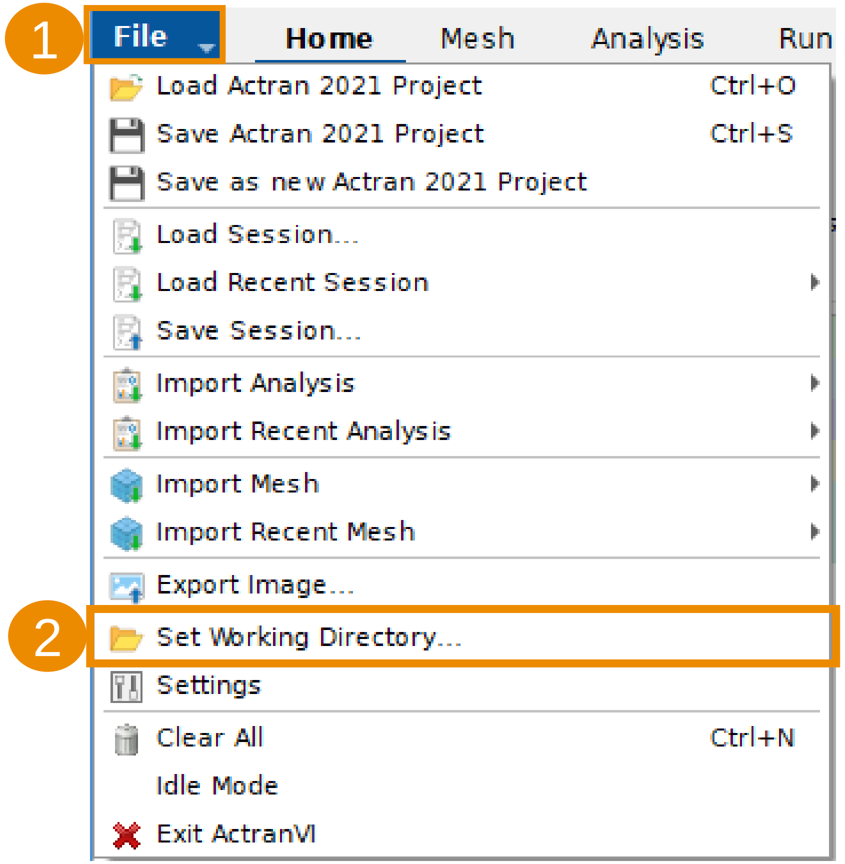
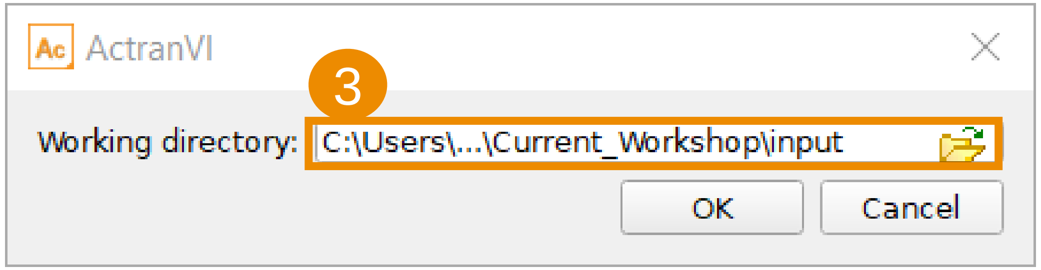
Set the working directory

Select the workshop input directory as the working directory

- The working directory is the project directory where all ActranVI related files are output

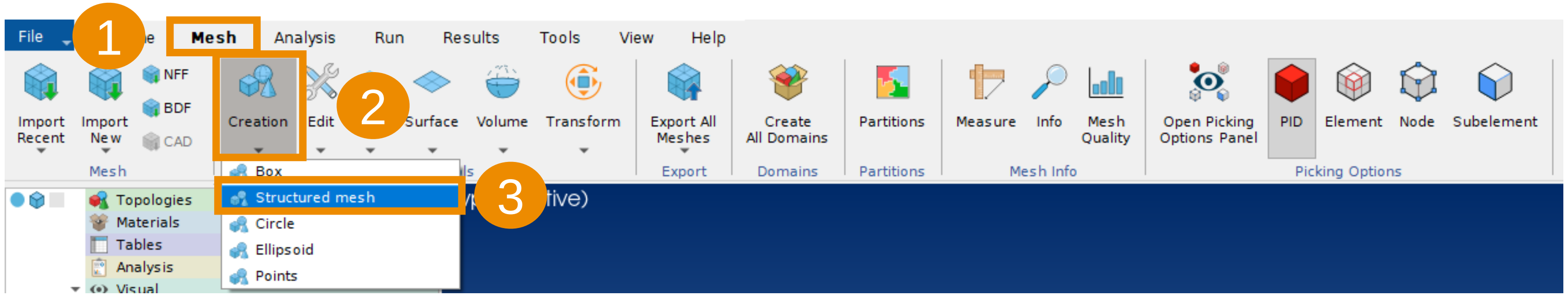




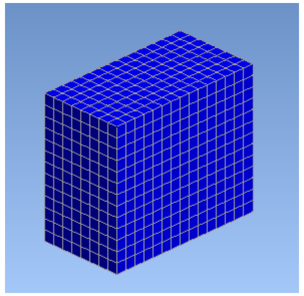
The working directory path should not contain any space or special character

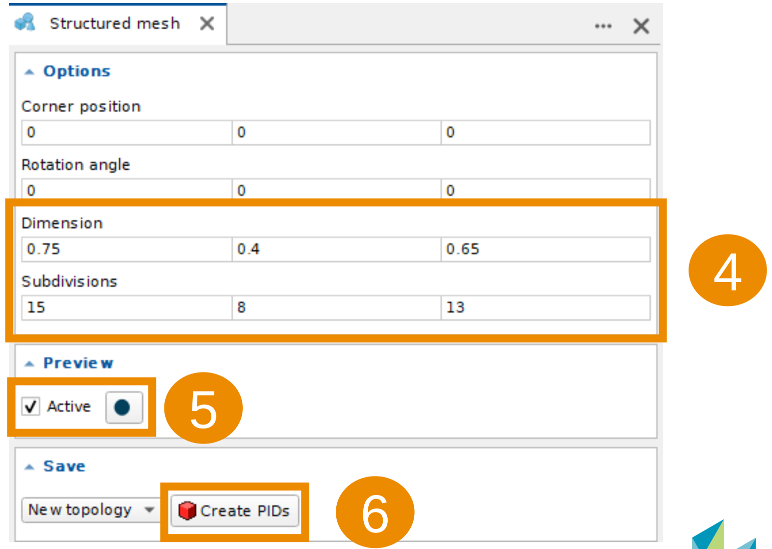
Create the mesh

- Create a structured mesh

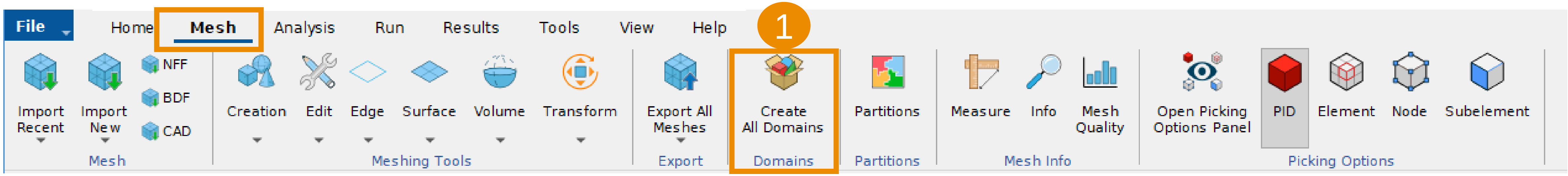


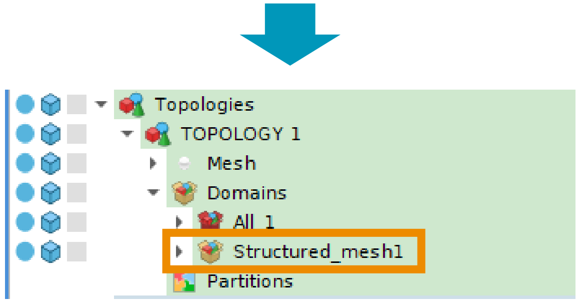
- Enter the following values for dimensions and discretization and create the PID
  - Dimensions: $L_x = 0.75\ m$, $L_y = 0.4\ m$, $L_z = 0.65\ m$
  - Subdivisons: $N_x = 15$, $N_y = 8$, $N_z = 13$ (element size: 0.05 m)
  - The mesh can be visualized before creation





Create the domains





Auto create domain

- Automatic domain creation based on PIDs
- One domain per PID

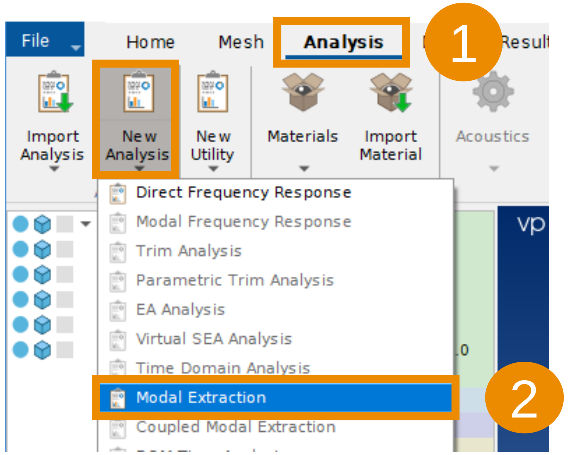
A ***Domain*** is a group of **one** or **several** PIDs

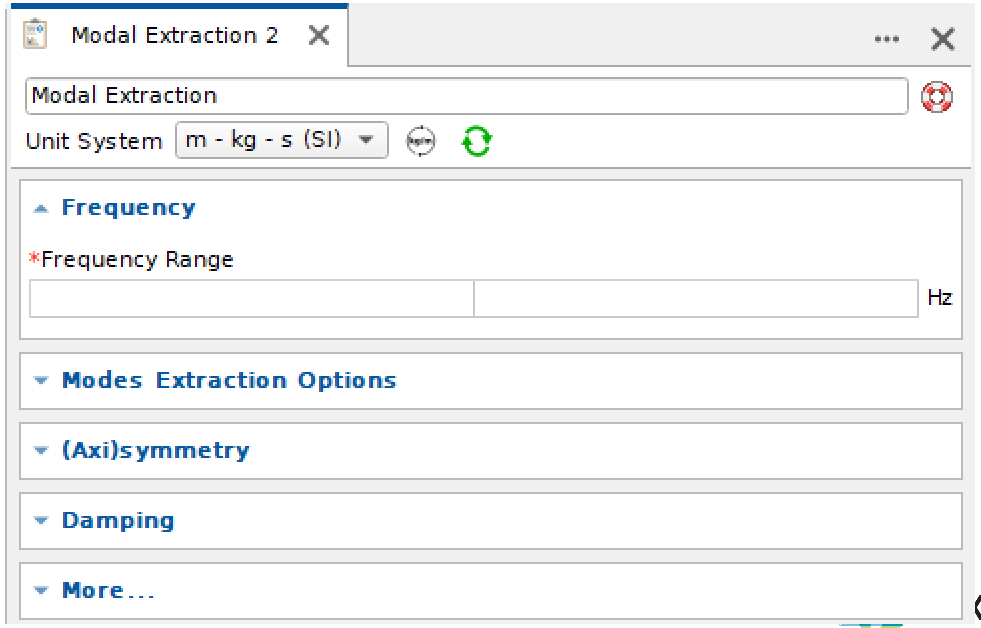
- *Domains* link PIDs to the analysis objects
- *Domains* decouple the topology from the analysis

Create the Modal Extraction Analysis

Add a *Modal Extraction* analysis

- A *Modal Extraction* is a computation procedure which provides computes the specific modes of a structure or an acoustic volume





Specify the frequency range of interest (1)

The wavelengths must be captured in the cavity

- Largest element length drives the max. frequency (smallest wavelength)
- 6 linear elements per wavelength are used
- Element length is 5 cm
- Maximum frequency supported by the mesh: 1133 Hz

$$\left.\begin{aligned} f_{max} &= \frac{c}{\lambda_{min}} \\ \lambda_{min} &= 6 * L_{max} \end{aligned}\right\} \quad f_{max} = 1133\ Hz$$

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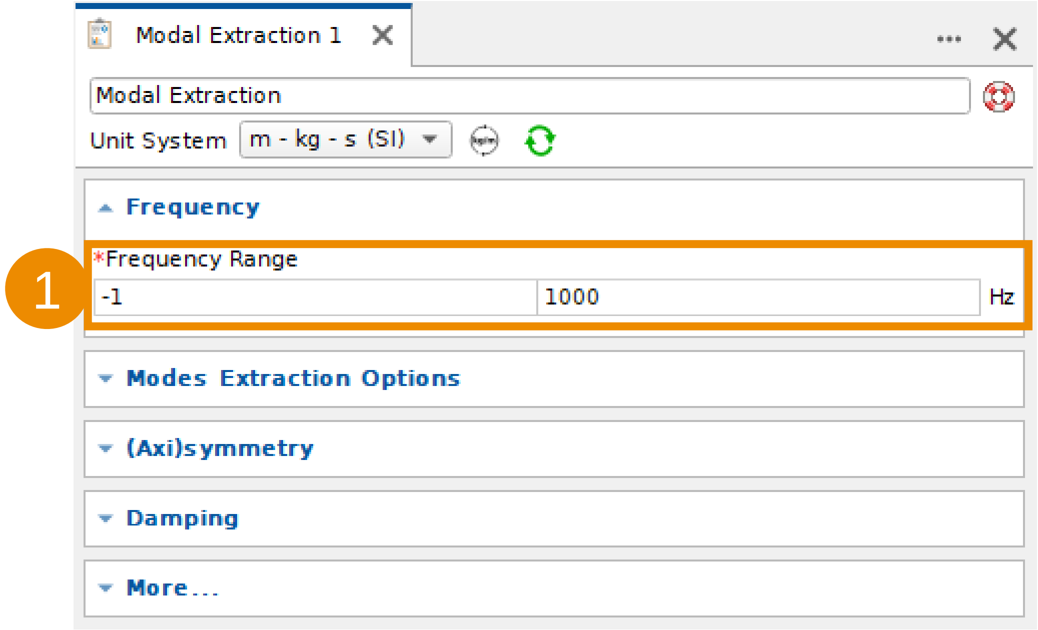
Specify the frequency range of interest (2)

Set the frequency rage in *analysis* properties

- Frequency range: -1 Hz to 1000 Hz
  (-1 Hz is set to make sure the breathing mode close to 0 Hz is captured)



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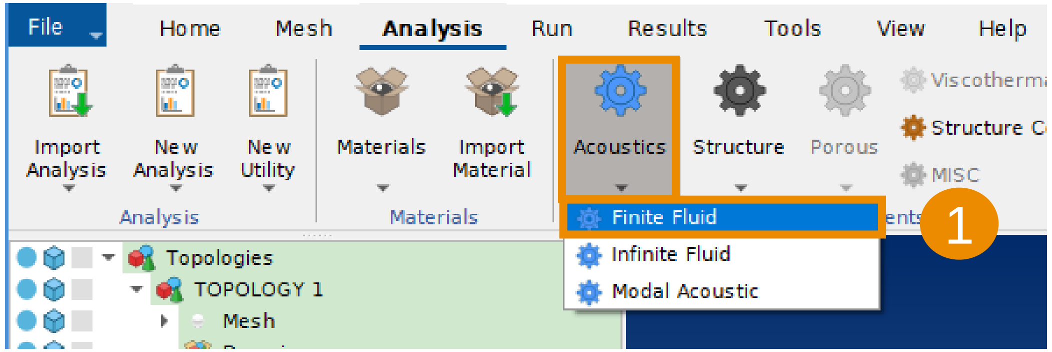
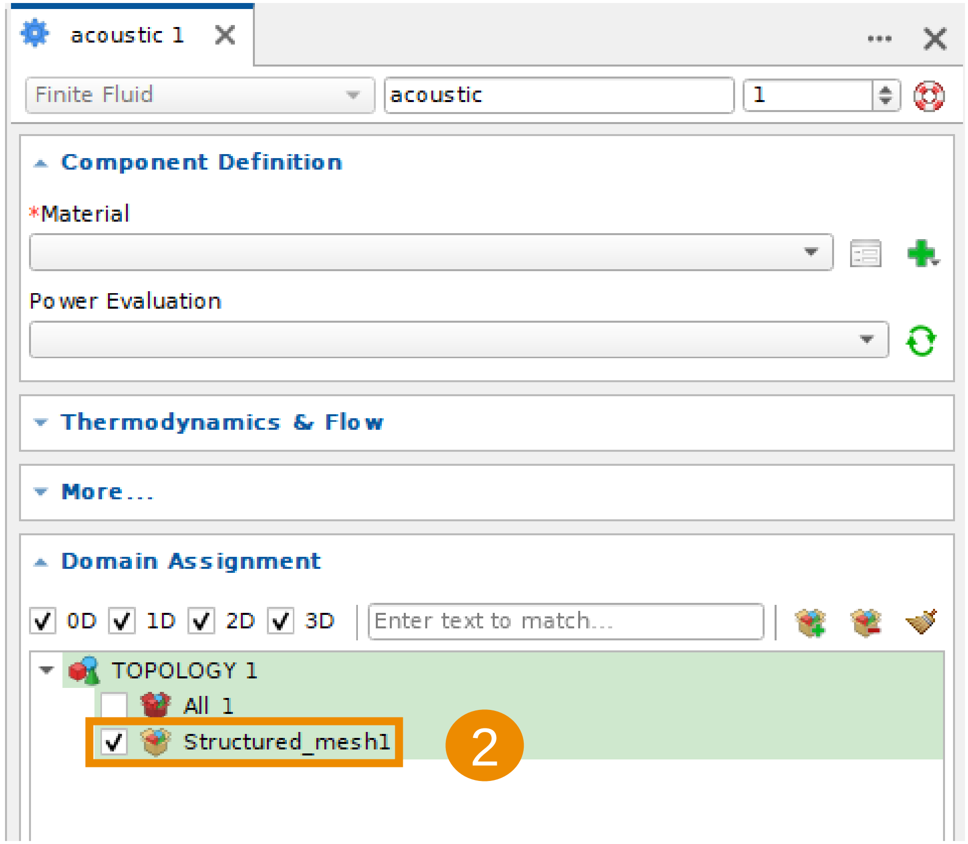
Create a Finite Fluid component (1)





Add a Finite Fluid component (Add a *Finite Fluid component*)

Set up the *Finite Fluid component* domain

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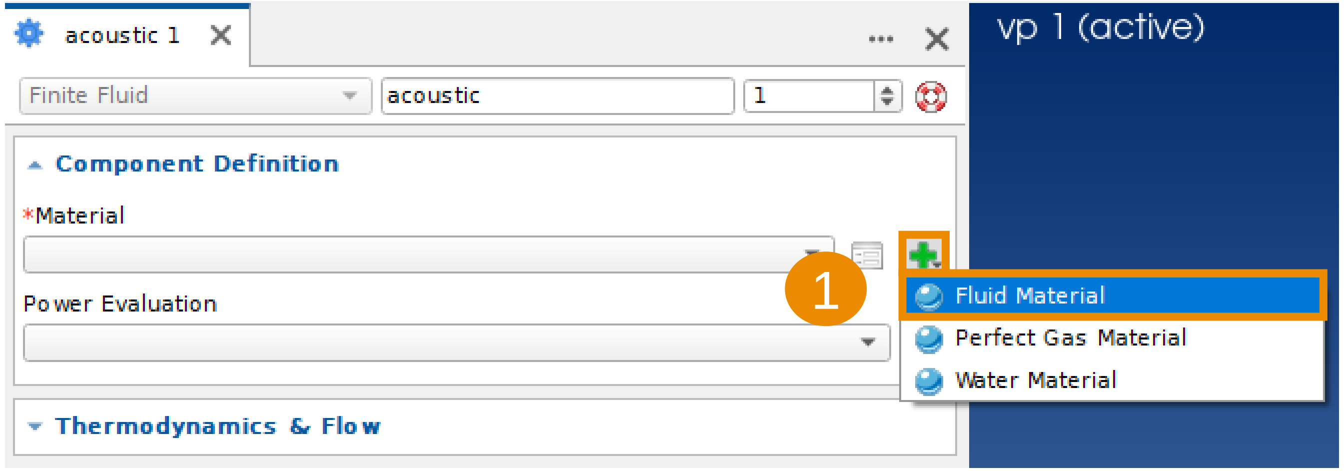
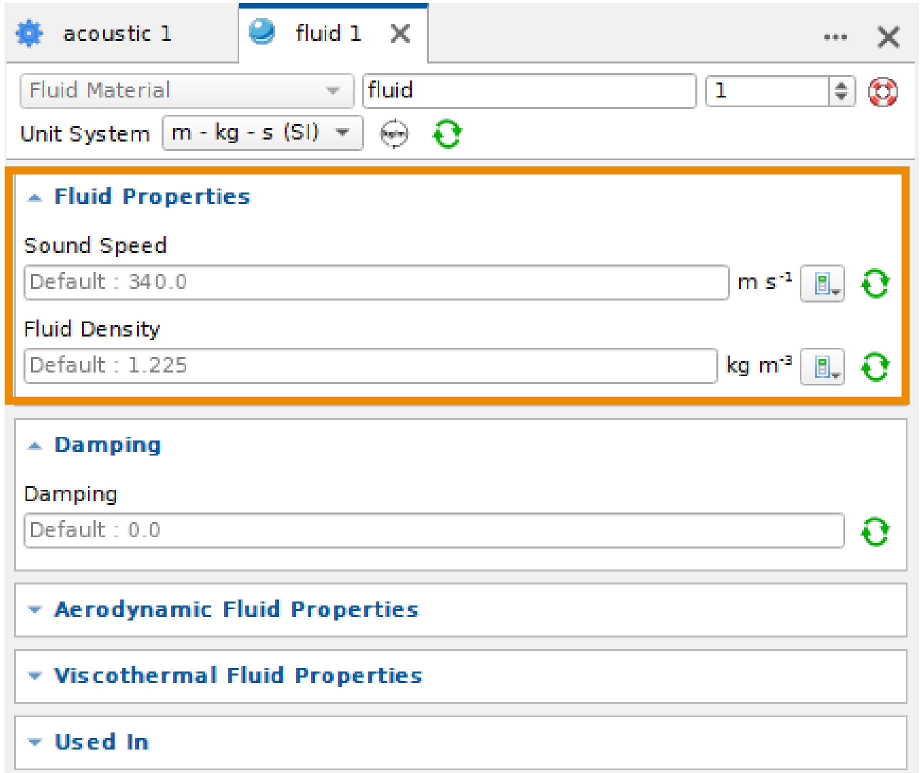
Create a Finite Fluid component (2)

Define a material for air

- Add a Fluid Material
- Let the values by default :
  - $c = 340\ m/s$
  - $\rho = 1.225\ kg/m^3$





Close both property windows (material & component)

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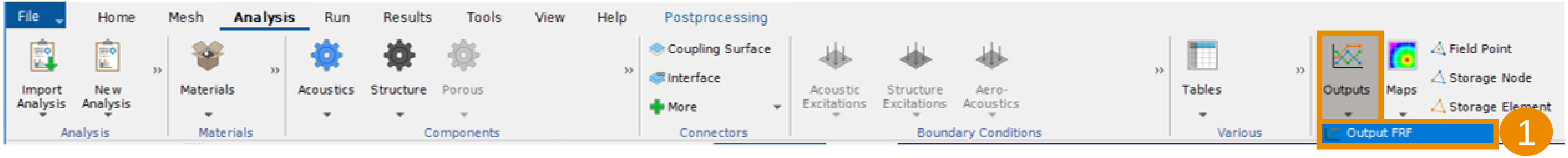
Post-processing parameters – FRF



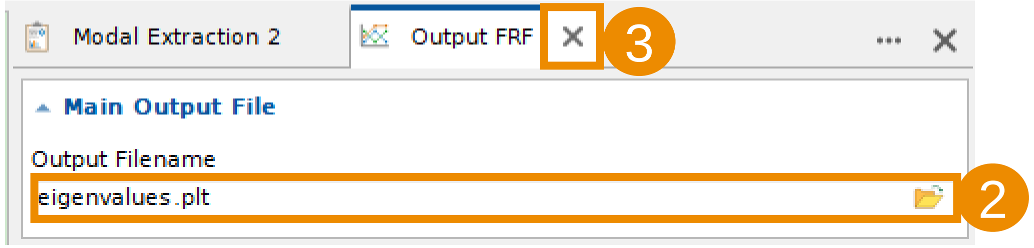
Create an output FRF post-processing parameter

Specify the name of the output file

Close the property window

NOTE

This FRF file will contain the list of the eigenfrequencies



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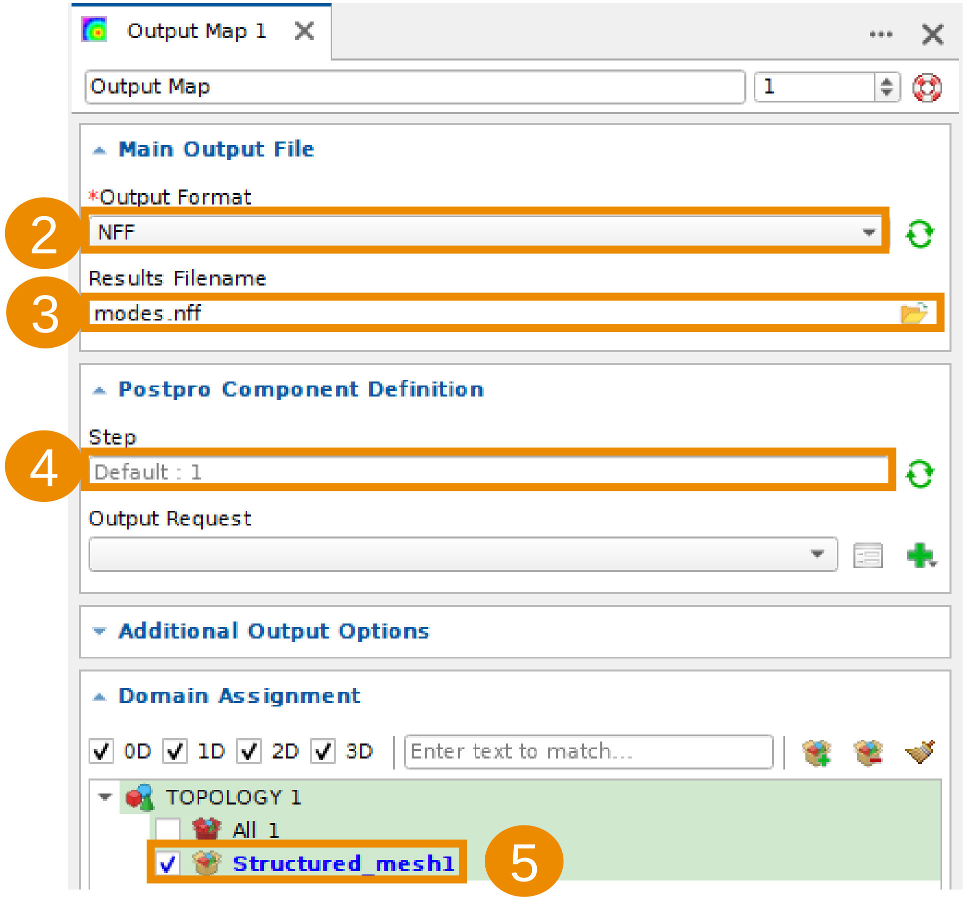
Post-processing parameters – Maps

Add an *Output Map post-processing parameter*

Specify a map in *.nff format to be saved in the whole mesh, at each frequency step



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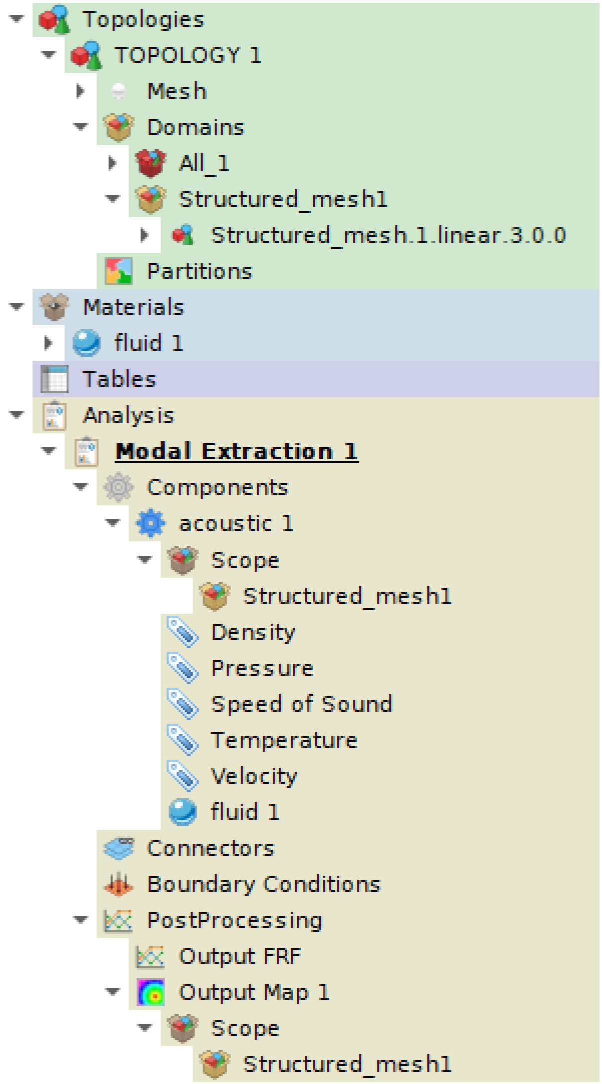
Check the analysis

The *Analysis* setup is now complete

All the parts of the *Analysis* are available and editable on the data tree panel

Check if the data tree is identical to the one shown



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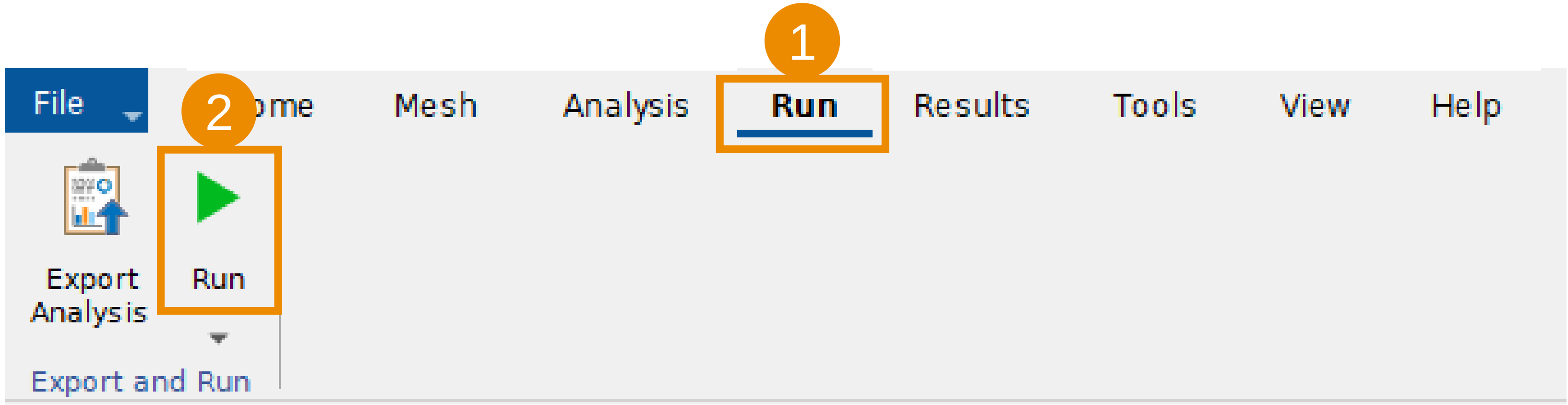
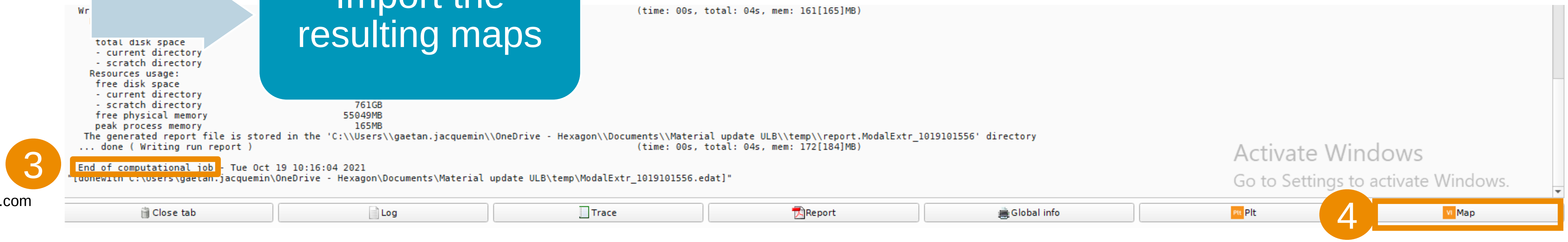
Launch the Actran analysis in ActranVI

Launch the computation

Check the log showing the computation progress

Import the resulting maps





Post-processing

Check the Eigen Frequencies

Open the eigenvalues.plt in a text editor

- The eigen frequencies a reported in the first column

```
BEGIN LOADCASE_INDEX
 1 0
END LOADCASE_INDEX
BEGIN UNIT_SYSTEM
      SI
END UNIT_SYSTEM
BEGIN OUTPUT_FRF
BEGIN TITLE
Actran Analysis
END TITLE
BEGIN DOMAIN Acoustic1 "acoustic"
 /*    NFreq   NLdCase   NRes                    Code of mass                    Code of mmass
        36       1       6                        100                             1401                            109
/*  Freq                  LoadCase                  Mass                         Modal_Mass                       MS
 1.7424708379351e-05        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 2.2708117039071e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 2.6217532814845e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 3.4684544199684e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 4.2773585380152e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 4.5665443352021e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 4.8427659305211e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 5.0169100382943e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 5.2656355204708e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 5.2818195948024e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 5.5069022259794e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 5.7492785660135e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 6.2569260201375e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 6.7840042377671e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 6.7965737173453e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 6.9123361214043e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 6.9821877234895e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 7.1658914391592e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 7.3928330785885e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 8.0189160001439e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
 8.1287260200767e+02        1       { 2.3887500000000e-01,  0.0000000000000e+00} { 1.0000000000000e+00,
```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Calculated vs analytical eigenfrequencies

- The first eigen-frequency is very close to 0 Hz: it is the cavity breathing mode

- Eigen-frequencies found by Actran calculation are close to Analytical values

Mode (i x j x m)	Analytical	Actran	Error
1 x 0 x 0	226.67	227.1	0.183%
0 x 0 x 1	261.54	262.2	0.244%
1 x 0 x 1	346.09	346.8	0.218%
0 x 1 x 0	425.00	427.7	0.644%
2 x 0 x 0	453.33	456.7	0.733%
1 x 1 x 0	481.67	484.3	0.542%
0 x 1 x 1	499.03	501.7	0.534%
0 x 0 x 2	523.08	526.6	0.667%
2 x 0 x 1	523.37	528.2	0.920%
1 x 1 x 1	548.09	550.7	0.474%

Relative error:

$$\epsilon = \frac{|f_{analytic} - f_{actran}|}{f_{analytic}} * 100$$

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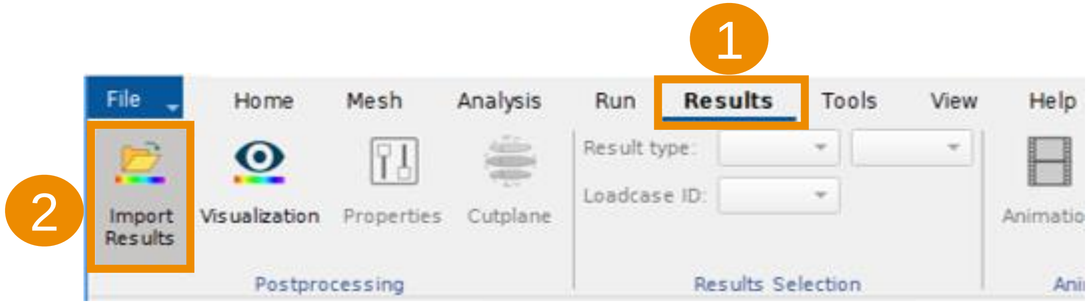
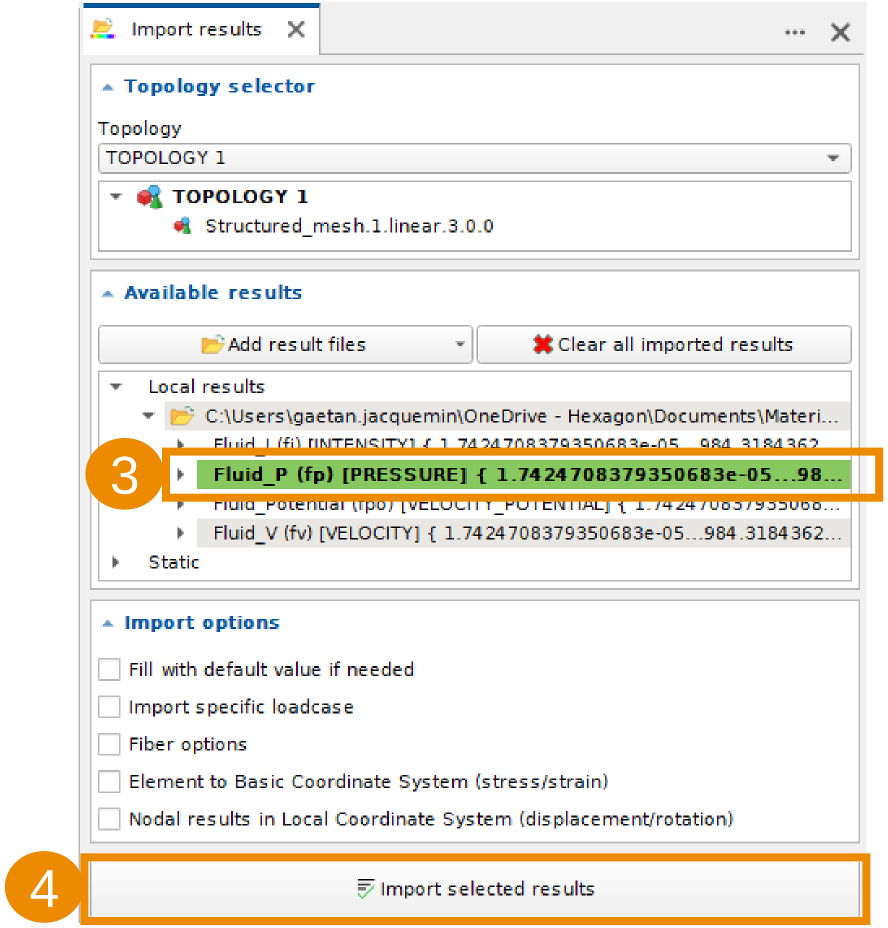
Visualize maps (1)

Go back to ActranVI

Import the pressure results





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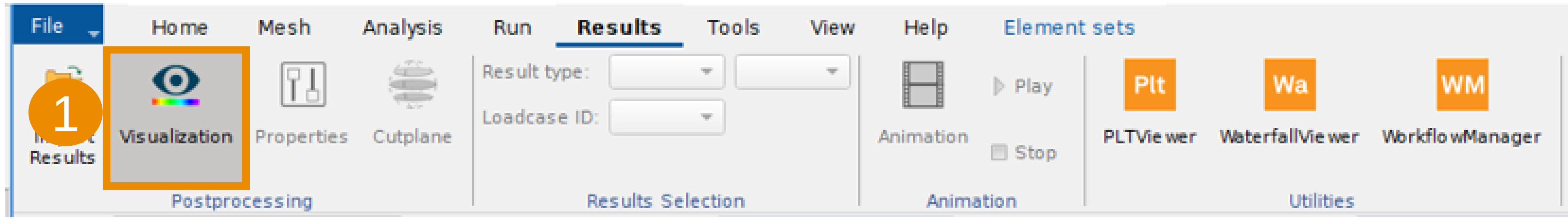
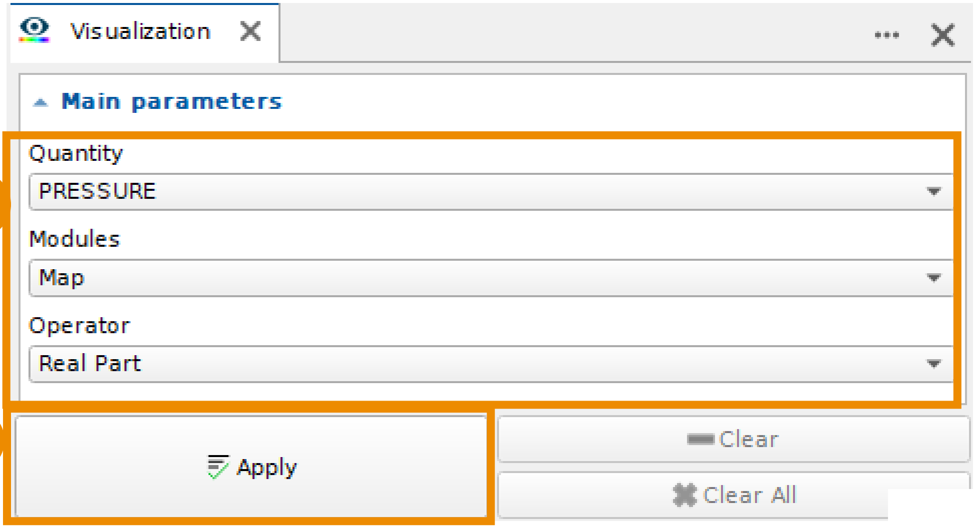
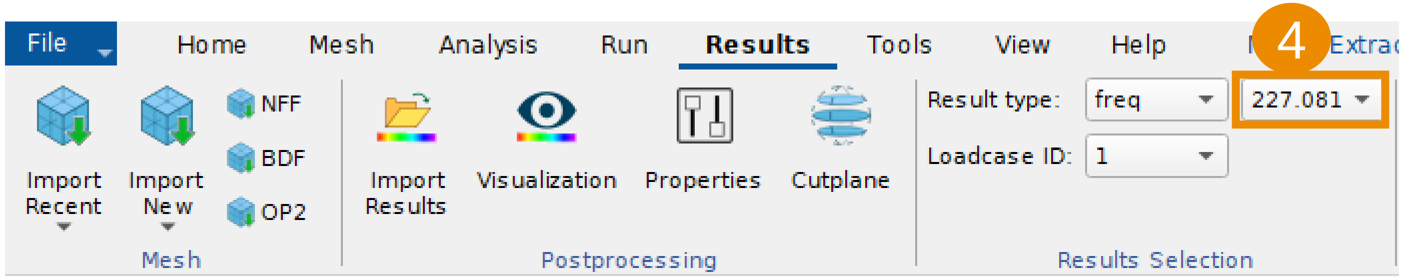
Visualize maps (2)

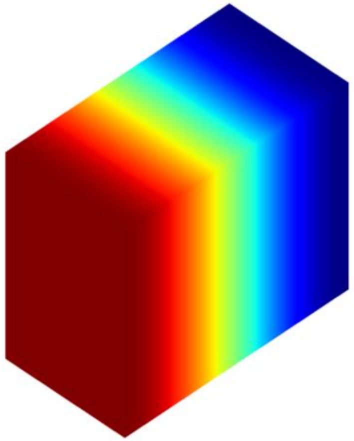


Visualize the map of the real part of the pressure results



Select the frequency in the ribbon to view the mode shapes





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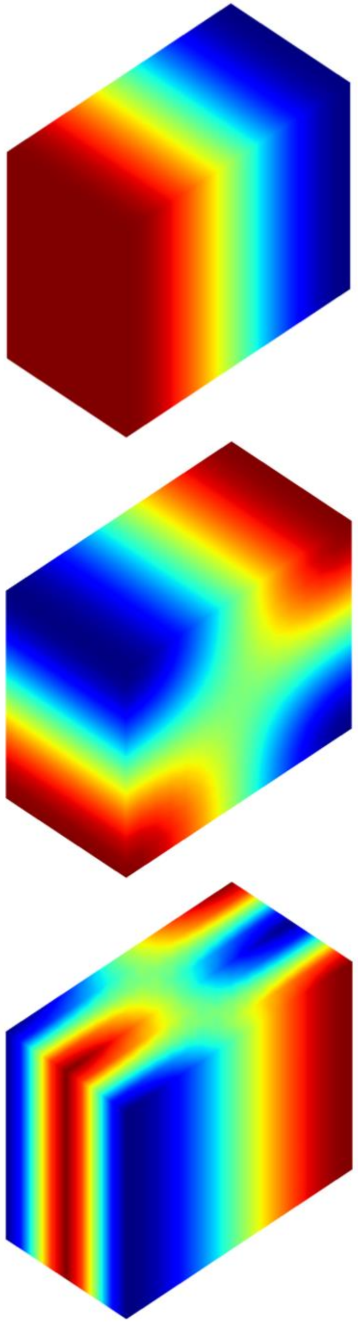
Visualize maps (3)

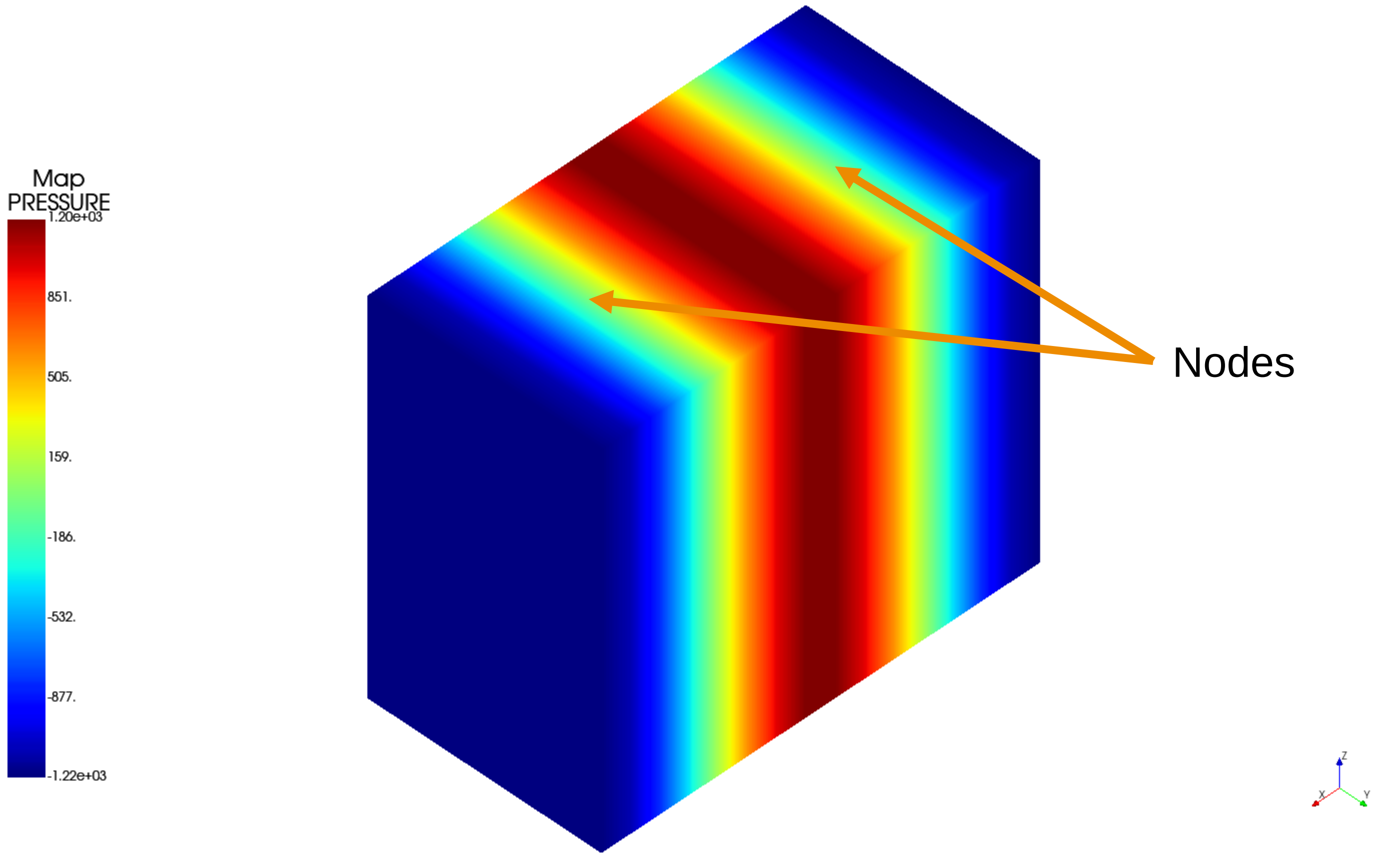
```
/*  Freq              Loa
 1.7424708379351e-05
 2.2708117039071e+02
 2.6217532814845e+02
 3.4684544199684e+02
 4.2773585380152e+02
 4.5665443352021e+02
 4.8427659305211e+02
 5.0169100382943e+02
 5.2656355204708e+02
 5.2818195948024e+02
 5.5069022259794e+02
 5.7492785660135e+02
 6.2569260201375e+02
 6.7840042377671e+02
 6.7965737173453e+02
 6.9123361214043e+02
 6.9821877234895e+02
 7.1658914391592e+02
 7.3928330785885e+02
 8.0189160001439e+02
 8.1287260200767e+02
 8.1882074632679e+02
 8.3342425925335e+02
 8.5410641604825e+02
 8.6993108284515e+02
 8.7198022214917e+02
 9.0106346378521e+02
```



Increasing complexity of acoustic pressure field with increasing frequency

Nodes of the cavity modes

- The nodes of cavity mode are the locations where pressure is equal to zero



Example: Mode at 456Hz

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Conclusions

Conclusion

- The acoustic modes of a cavity were extracted

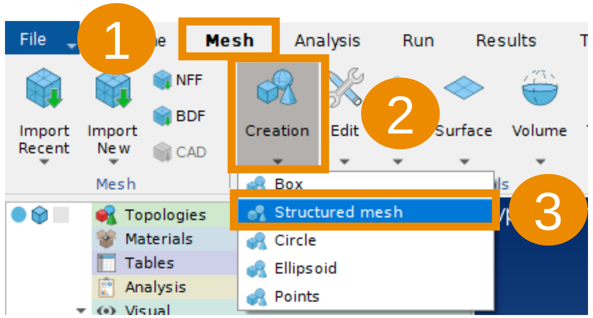
- The model involved
  - A Modal Frequency Response analysis (FRF)
  - Finite Fluid component for the cavity
  - FRF and Map outputs to export the eigenfrequencies and eigenmode shape

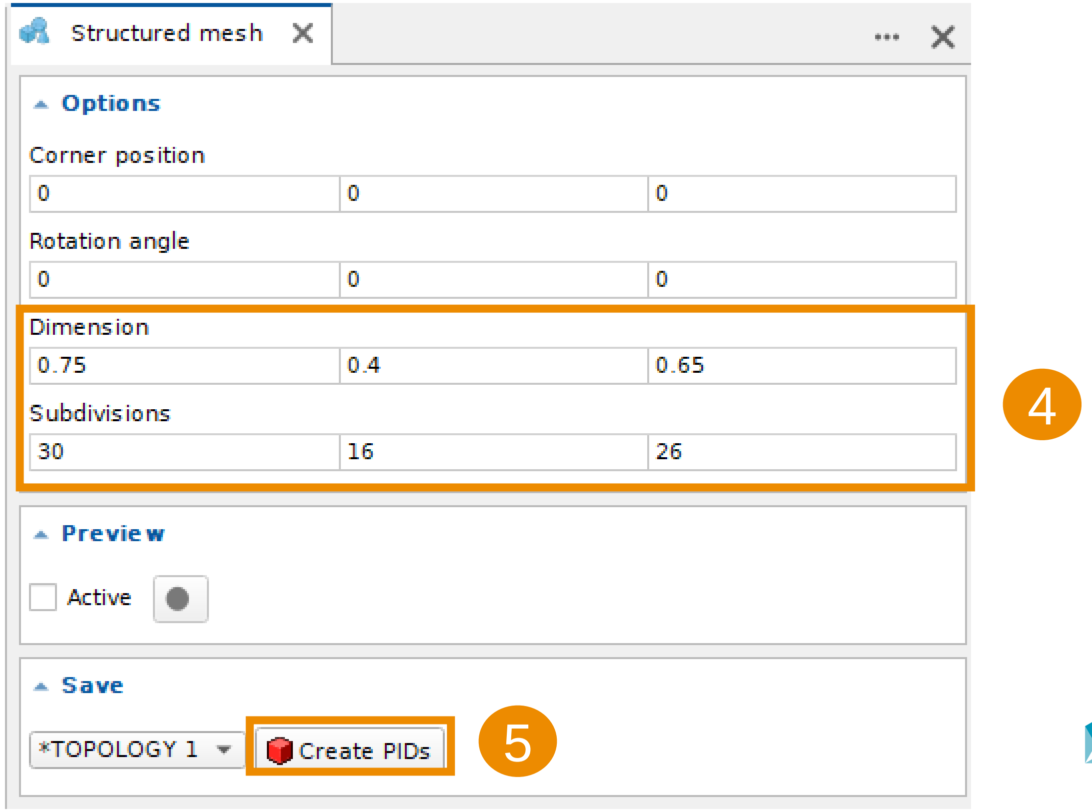
- The results highlighted:
  - A breathing mode
  - Higher mode complexity as the frequency increases
  - Presence of nodes where the pressure is zero

Going further… (optional)

Refining the mesh to increase model accuracy

- Refining the cavity mesh can increase the accuracy of numerical prediction of the eigen-frequencies. To refine the mesh, two methods can be used
- Method 1: decrease the mesh step, for example, from 0.05m to 0.025m





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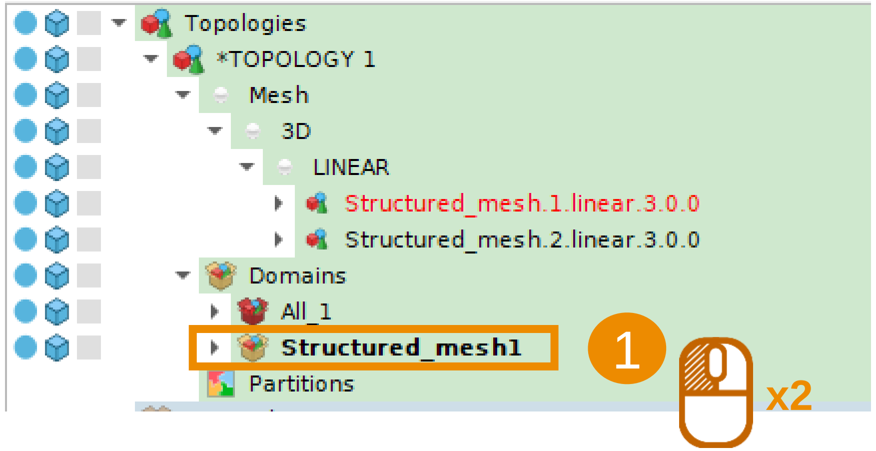
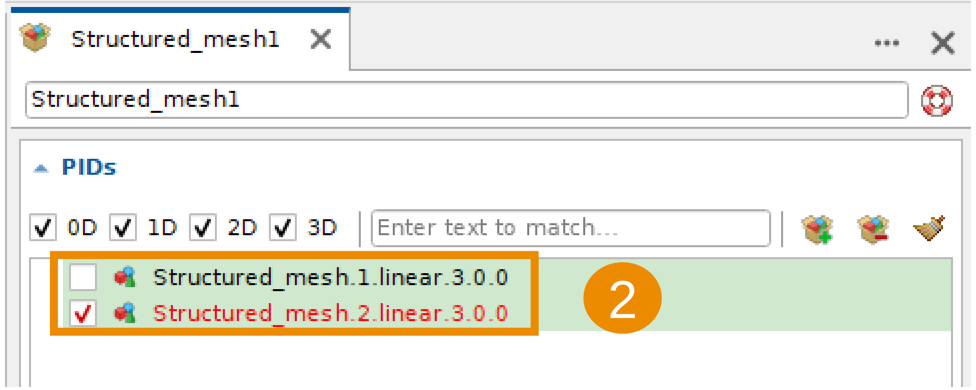
Refining the mesh to increase model accuracy

- Re-assign the domain





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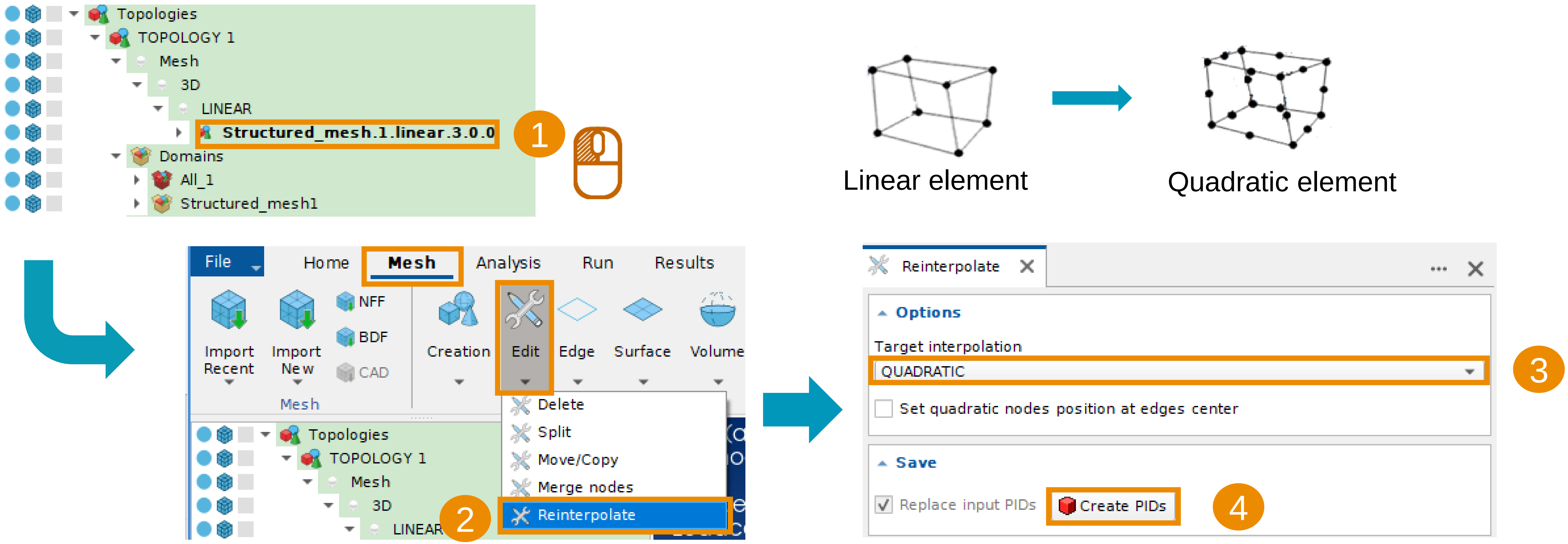
Refining the mesh to increase model accuracy

- Method 2: Change the mesh from linear interpolation from quadratic interpolation



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Improved Numerical Accuracy with Quadratic Elements Mesh

- Change the mesh from linear to quadratic interpolation increases the numerical accuracy as shown in the table below

Mode orders				Linear elements model		Quadratic elements model	
i	j	m	Analytical Solution (Hz)	Numerical Solution (Hz)	Error *	Numerical Solution (Hz)	Error *
1	0	0	226.67	227.08	0.18%	226.67	0.00%
0	0	1	261.54	262.18	0.24%	261.54	0.00%
1	0	1	346.09	346.85	0.22%	346.09	0.00%
0	1	0	425	427.74	0.64%	425.01	0.00%
2	0	0	453.33	456.65	0.73%	453.34	0.00%
1	1	0	481.67	484.28	0.54%	481.67	0.00%
0	1	1	499.03	501.69	0.53%	499.03	0.00%
0	0	2	523.08	526.56	0.67%	523.10	0.00%
2	0	1	523.37	528.18	0.92%	523.38	0.00%
1	1	1	548.09	550.69	0.47%	548.10	0.00%
1	0	2	570.08	574.93	0.85%	570.09	0.00%
2	1	0	621.4	625.69	0.69%	621.41	0.00%

$$^{*}\epsilon = \frac{|f_{analytic} - f_{actran}|}{f_{analytic}} * 100$$

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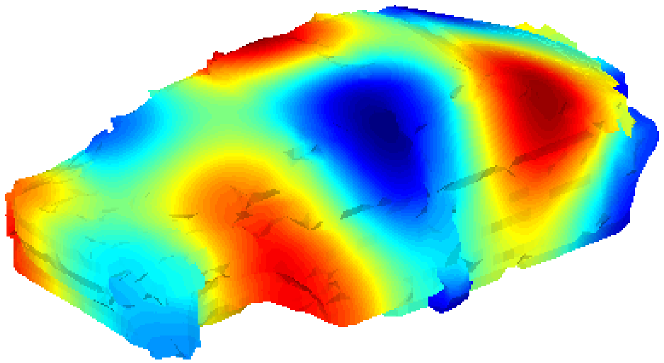
Going Further

- Visualize how cavity modes are modified if the cavity dimensions are changed

- Compute modes of cavities of complex shapes (external mesh is needed)
  - Example ➔ computing the modes of a car compartment is a frequently performed task in automotive NVH (Noise, Vibration, Harshness) analysis



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