Extraction of acoustic cavity modes

Actran Student Edition Tutorial

Workshop description

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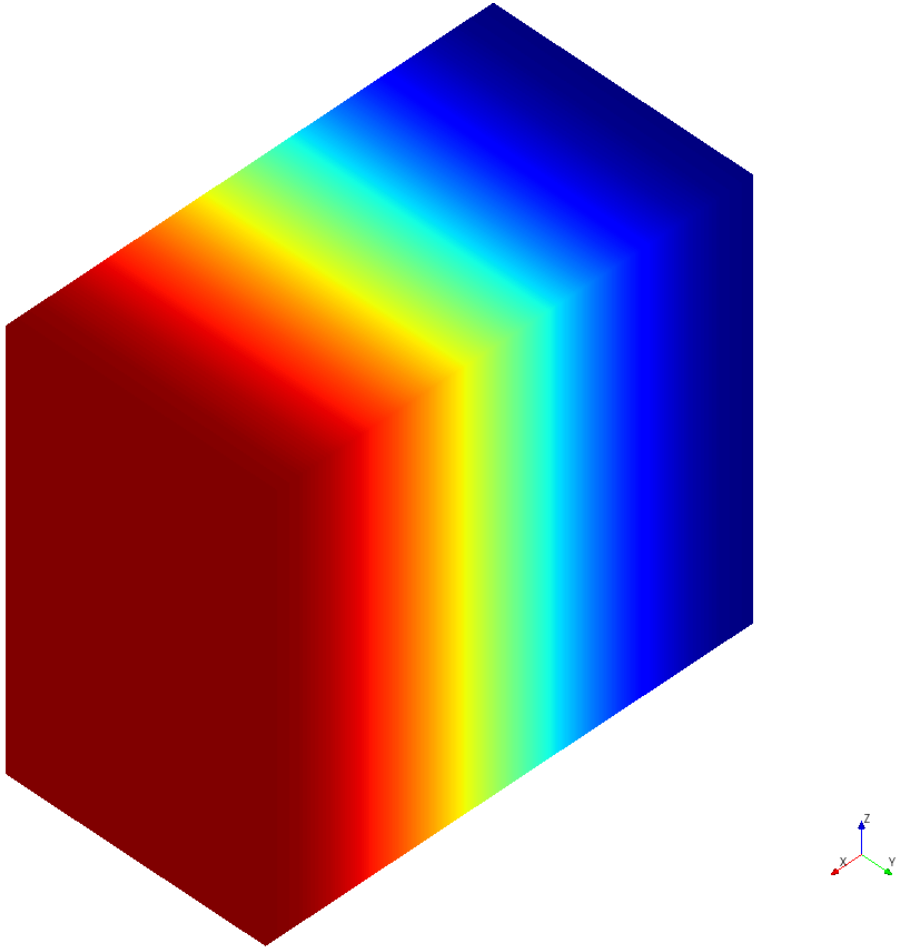
Introduction

- 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 2022 Student Edition



Workshop strategy

Modal Extraction computes the modes and eigenfrequencies of a system

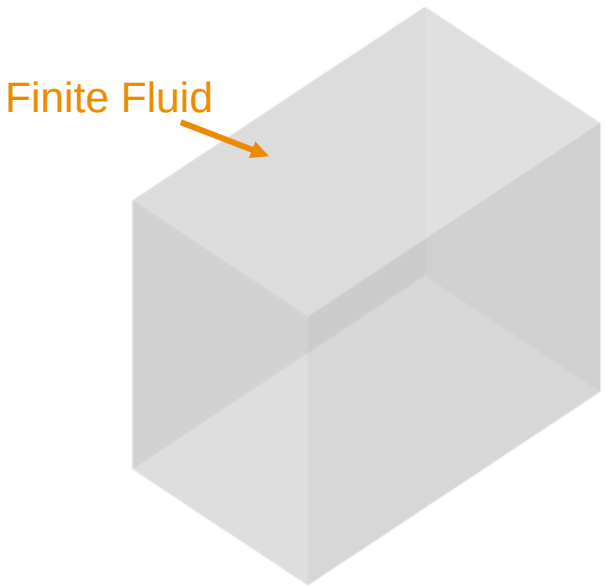
- Acoustic modes provide the specific acoustic pattern inside a cavity
- Each mode is linked to an eigenfrequency, which can be associated to a cavity resonance

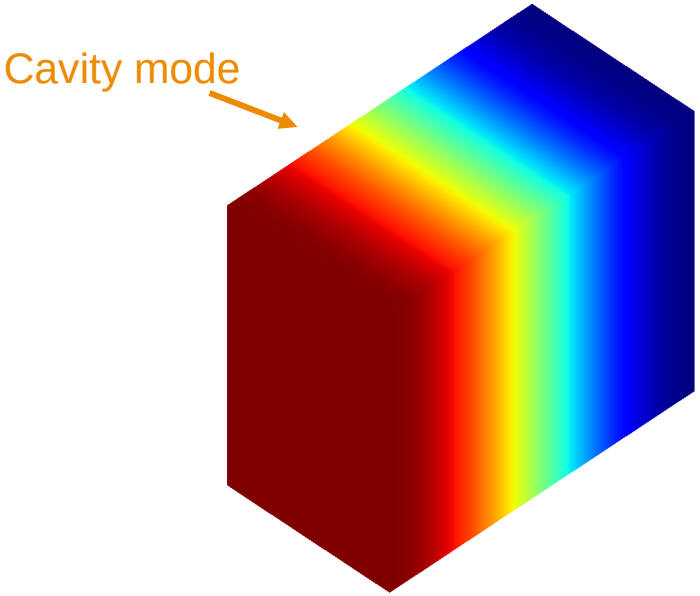
Modes are computed for an acoustic cavity

- The cavity walls are assumed rigid
- Only a *finite fluid component* is defined
- Modal extraction is only suitable for undamped system

Results post-processing

- A *plt file containing the eigen frequencies is created
- A *.nff database containing the cavity modes is created

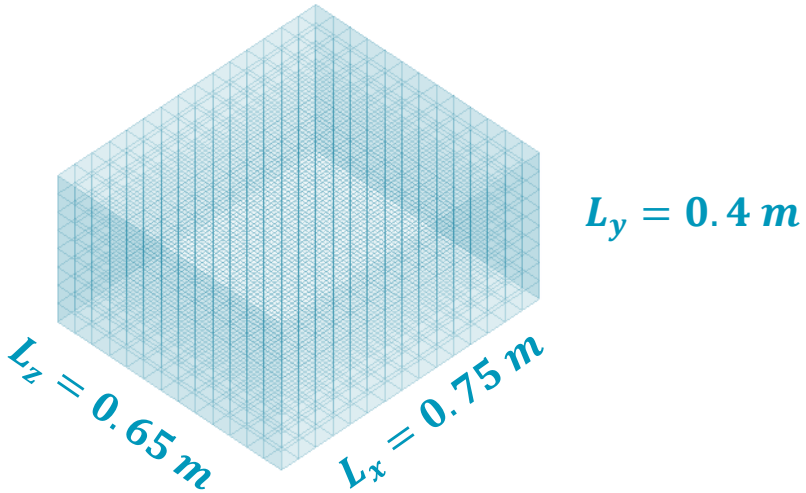




Analytical solution

- Considering a cavity 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 $\rho = 1.225\ kg/m^3$
- The 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

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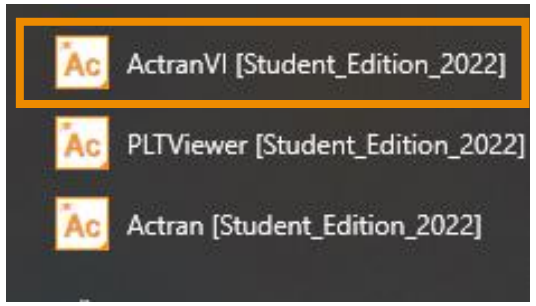
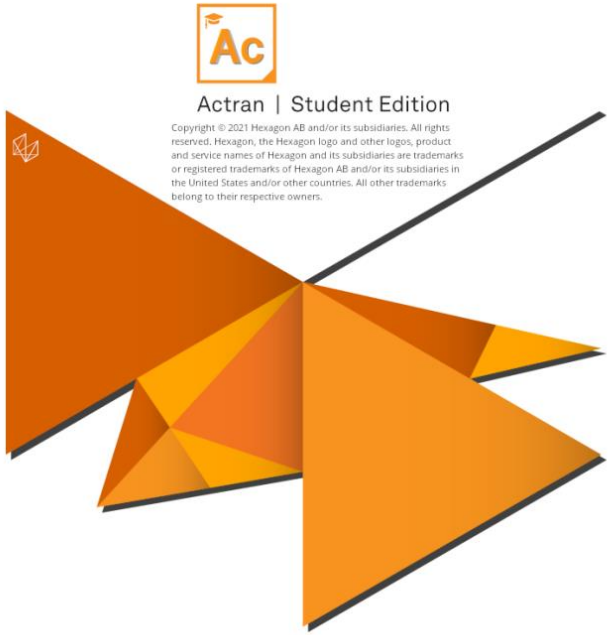
Start ActranVI

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



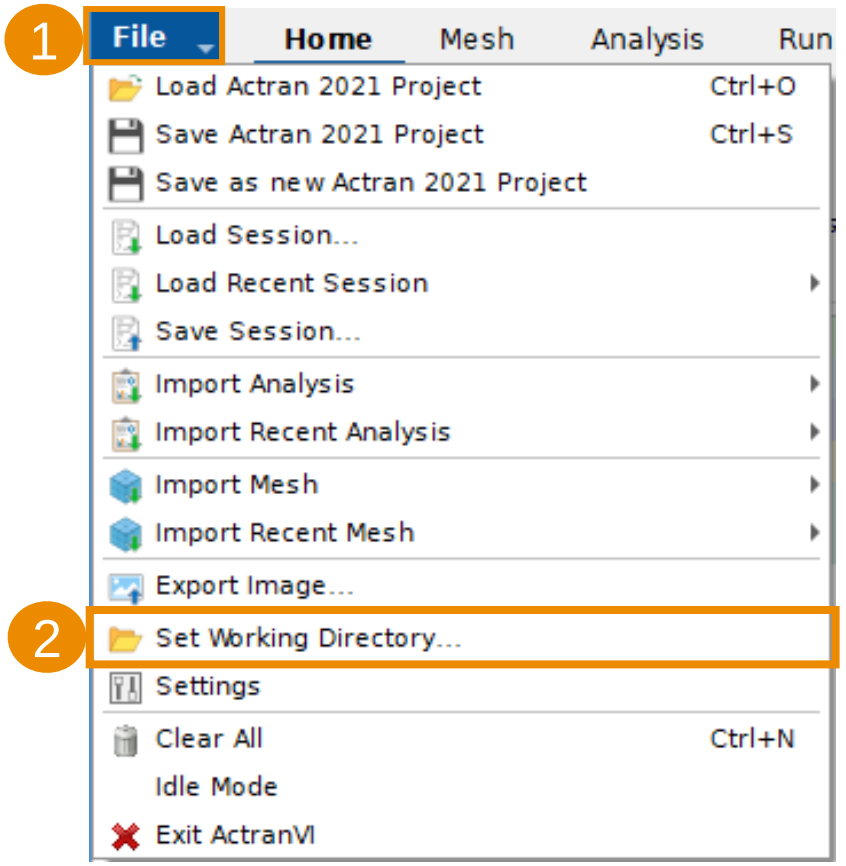
(Windows Start Menu)



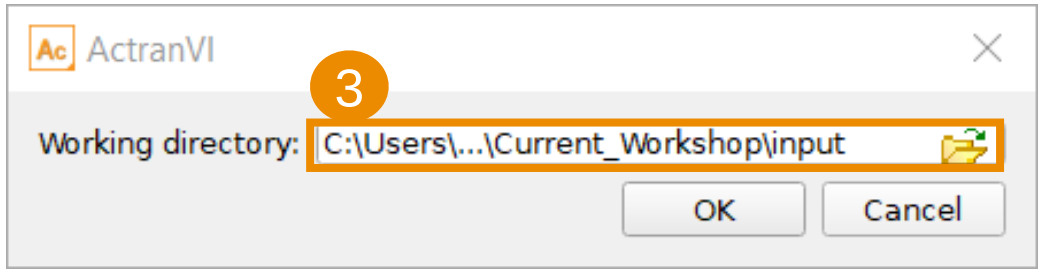
Set the working directory

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

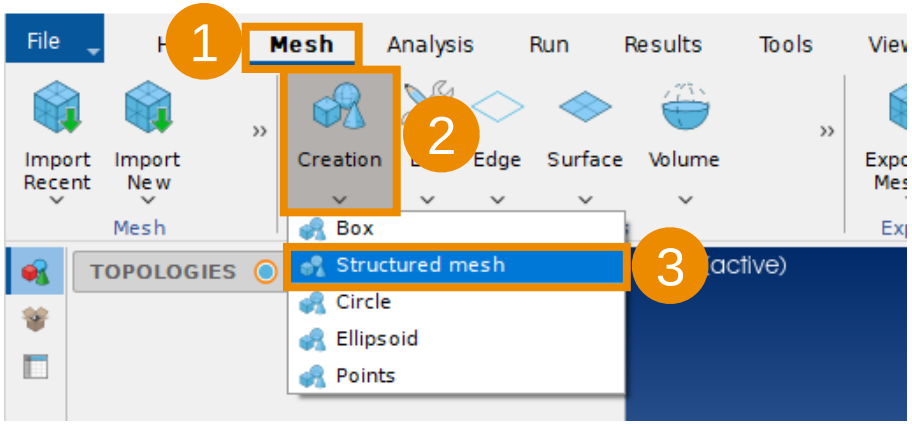


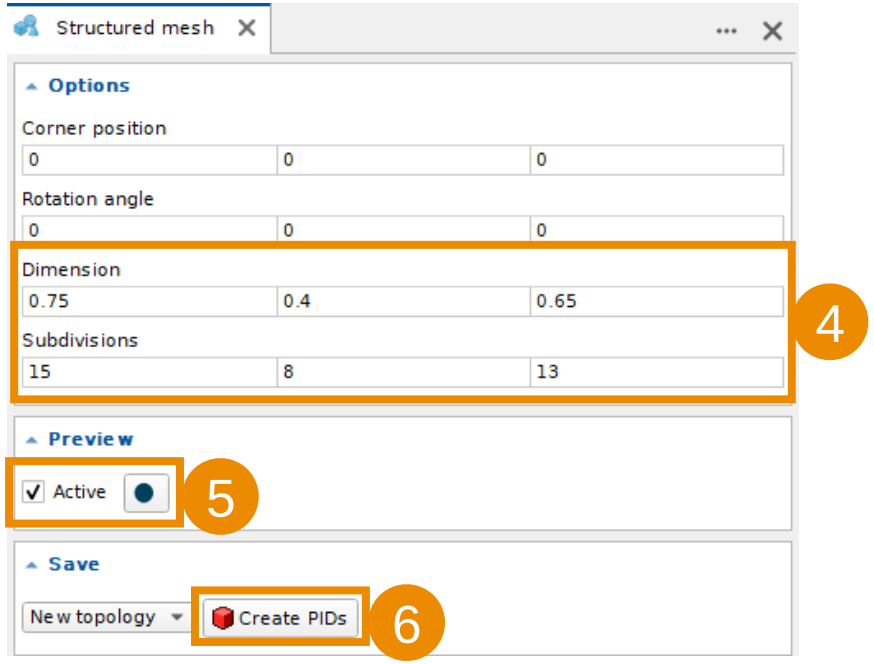
Create the mesh

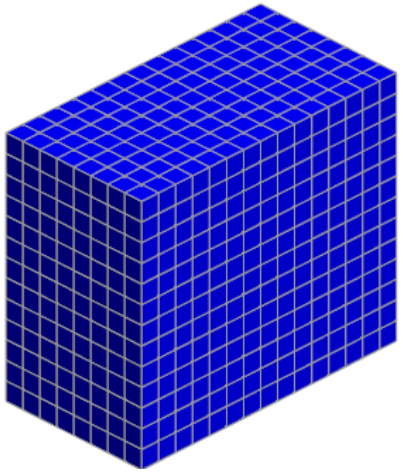
Select structured mesh tool in *Meshing Tools*

Set the dimension and activate the Preview

Create PID







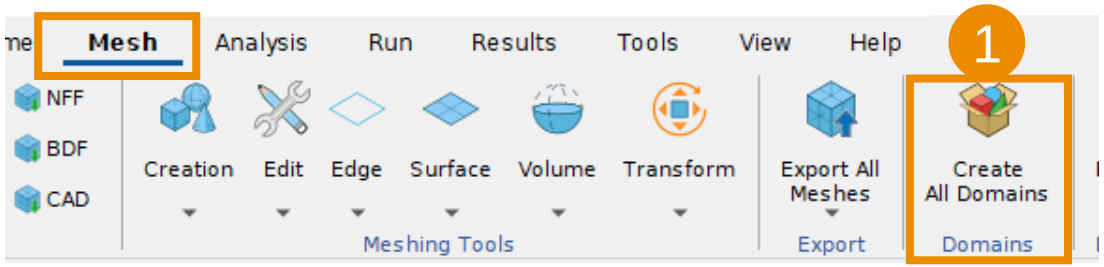
Create the domain

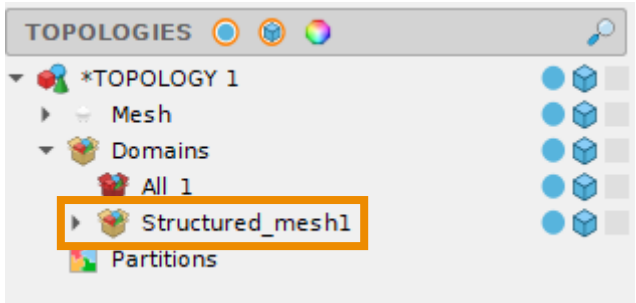
Auto create domain

- 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

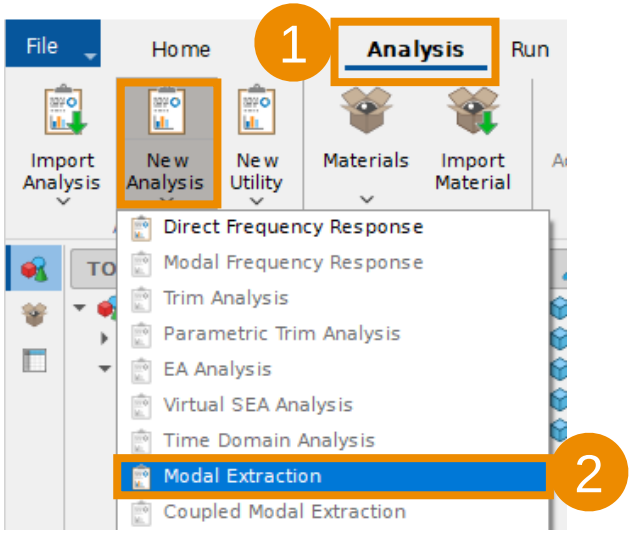


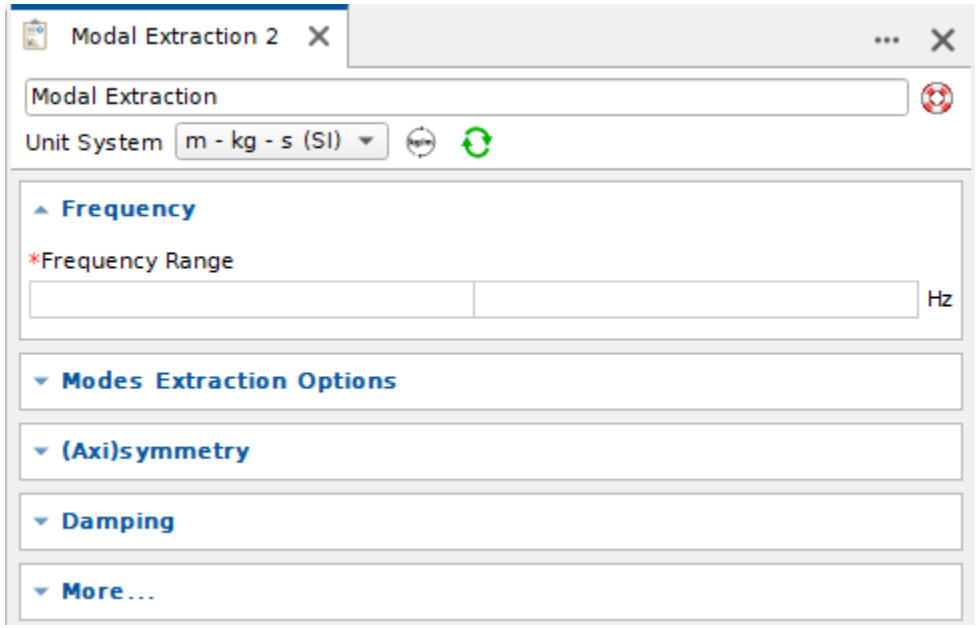


Create the Modal Extraction Analysis

Add a *Modal Extraction* analysis

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





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Specify the frequency range of interest (1)

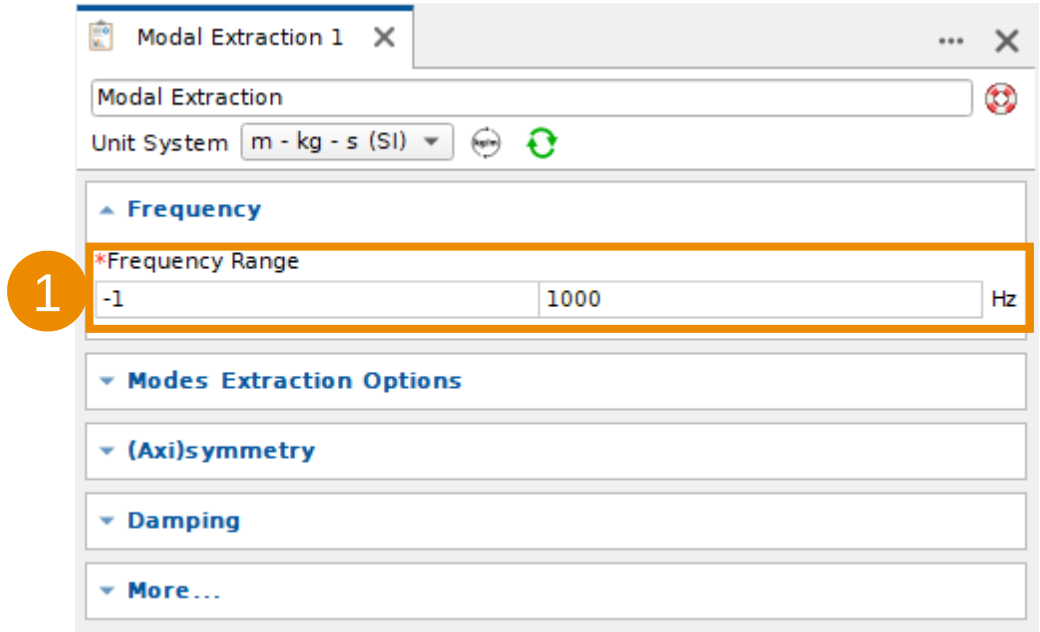
The wavelengths must be captured in the cavity

- Largest element length drives the max. frequency (smallest wavelength)
- The meshing criteria of 6 linear elements per wavelength is used
- Element length is 5 cm → maximum frequency supported by the mesh is 1133 Hz

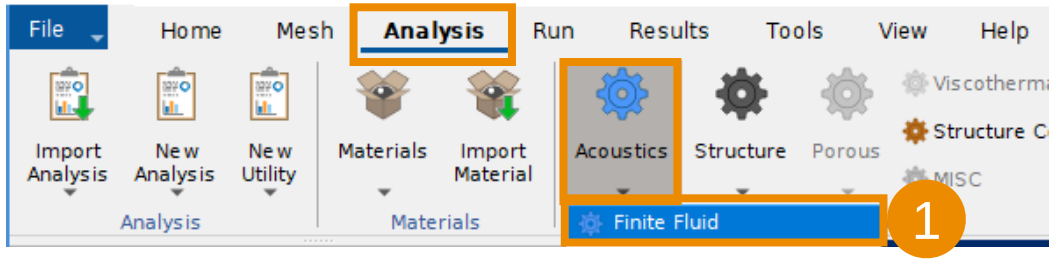
$$\left.\begin{aligned} f_{max} &= \frac{c}{\lambda_{min}} \\ L_{max} &= \frac{\lambda_{min}}{6} = 0.05m \end{aligned}\right\} \quad f_{max} = \frac{340}{6 * 0.05} = 1133\ Hz$$

Set the frequency range in the 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)

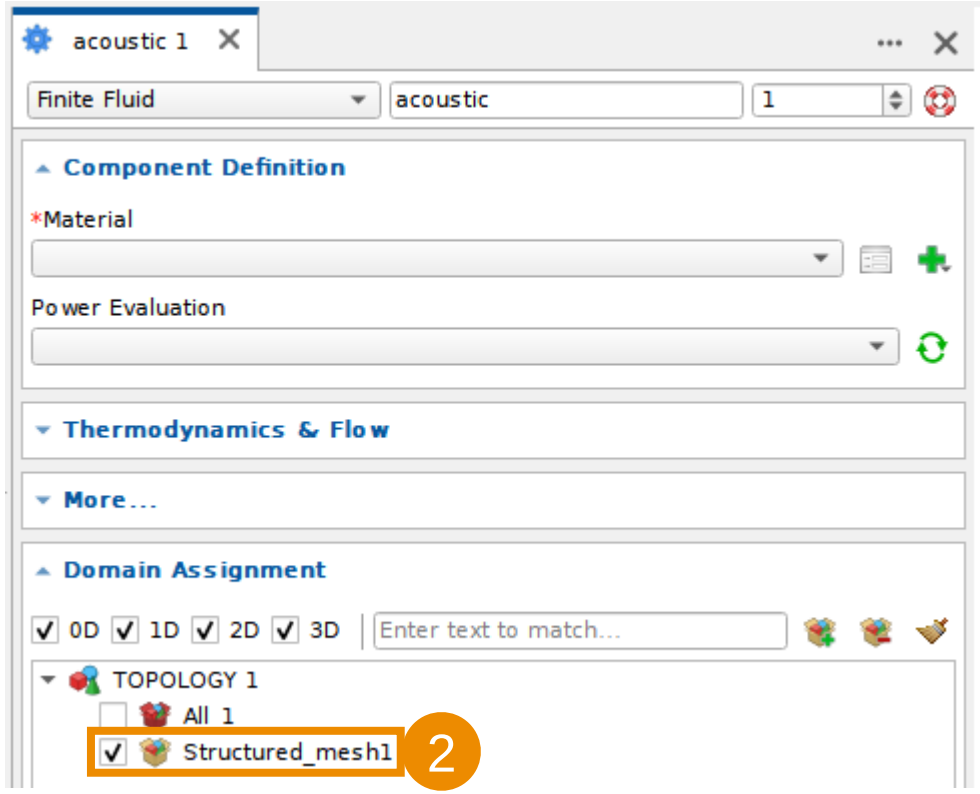


Create a Finite Fluid component (1)



Add a *Finite Fluid component*

Set up the *Finite Fluid component* domain



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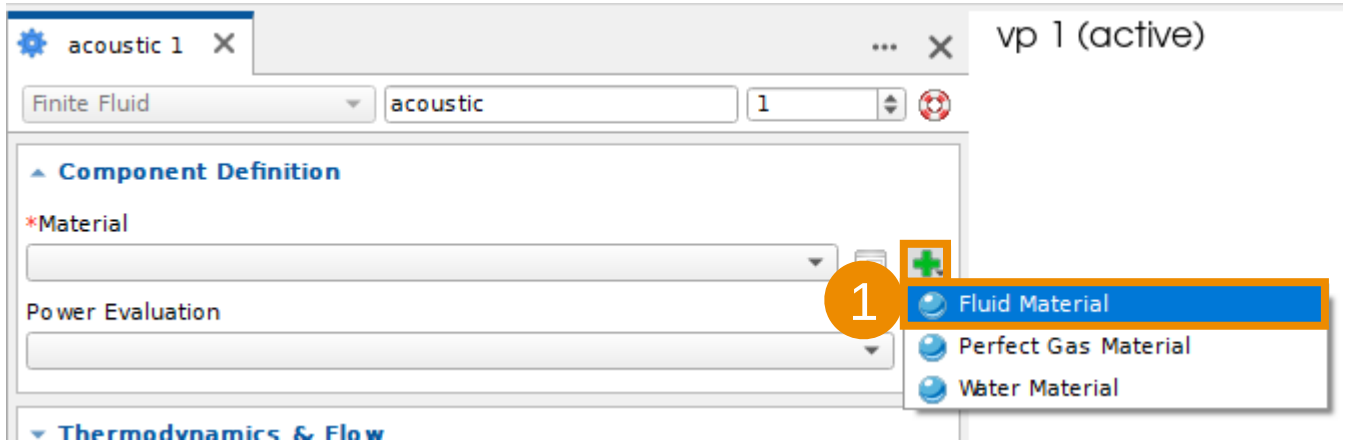
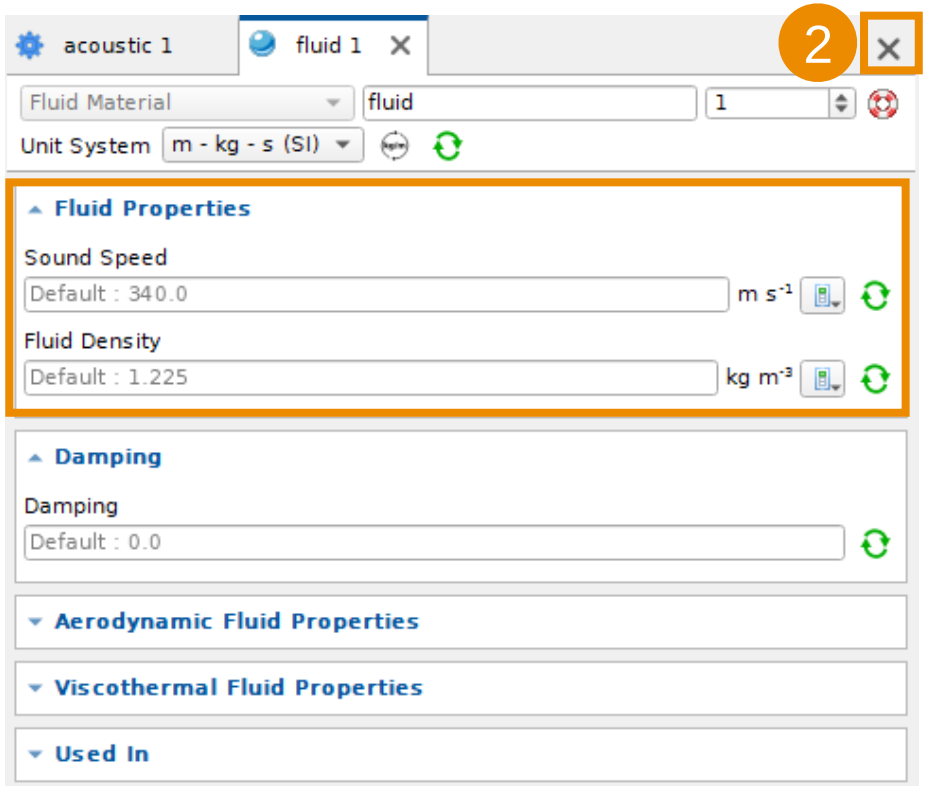
Create a Finite Fluid component (2)

Define a material for air

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





Close both property windows (material & component)

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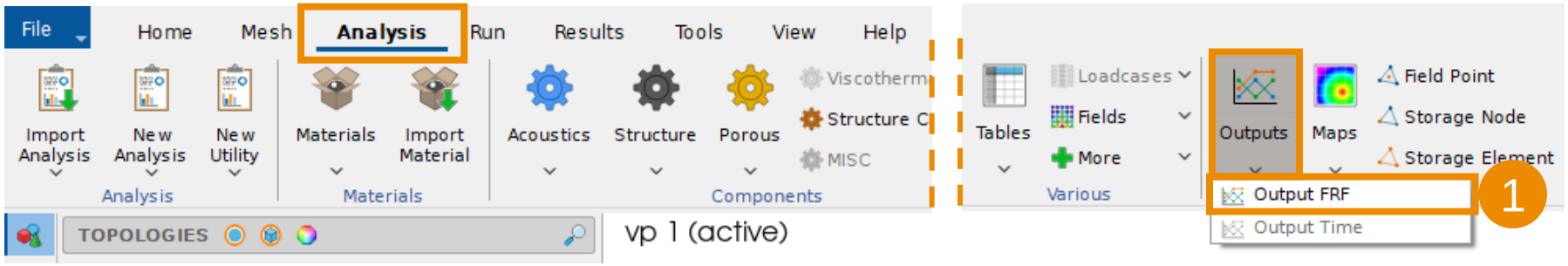
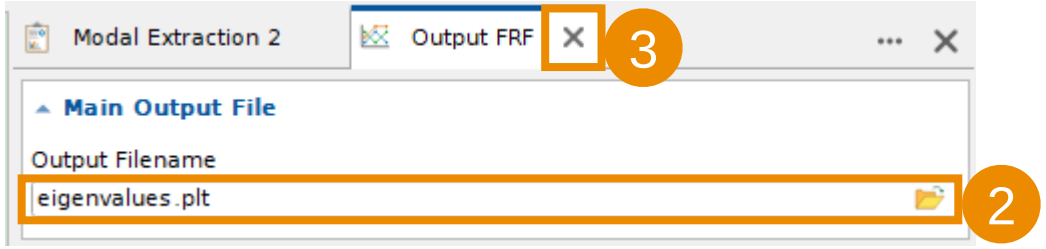
Post-processing parameters – FRF

Create an output FRF post-processing parameter



Set the file name to *Eigenvalues.plt*



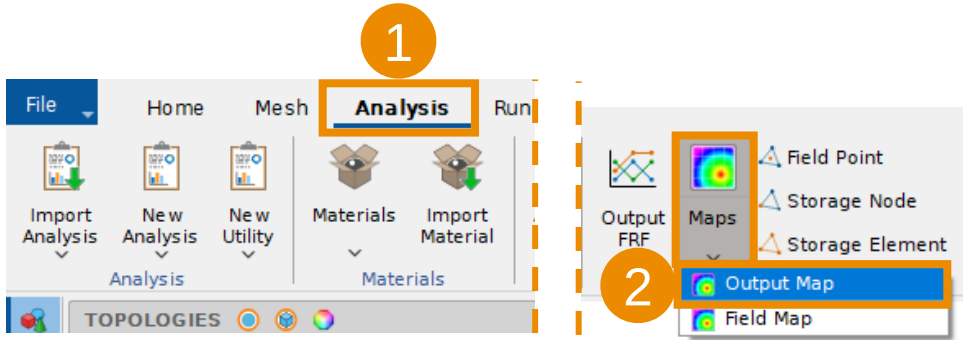
Close the property window

NOTE

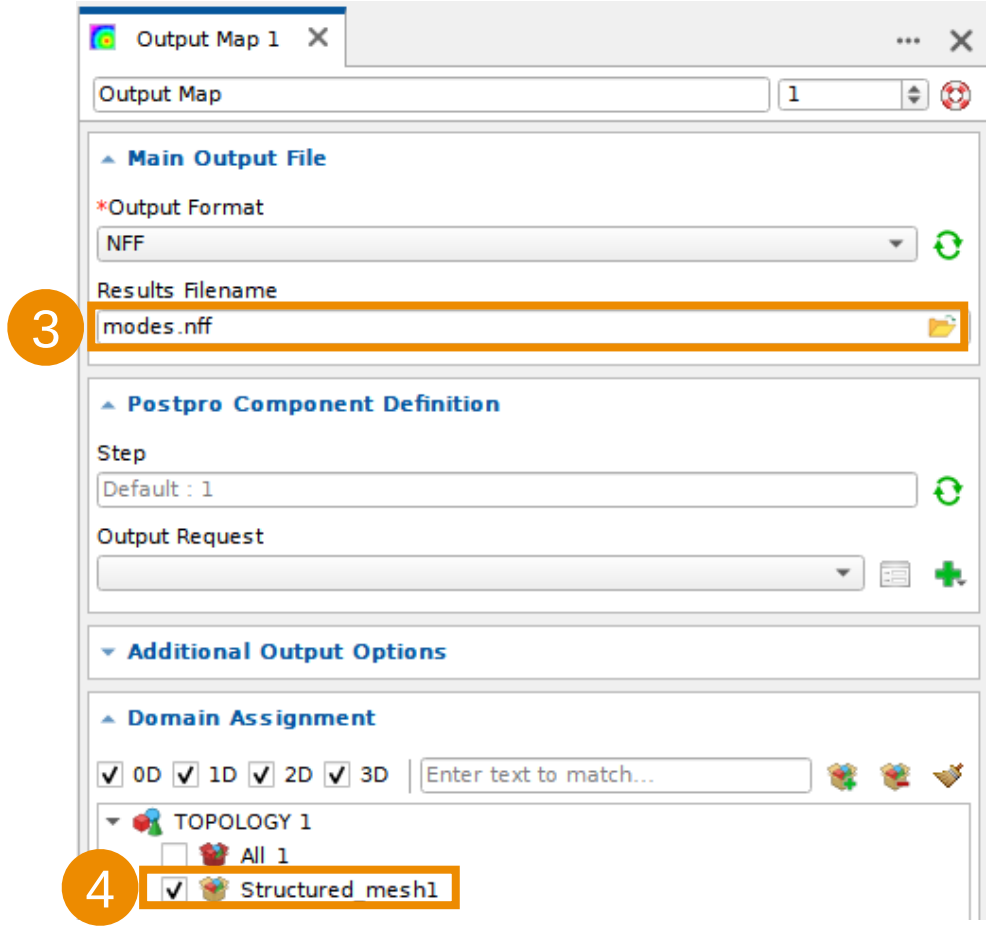
This FRF file will contain the list of the eigenfrequencies

Post-processing parameters – Maps

Add an *Output Map post-processing parameter*



The map folder *modes.nff* will contain the modes shape on the cavity mesh at each frequency step

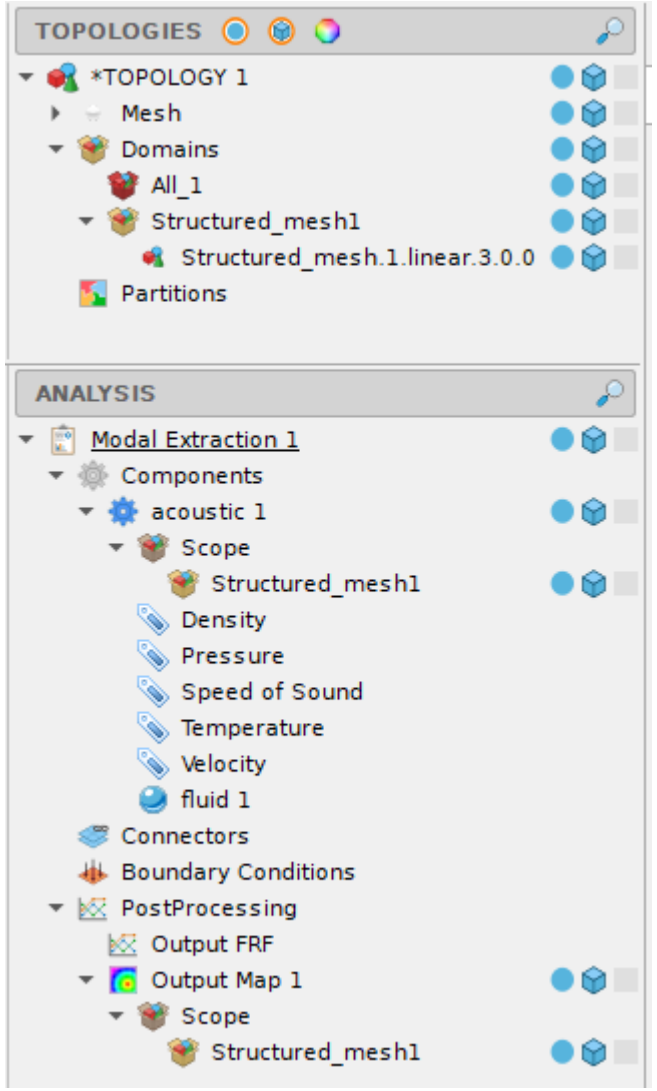


Check the analysis

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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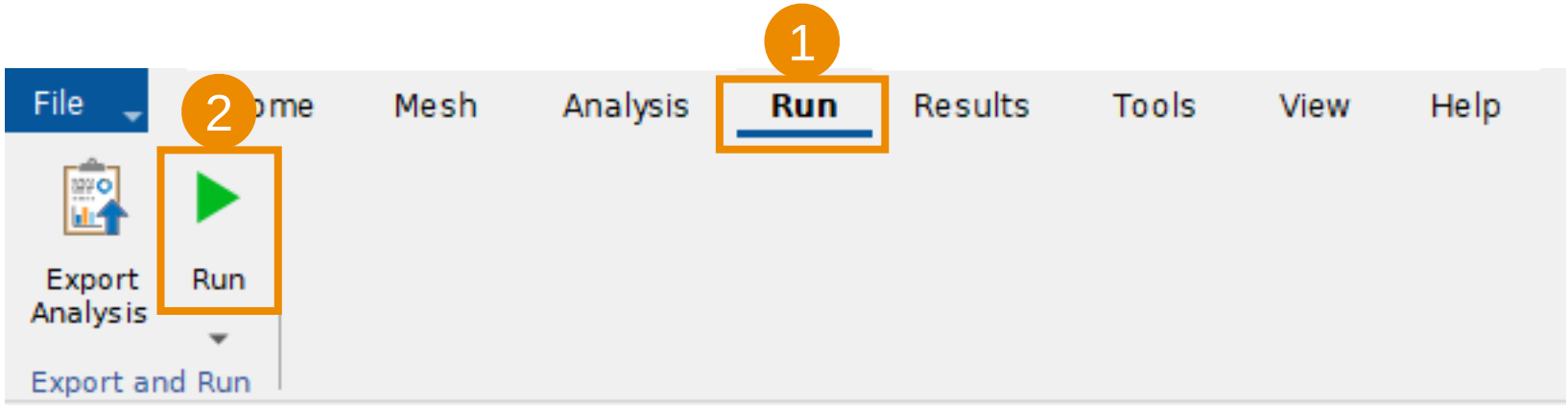
Launch the analysis in ActranVI

Launch the computation

Check the log showing the computation progress

Import the map folder



Post-processing

Check the Eigen Frequencies

Open the eigenvalues.plt in a text editor

- The eigenfrequencies are 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,
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  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,
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  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,
```

NOTE

- *The first mode with a very low eigenfrequency is the breathing mode:*
  - *This mode is theoretically 0 Hz*
  - *The Actran value is very low and unlike the higher eigenfrequencies, it may then be machine-dependent due to rounding-up error*

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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%

NOTE

As the breathing mode eigenfrequency is very low, the value output by Actran may be machine-dependent due to rounding-up error

Relative error:

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

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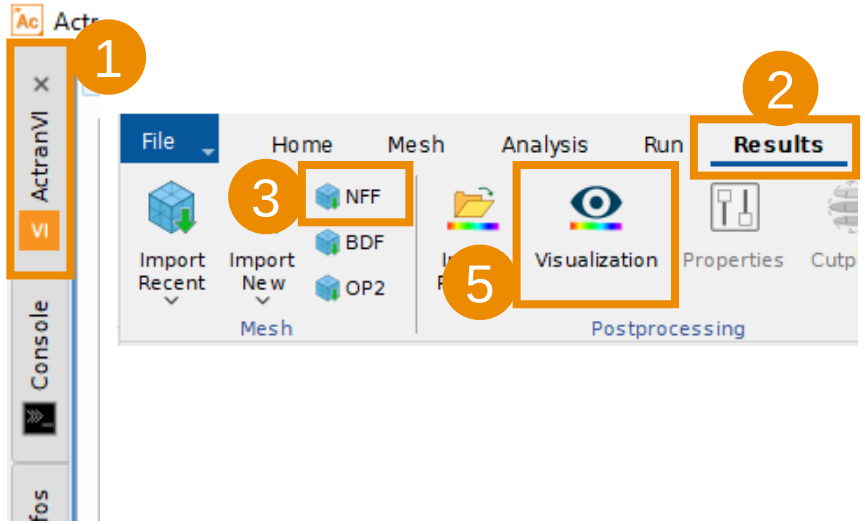
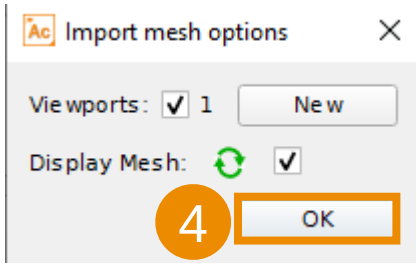
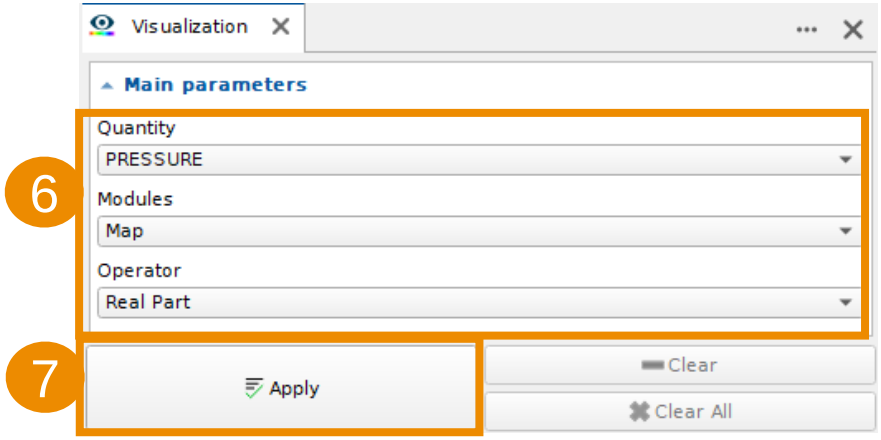
Visualize field maps (1)

Import the results







Go back to ActranVI → Import the folder *modes.nff* → Visualize the pressure real part

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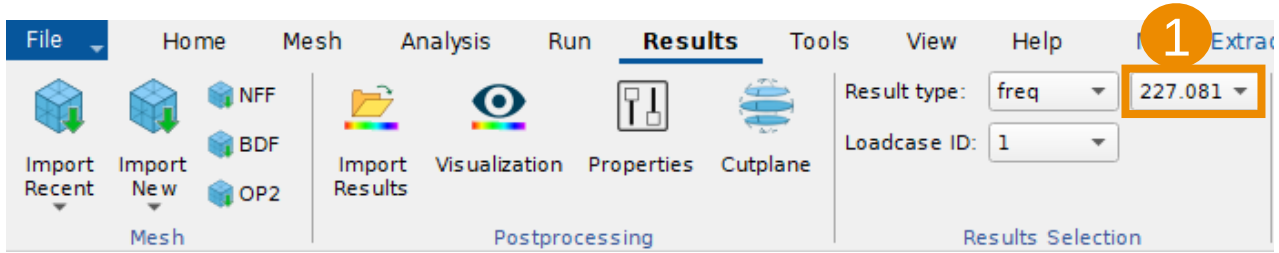
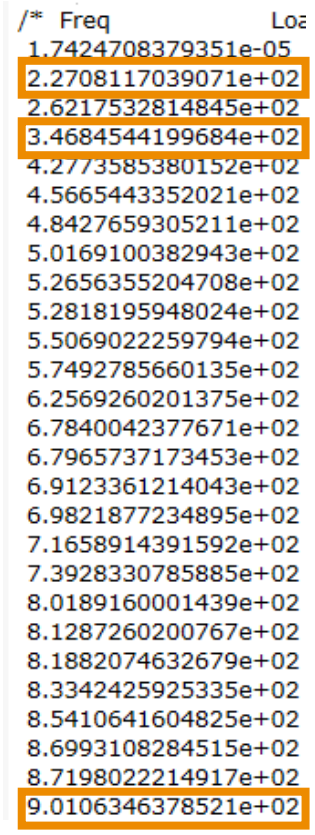
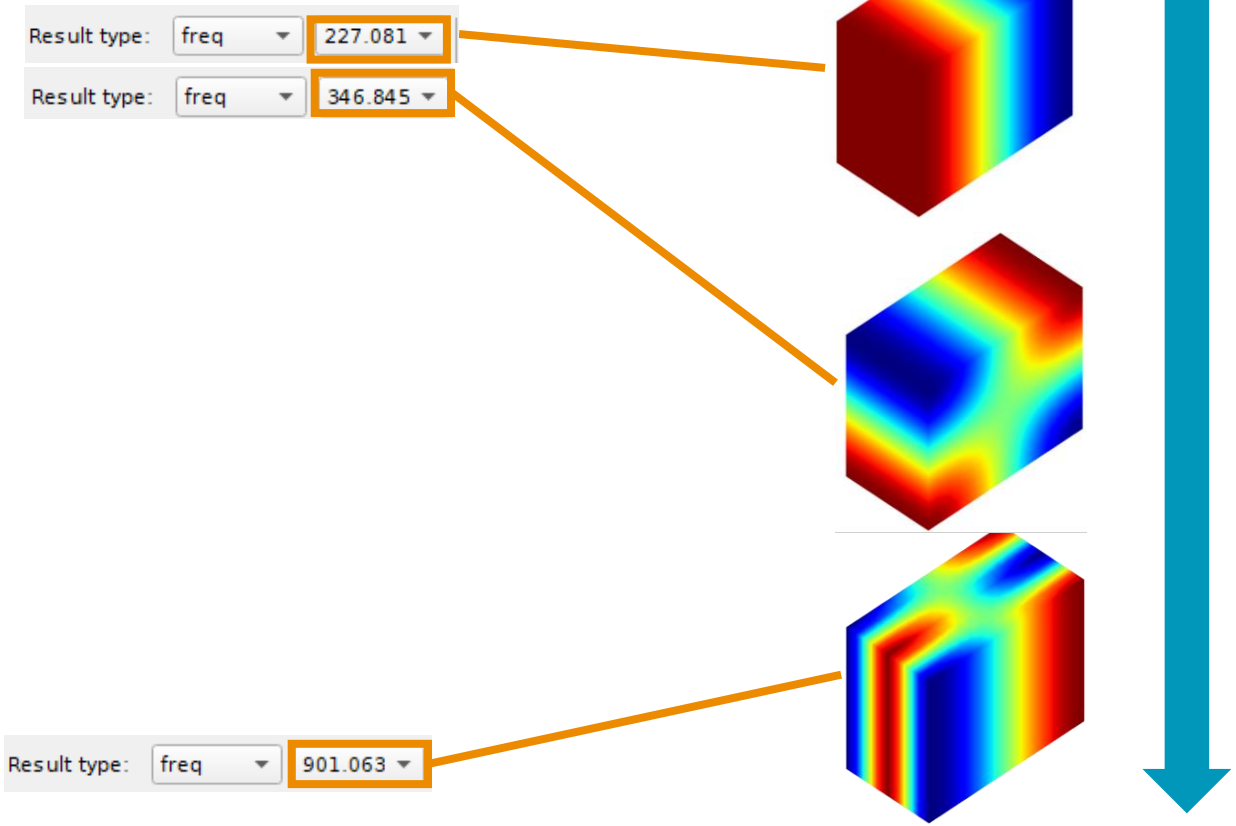
Visualize maps (2)







Increasing complexity of acoustic pressure field with increasing frequency

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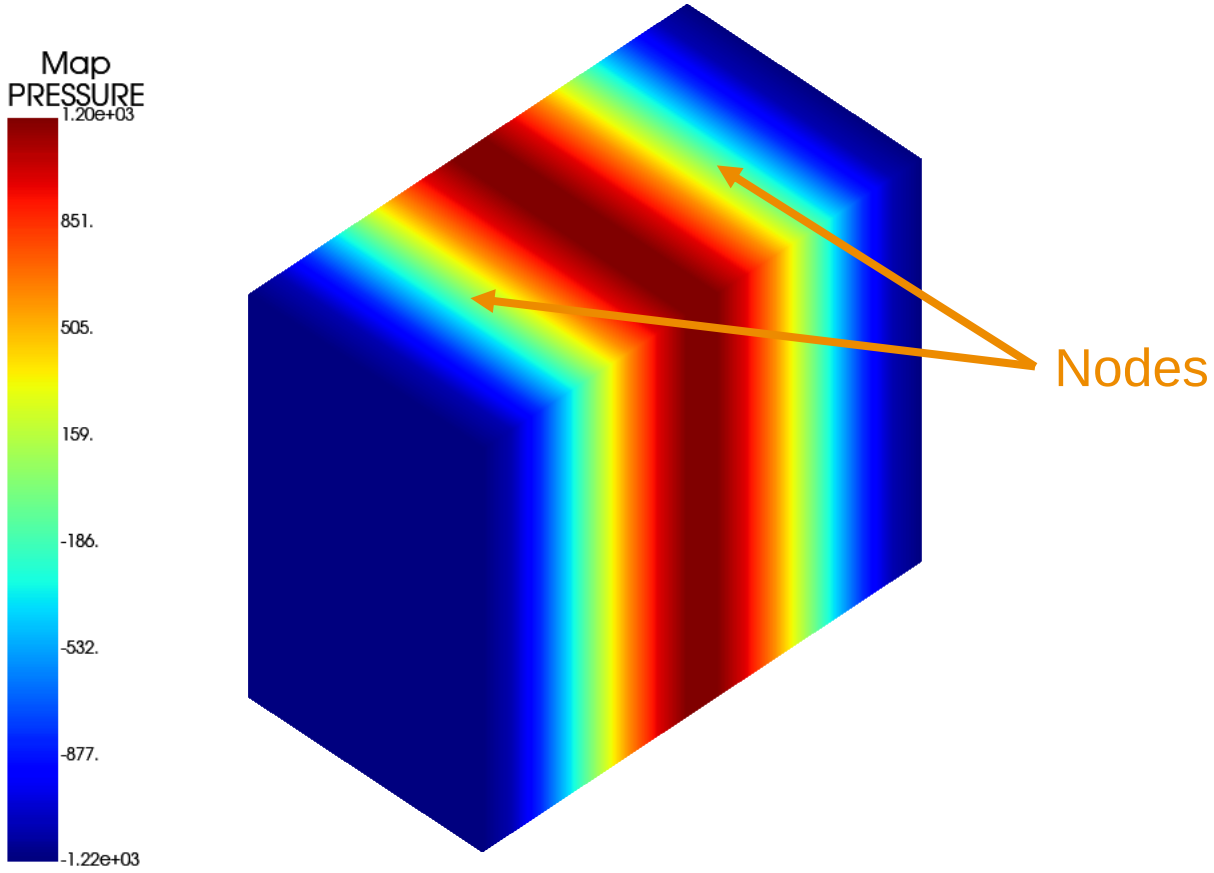
Nodes of the cavity modes

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



Example: Mode at 456Hz

Conclusions

Conclusions

- The acoustic modes of a cavity were extracted

- The model involved
  - A Modal Extraction Analysis
  - Finite Fluid component for the cavity
  - FRF and map outputs to export the eigenfrequencies and eigenmode shape

- The results highlighted:
  - A breathing mode very close to 0 Hz (theoretical value)
  - Higher mode complexity as the frequency increases
  - Presence of acoustic mode nodes (where the pressure is zero)

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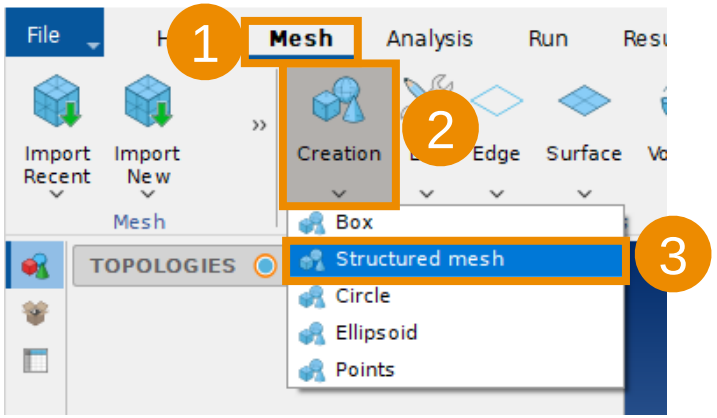
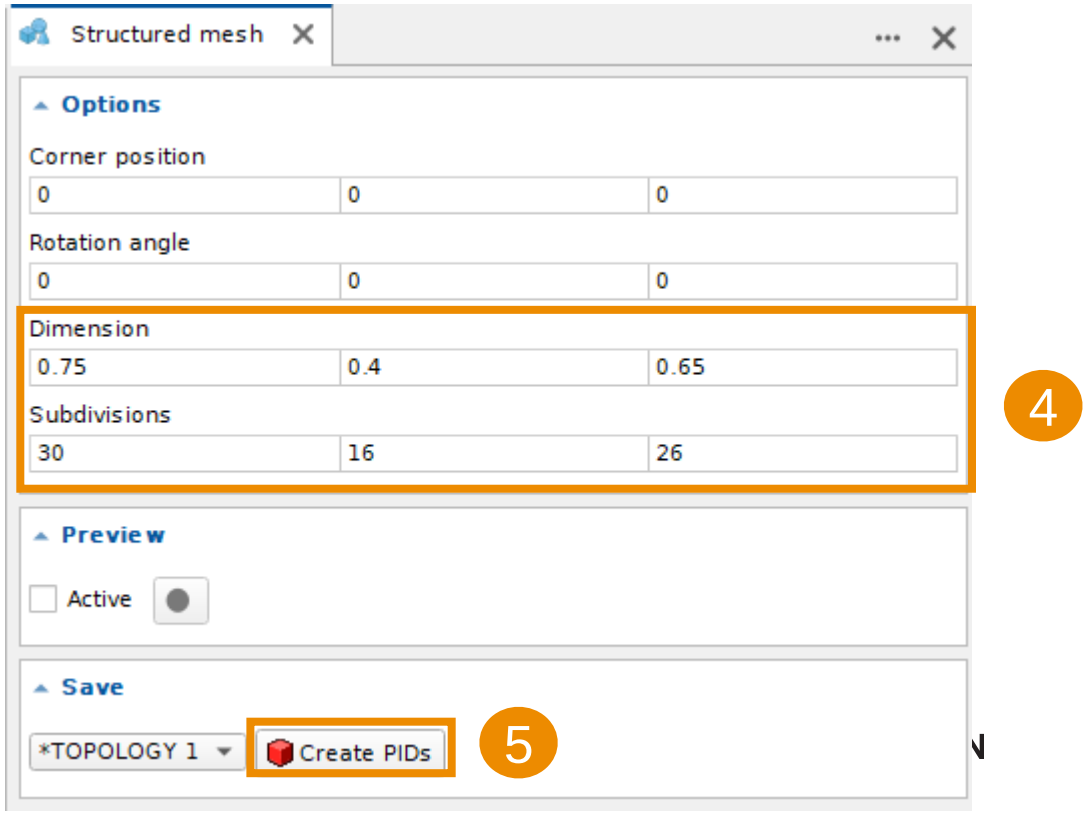
Going further (optional)

Refining the mesh to increase model accuracy

Method 1

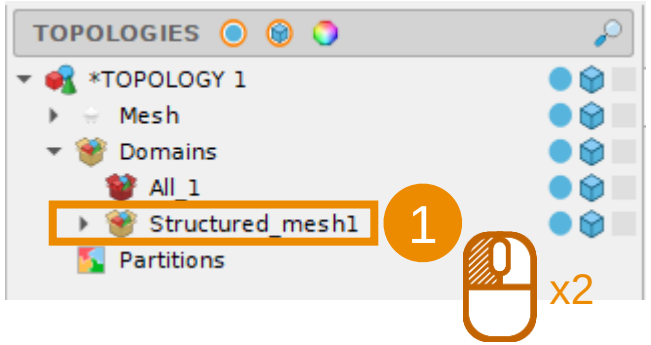
- Decrease the mesh size
- From 0.05m to 0.025m

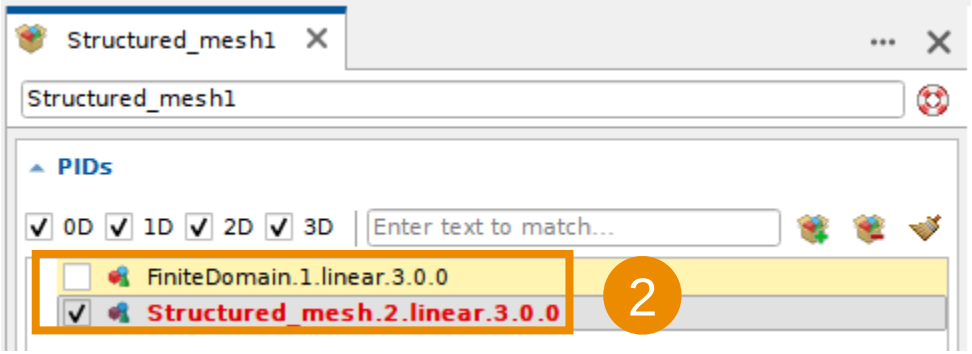




Refining the mesh to increase model accuracy

Re-assign the domain to the newly created element set





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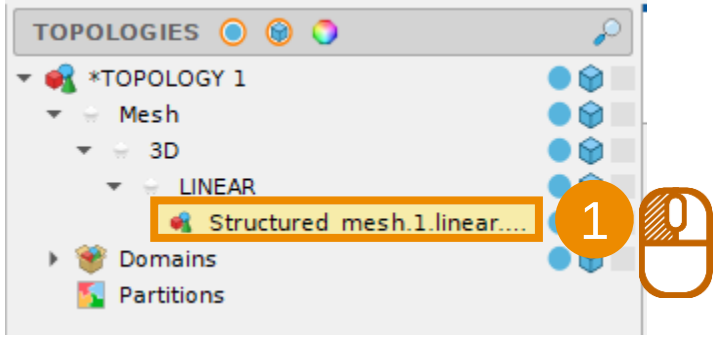
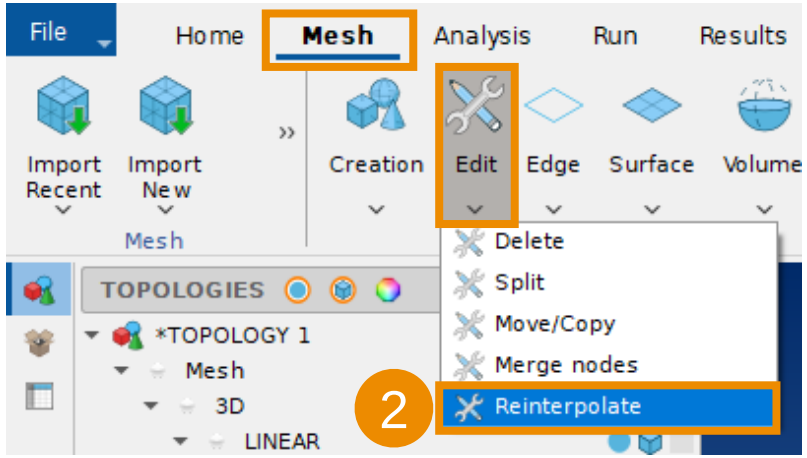
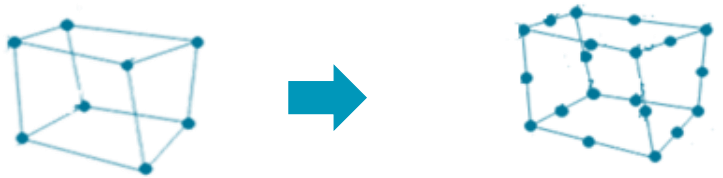
Refining the mesh to increase model accuracy



Method 2

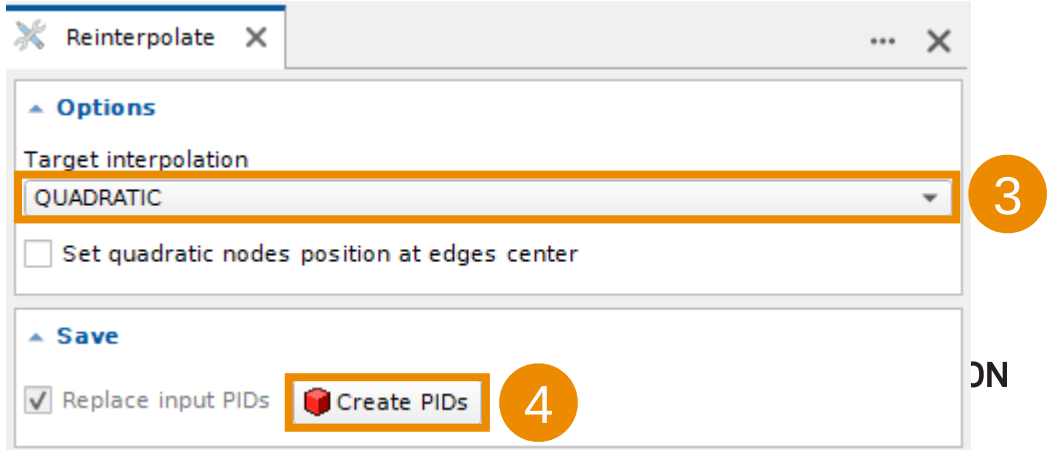
- Change the mesh interpolation
- From linear to quadratic





Linear element

Quadratic element



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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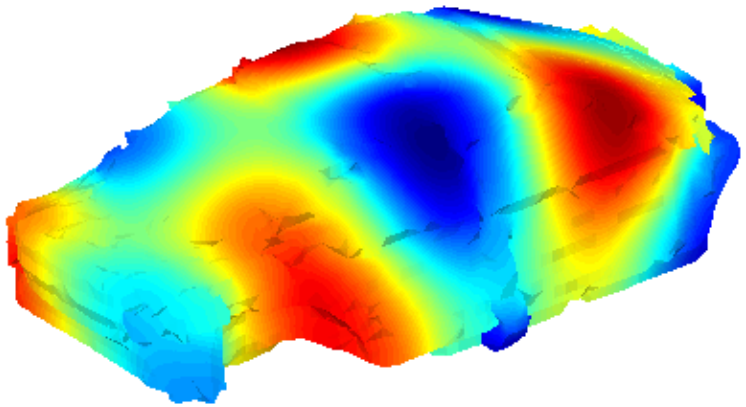
Going further with other cavity shapes

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

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



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