From Music to Non-Invasive Therapies via COMSOL Multiphysics® Models

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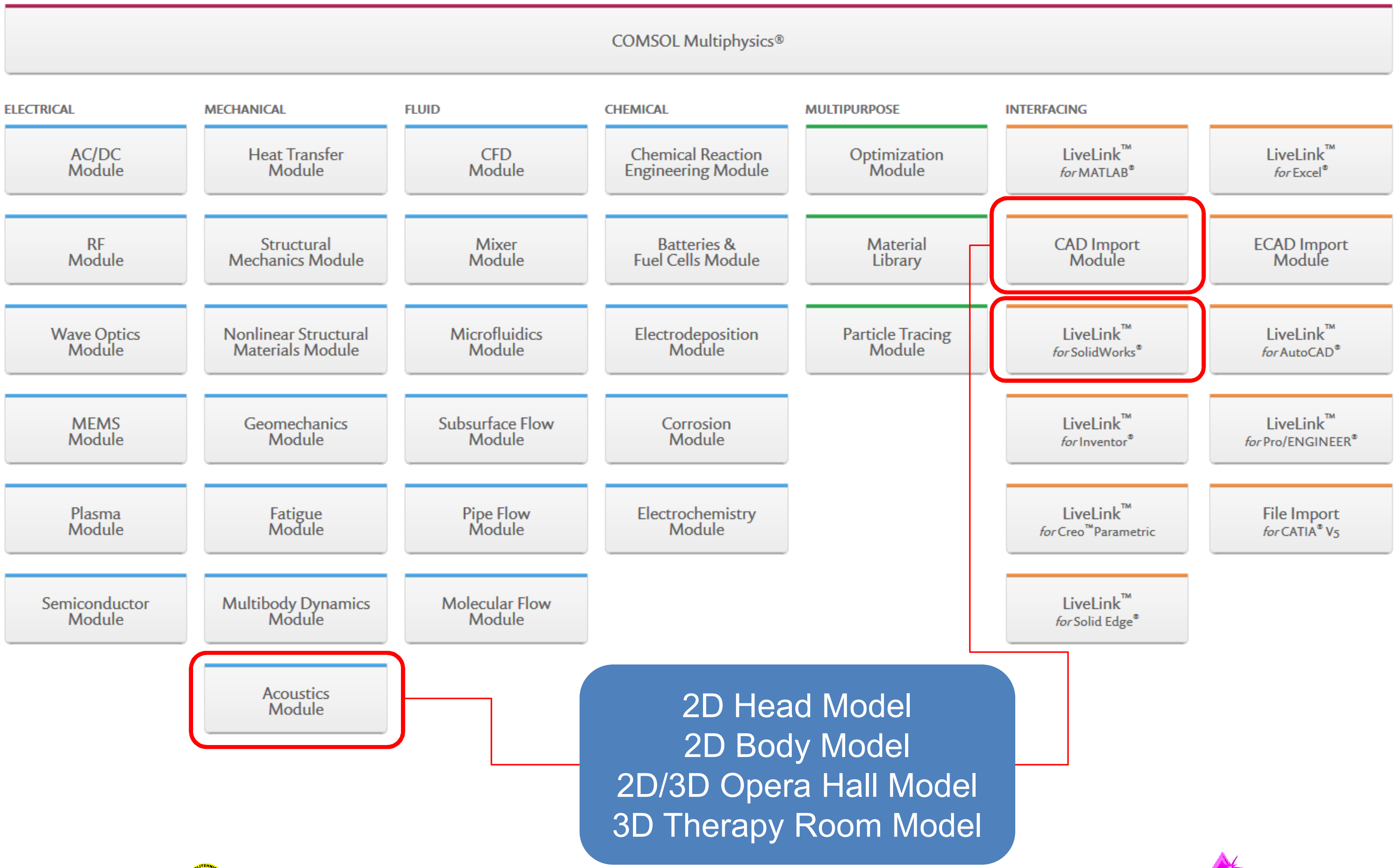
OVERVIEW

- Research Problem: Acoustic Environment
- Use of COMSOL Multiphysics®
- Model Definition (M1- M5) -Computational methods
- Results (M1-M5)
- COMSOL Multiphysics ® : Support for next integrated therapeutic tools
- Conclusions : Who should "*play*" COMSOL each day?

Research Problem: Acoustic Environment

Use of COMSOL Multiphysiscs®



Use of COMSOL Multiphysiscs® (cont.)

Acoustics Module

Product Features

- Acoustic-shell interaction
- Acoustic-solid interaction
- Acoustic-structure interaction
- Aeroacoustics
- Compressible potential flow
- Elastic waves

- Poroelastic waves
- Pressure acoustics
- Structural vibrations
- Thermoacoustics
- Thermal and viscous losses

- Far-field and directivity calculations
- Impedance, hard-wall, and soft-wall boundaries
- Perfectly matched layers for modeling infinite domains
- Piezoacoustics
- Piezoelectric devices
- Pipe acoustics

CAD Import Module

Product Features

- File import of Parasolid®, ACIS®, STEP, IGES, Inventor®, PTC® Creo Parametric™, and SolidWorks® file formats
- Encapsulate geometries to model phenomena in the surrounding domains
- Export geometry files to the Parasolid® and ACIS® file formats
- Convert third-party file formats to the COMSOL geometry kernel

- Detaching faces from a solid object to create a new solid object
- Cap holes or empty spaces to fill the space and create modeling domains
- Patch removed faces by growing or shrinking the surrounding surfaces to cover the removed face

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Model Definition (M1-M2)

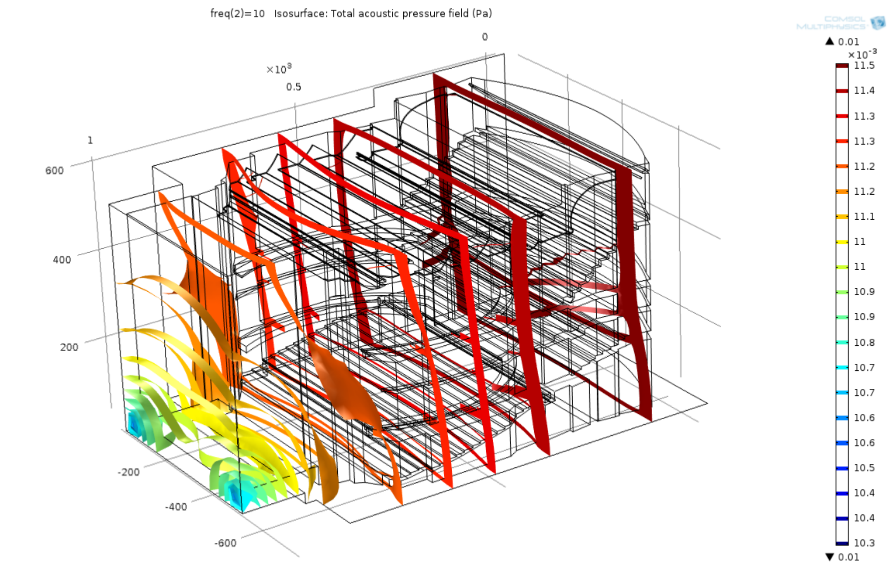
MODEL PARAMETERS	Opera Hall ‖ Opera Hall + Body
Definitions	Boundary System , Global Cartesian (Plane + Spatial) (Opera Hall + Body)
Geometry	Imported- Selected Domain (Opera Hall, Body Contour, Air/Surrounding Environment geometry)
Materials	Concrete, Wood, Muscle , Air (Appendix, Table1)
	Pressure Acoustics $\nabla\cdot -\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$ $p_t = p + p_b$ $k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2 - k_z^2$ $c_c = c, \quad \rho_c = \rho$ Sound Hard Boundary (Walls) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) = 0$ Acoustic-Structure Boundary1 (Body Contour) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) = -\mathbf{n}\cdot \boldsymbol{u}_{tt}$ $\sigma\cdot\mathbf{n} = p_t\mathbf{n}$
Mesh	Extremely fine / Number of degrees of freedom (DOF): 255944

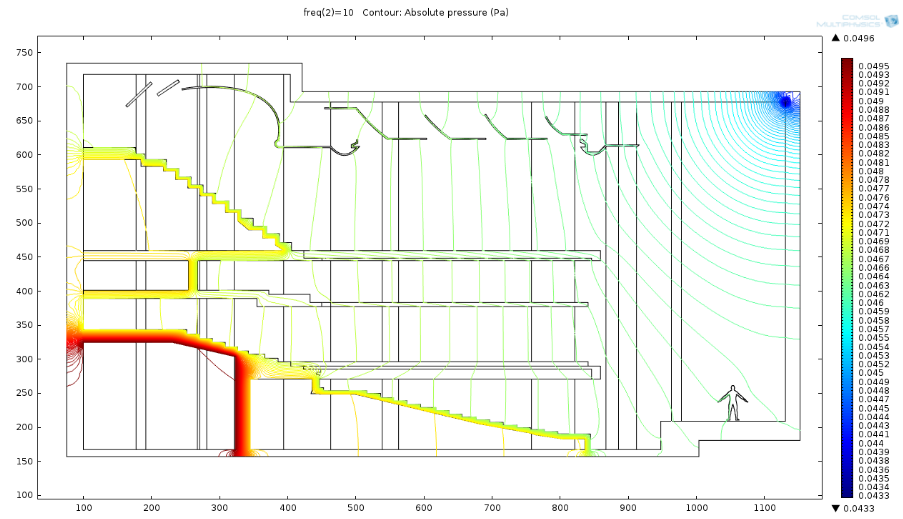
STUDY

Frequency Domain	Pressure Acoustics C1_[1-100] Hz C2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module

RESULTS

Plot Groups	2D Plot Group 2- Absolute Pressure 2D Plot Group 3 Sound Pressure level 3D Plot Group 4- Absolute Pressure 3D Plot Group 5 Sound Pressure level 2D Plot Group 6 – Mesh 3D Plot Group 7 – Mesh



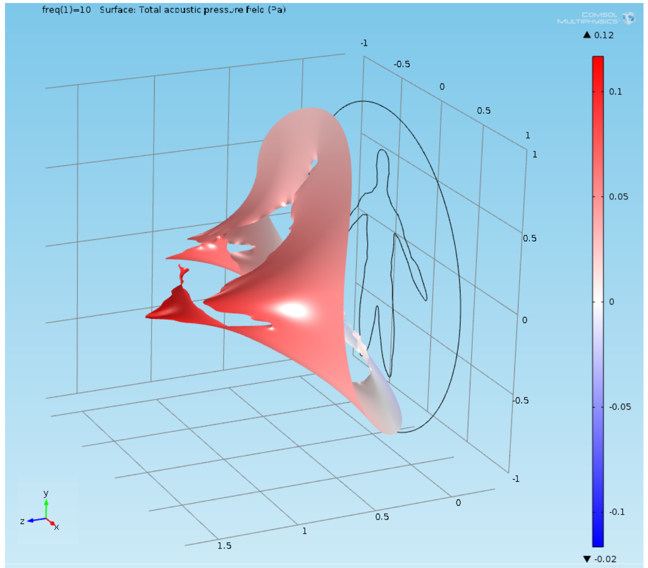


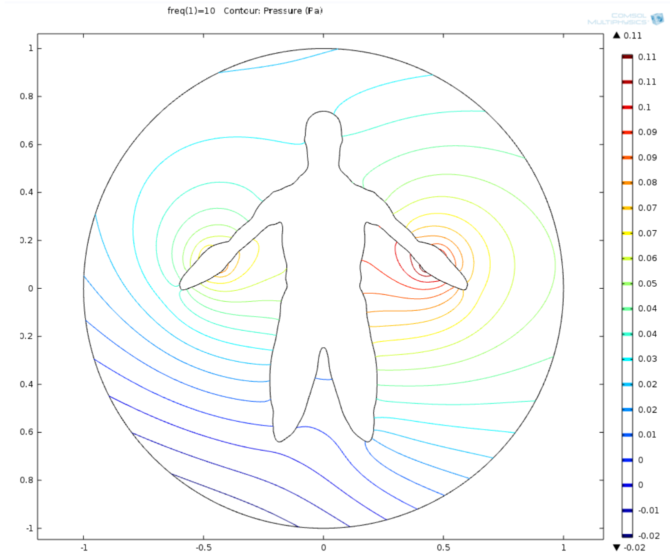
Model Definition (M3)

MODEL PARAMETERS	Body
Definitions	Boundary System , Frequency, Wave direction angle, Incident wave direction vector
Geometry	Imported- Selected Domain (Body Contour, Air/Surrounding Environment geometry)
Materials	Muscle , Air (Appendix, Table1)
Frequency Domain	Acoustic-Solid Interaction $\nabla\cdot -\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$ $p_t = p + p_b$ $k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2$ $-\rho\omega^2\mathbf{u} - \nabla\cdot\sigma = \mathbf{F}_V e^{i\phi}$ Sound Hard Boundary (Walls) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) = 0$ Acoustic-Structure Boundary1 (Body Contour) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) = -\mathbf{n}\cdot\mathbf{u}_{tt}$ $\sigma\cdot\mathbf{n} = p_t\mathbf{n}$ Linear Elasticity (Body) $-\rho\omega^2\mathbf{u} - \nabla\cdot\sigma = \mathbf{F}_V e^{i\phi}, \quad \sigma = \mathbf{s}$ $\mathbf{s} - \mathbf{S}_0 = \mathbf{C} : (\epsilon - \epsilon_0 - \epsilon_{inel})$ $\epsilon = \frac{1}{2}\left[(\nabla\mathbf{u})^T + \nabla\mathbf{u}\right]$ Plane Wave Radiation1 (Walls) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) + i\frac{k}{\rho_c}p + \frac{i}{2k\rho_c}\Delta_T p = Q_i$ Incident Pressure Field (inwards) $-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) + i\frac{k}{\rho_c}p + \frac{i}{2k\rho_c}\Delta_T p = Q_i$ $Q_i = i\frac{k}{\rho_c}p_i + \frac{i}{2k\rho_c}\Delta_T p_i + \mathbf{n}\cdot\frac{1}{\rho_c}\nabla p_i$ $p_i = p_0 e^{-ik_{eq}\frac{(\mathbf{r}\cdot\mathbf{e}_k)}{\lVert\mathbf{e}_k\rVert}}$
Mesh	Extremely fine Number of degrees of freedom (DOF): 154949-Upper Left source

STUDY

Frequency Domain	Acoustic-Solid Interaction [100-16000] Hz
Solver Configurations	COMSOL Multiphysics – Acoustic Module





Model Definition (M4)

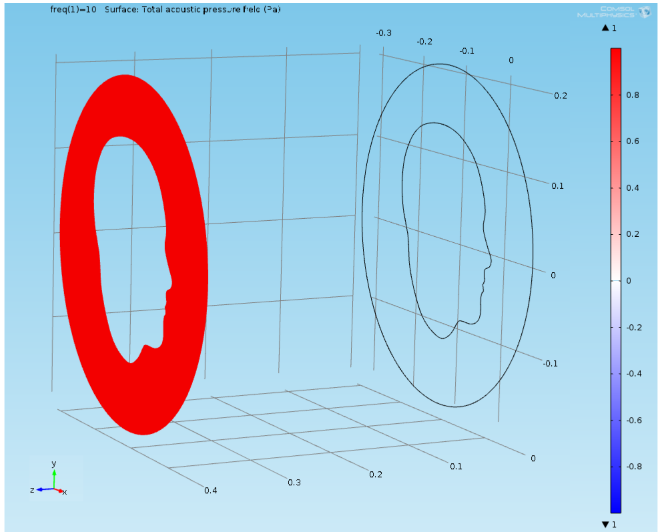
MODEL PARAMETERS	Head
Definitions	Boundary System , Global Cartesian
Geometry	Imported -Selected Domain (Brain, Fluid Buffer, Muscle, Skull, Air/Surrounding Environment geometry)
Materials	Brain , Fluid Buffer, Skull, Muscle, Air (Appendix, Table1)
Frequency Domain	Pressure Acoustics $\nabla \cdot -\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$ $p_t = p + p_b$ $k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2 - k_z^2$ $c_c = c, \quad \rho_c = \rho$
Mesh	Extremely fine Number of degrees of freedom (DOF): 961765 (A1) –Frontal source 962861 (A2)- Upper Left source

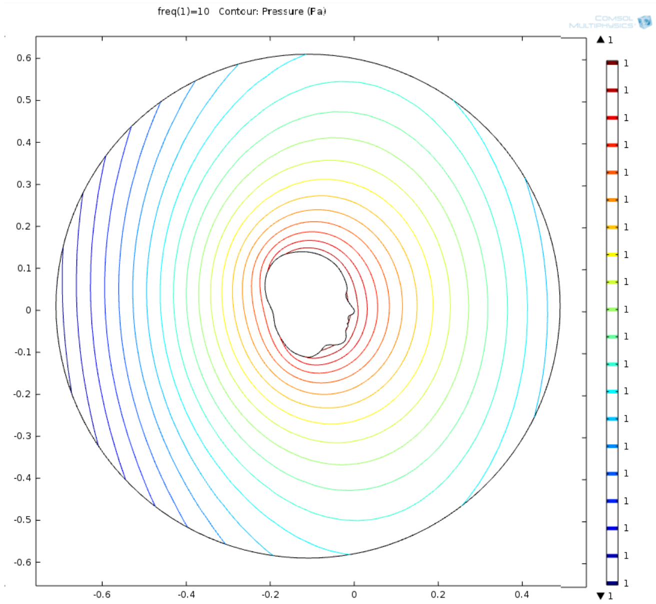
STUDY

Frequency Domain	Pressure Acoustics A1_[6-20] Hz A2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module

RESULTS

Plot Groups	Acoustic Pressure (acsl) Sound Pressure Level (acpr) 2D Plot Group 3- Absolute Pressure 2D Plot Group 4 – Instantaneous local velocity 2D Plot Group 5 Sound Pressure Level 2D Plot Group 6 – Mesh





Model Definition (M5)

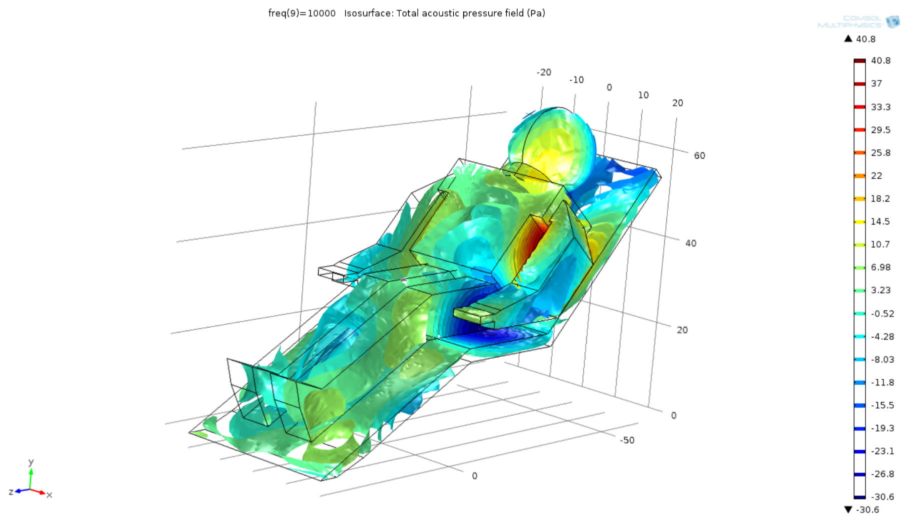
MODEL PARAMETERS	Relaxing Therapy Room
Definitions	Boundary System , Global Cartesian (Spatial) (Therapy Room + Body)
Geometry	Imported- Selected Domain (Therapy Room, Body Contour, Air/Surrounding Environment geometry)
Materials	Concrete, Wood, Muscle , Air (Appendix, Table1)
Frequency Domain	Pressure Acoustics $p_t = p + p_b$ $\nabla \cdot -\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$ $k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2 - k_z^2$ $c_c = c, \quad \rho_c = \rho$ Sound Hard Boundary (Walls) $-\mathbf{n} \cdot \left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) = 0$ $\sigma \cdot \mathbf{n} = p_t \mathbf{n}$ Acoustic-Solid Interaction $\nabla \cdot -\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$ $p_t = p + p_b$ $k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2$ $-\rho\omega^2 \mathbf{u} - \nabla \cdot \sigma = \mathbf{F}_V e^{i\phi}$ Linear Elasticity (Body) $-\rho\omega^2 \mathbf{u} - \nabla \cdot \sigma = \mathbf{F}_V e^{i\phi}, \quad \sigma = \mathbf{s}$ $\mathbf{s} - \mathbf{S}_0 = \mathbf{C} : (\epsilon - \epsilon_0 - \epsilon_{inel})$ $\epsilon = \frac{1}{2}\left[(\nabla \mathbf{u})^T + \nabla \mathbf{u}\right]$ Spherical Wave Radiation1 $-\mathbf{n} \cdot \left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) + \left(ik_{eq} + \frac{1}{r}\right)\frac{p2}{\rho_c} - \frac{r\Delta_T p2}{2\rho_c(1 + ik_{eq} r)} = Q_i$
Mesh	Extremely fine / Number of degrees of freedom (DOF): 114864

STUDY

Frequency Domain	Pressure Acoustics D1_[1-100] Hz D2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module

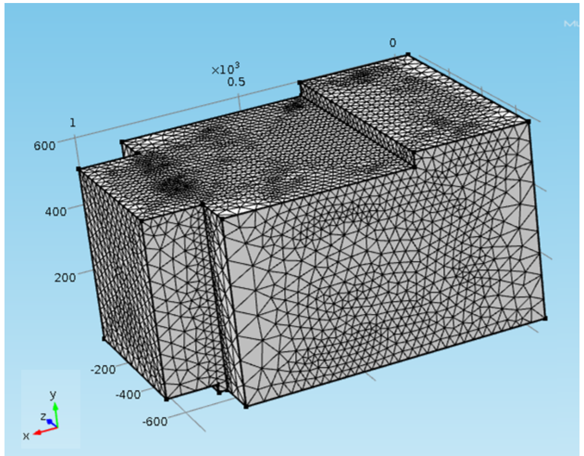
RESULTS

Plot Groups	Acoustic Pressure (acpr) Sound Pressure Level (acpr) Acoustic Pressure-Isosurfaces (acpr) 3D Plot Group 4 –Absolute Pressure-Isosurface 3D Plot Group 5 Local acceleration (spatial) 3D Plot Group 6 – Mesh

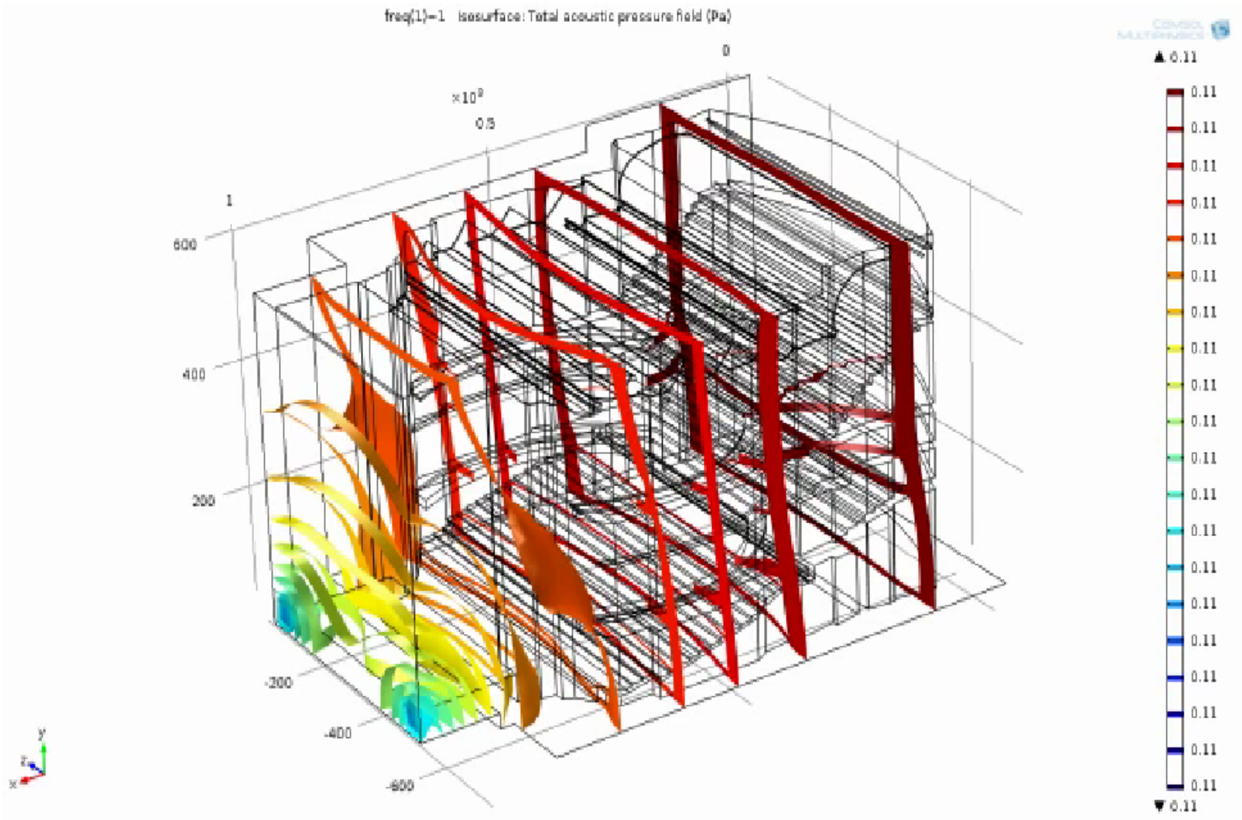


Results of COMSOL Multiphysiscs® use :

2D Plane waves on Concert Hall



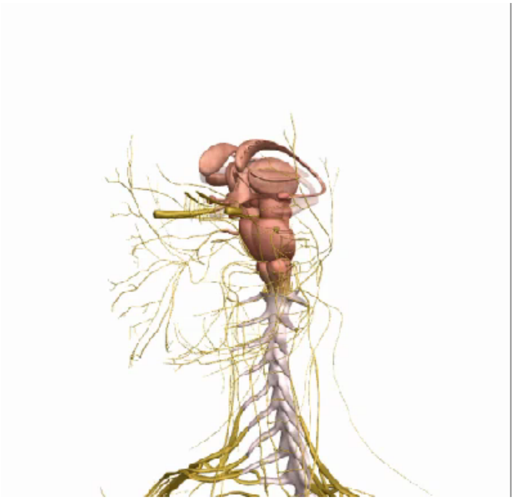
- User controlled mesh
- Number of degrees of freedom solved for
  DOF 848439

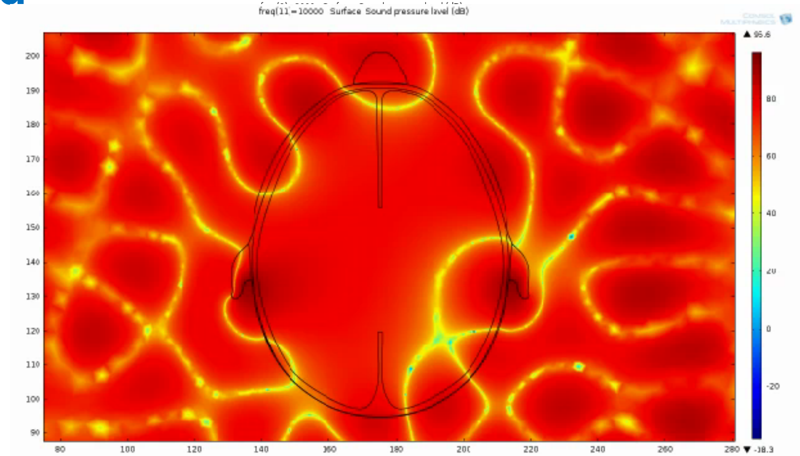


Flow dual point (acoustic sources) Qv= 2e-4 m3/s

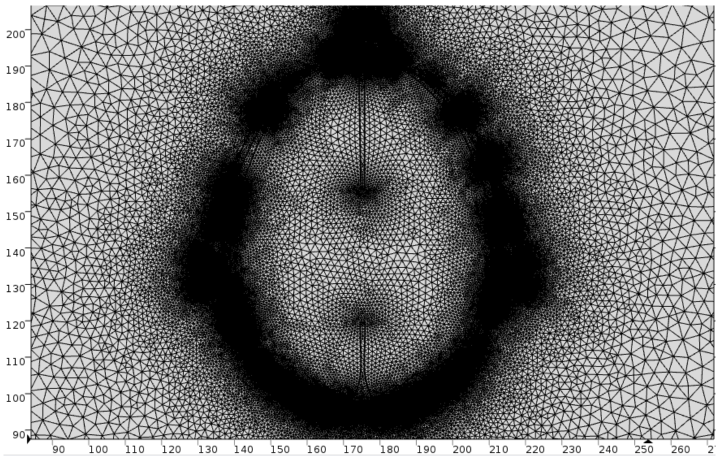
f= [10-16000] Hz

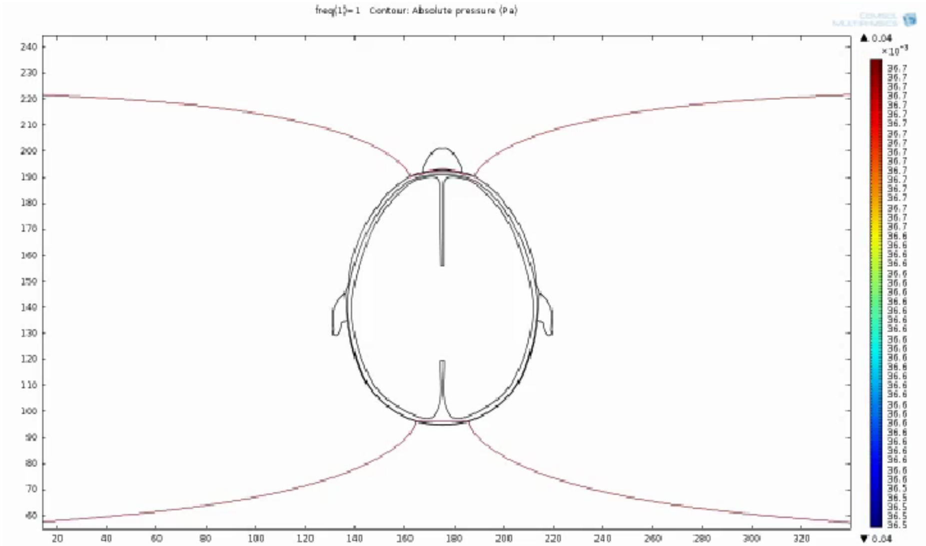
Results of COMSOL Multiphysiscs® use :
2D Frontal Source Plane waves on Head





Surface : Sound Pressure level (dB)



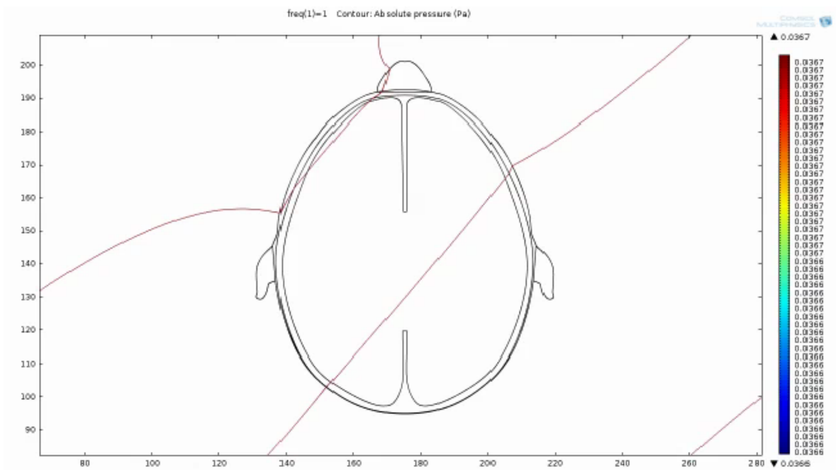


- Physics controlled mesh
- Mesh extremely fine DOF 961765

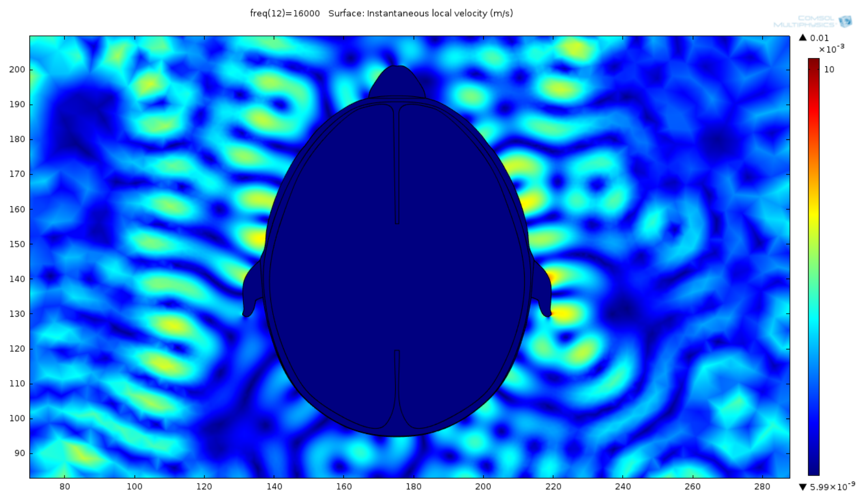
Contour : Absolute Pressure (Pa)

Results of COMSOL Multiphysiscs® use :
2D Up -Left Source **Plane waves on Head**

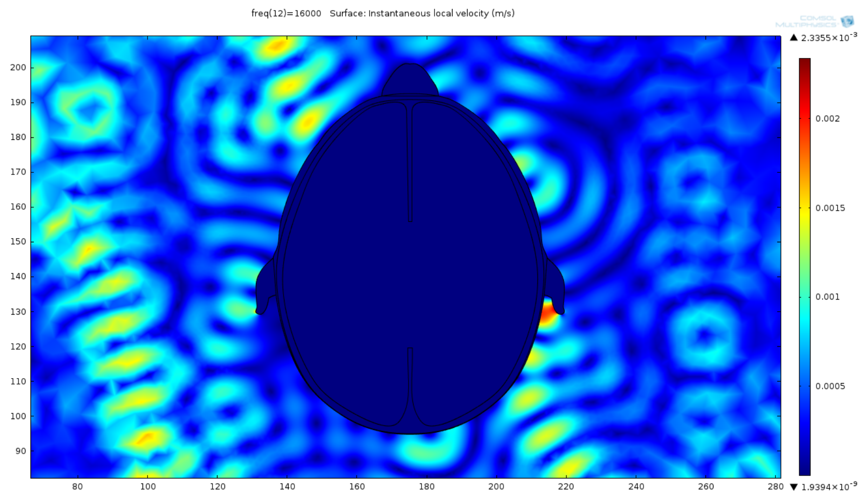
Surface : Sound Pressure level (dB)



Contour : Absolute Pressure (Pa)



Front Source: Instantaneous local Pressure velocity (m/s)



Left Source: Instantaneous local Pressure velocity (m/s)

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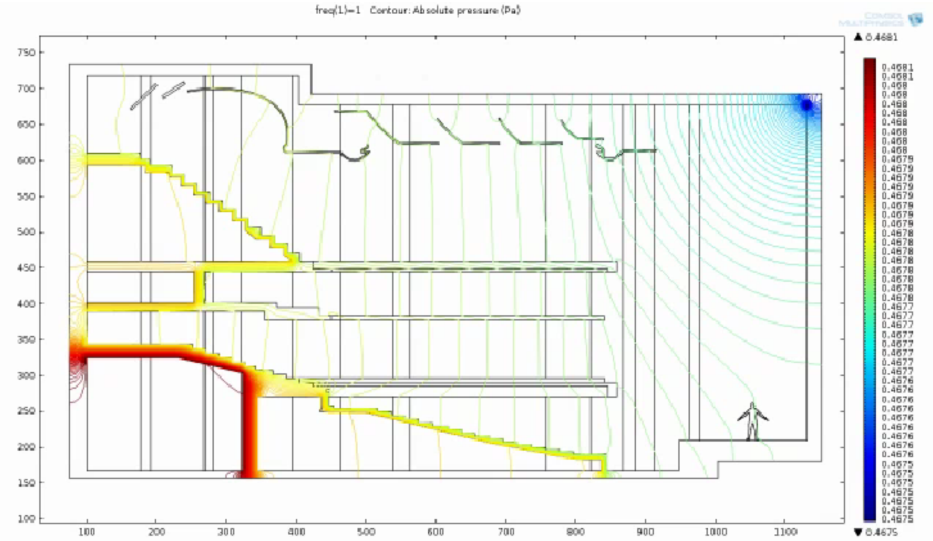
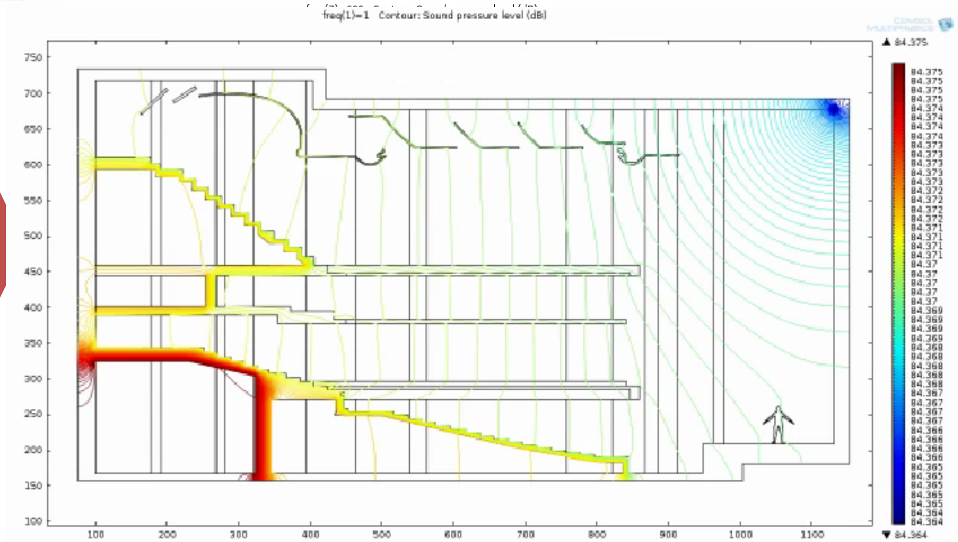
Results of COMSOL Multiphysiscs® use : *2D Up -Left Source* **Plane waves on Opera Hall**

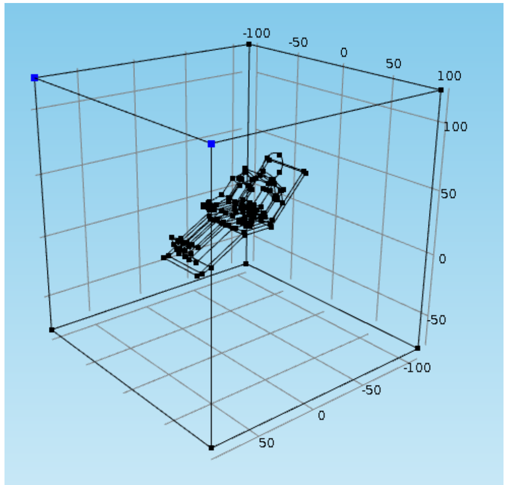


OPERA HALL 2D MODEL + BODY
Module: Pressure ACOUSTICS
Sound Pressure level (dB)
Frequency Domain [1-16000] Hz
Mesh Extremely Fine; DOF 255944

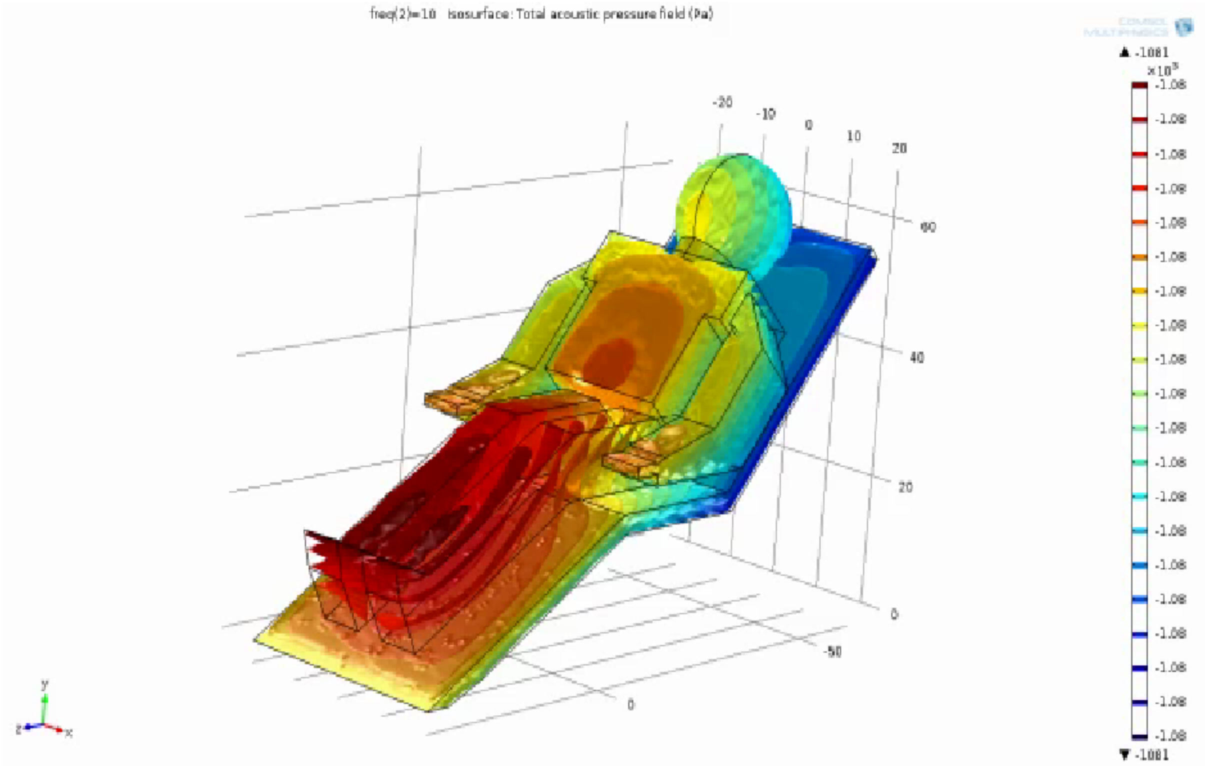
OPERA HALL 2D MODEL + BODY
Module: Pressure ACOUSTICS
Absolute Pressure (Pa)
Frequency Domain [1-16000] Hz
Mesh Extremely Fine; DOF 255944



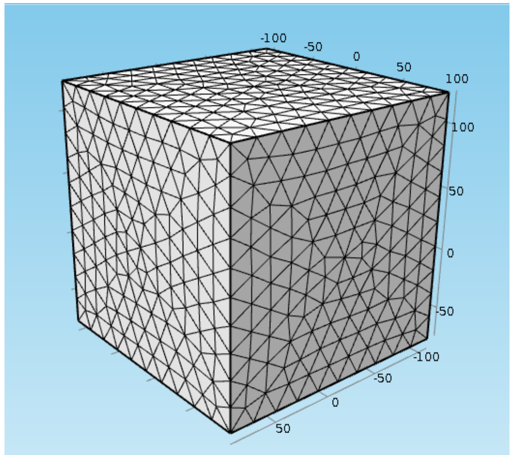
Results of COMSOL Multiphysiscs® use : **Vibration Therapy**



- Spherical waves propagation
- Free space reference power (RMS) : P_{RMS}=2e-6 W

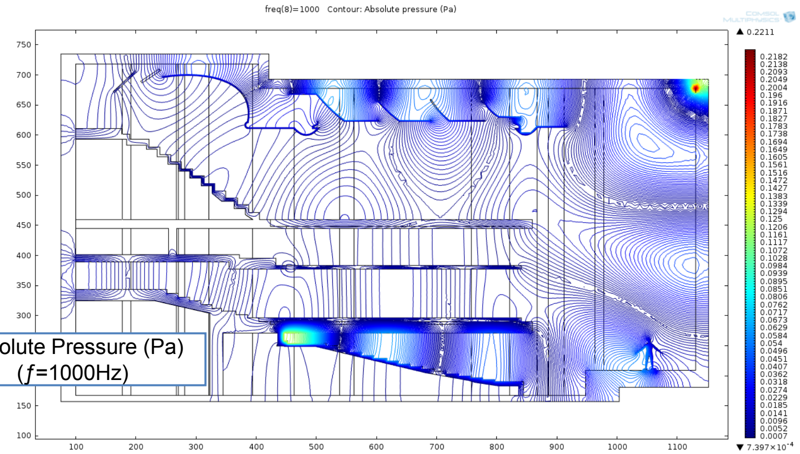


Monopole Point Source (armchair embedded)
f = [1-16000] Hz

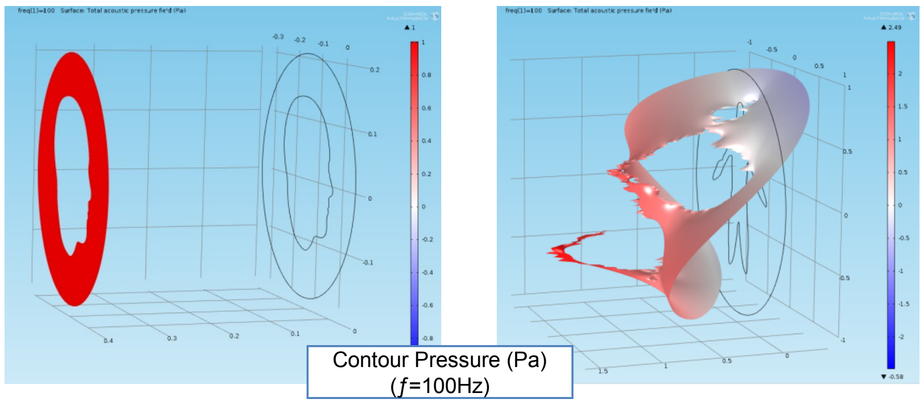


- Physics controlled mesh
- Mesh extremely fine DOF 114864

COMSOL Multiphysics ® :
Support for next integrated therapeutic tools – (Music = Acoustic Therapy)



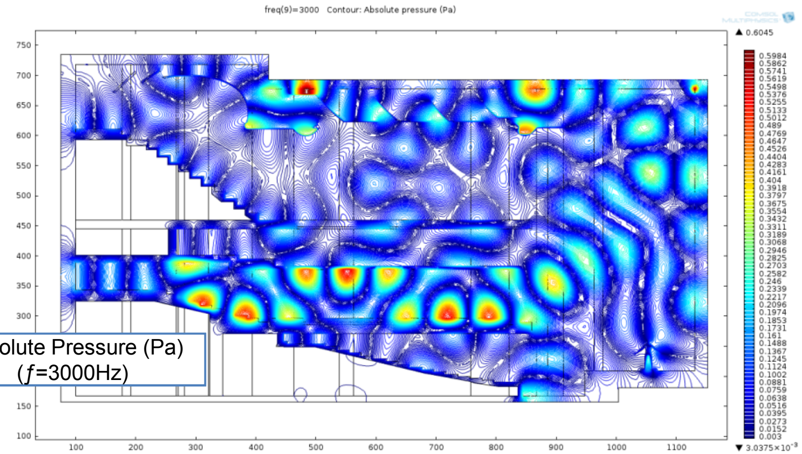
Absolute Pressure (Pa)
(f=1000Hz)



Contour Pressure (Pa)
(f=100Hz)

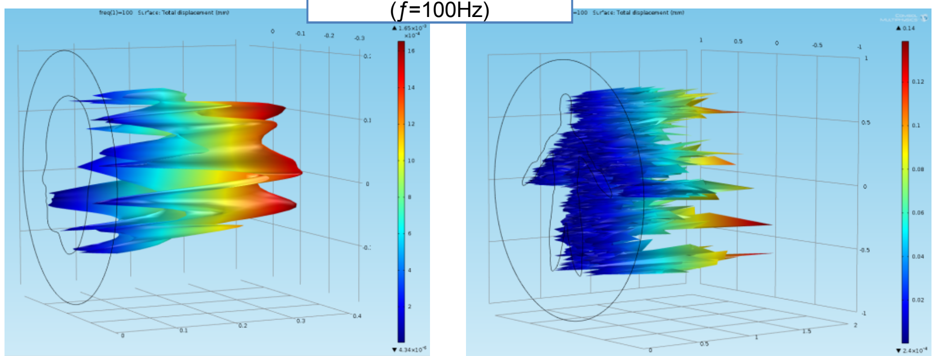
The *best places* from the Opera Hall are effective only up to frequencies below 3 kHz

Orchestra Conductor's body would be acoustically impacted at a higher level than the bodies from the audience, but all those attending the event will be impacted by the dynamic-nonlinear distribution of the acoustic field

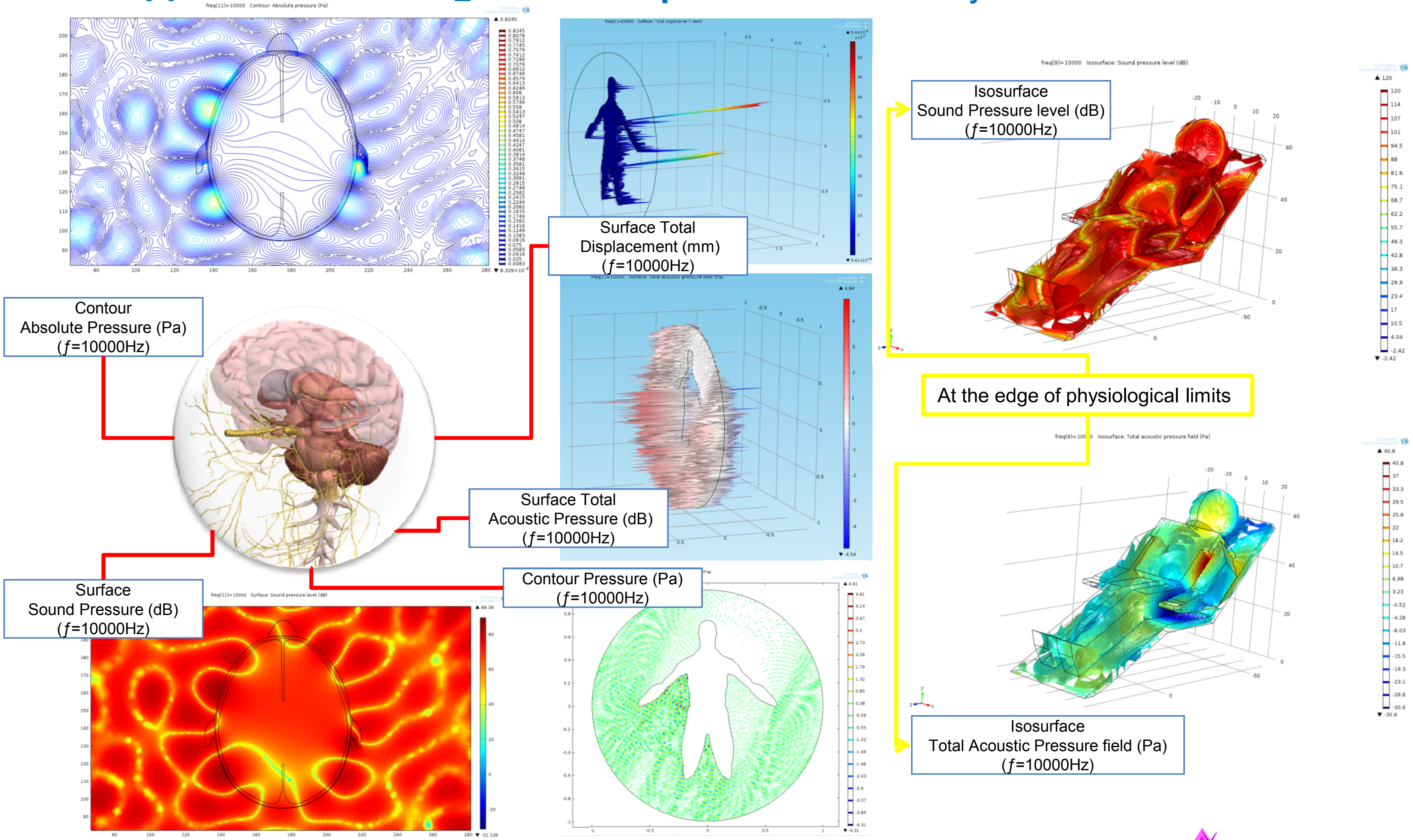


Absolute Pressure (Pa)
(f=3000Hz)

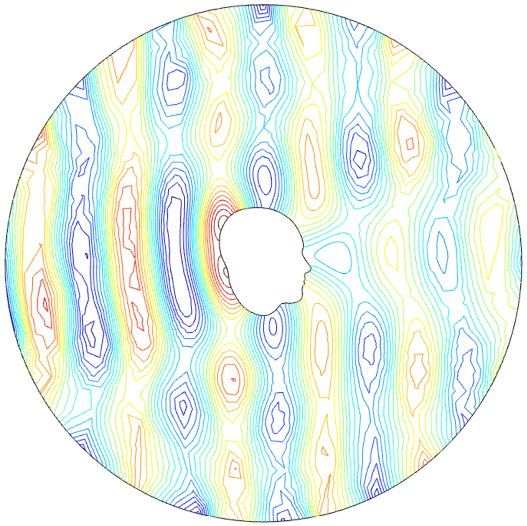
Total Displacement (mm)
(f=100Hz)

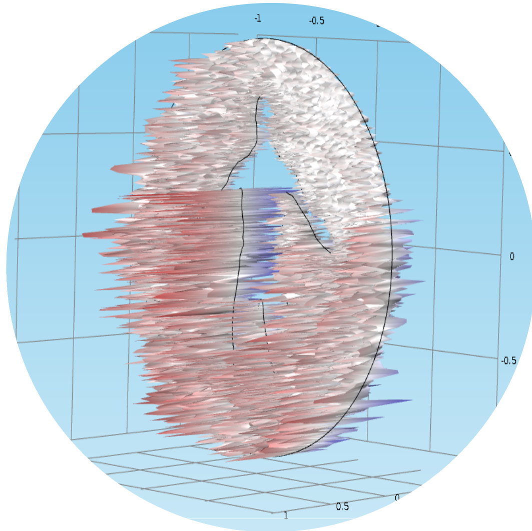


COMSOL Multiphysics ® :
Support for next integrated therapeutic tools -Safety Thresholds



Conclusions : Who should "play" COMSOL each day?





At the edge of physiological limits (6-10kHz) very short exposure time to such stimuli
Limits may be reached during a concert, but should not be the prevalent acoustic signal of the environment

The entire body is exposed to environmental acoustic stimuli!

Neither Music nor Vibration therapy should exceed the [6-10] kHz upper limit band without permanent physiological outcomes

Professional continuous environmental Acoustic Stimuli within or above [6-10] kHz should be carefully monitored and adequately addressed (safety equipment)

Improper use of earphones for musical audition may reach similar results with the professional unsafely acoustic exposure

Thank you!

Q & A