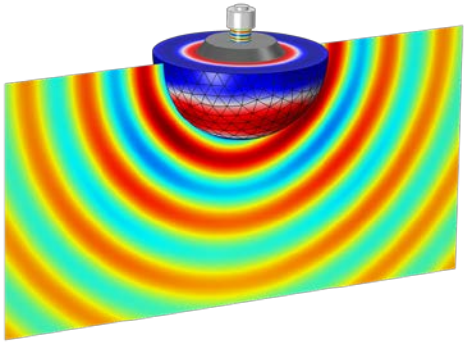
COMSOL Day
Orange County

Thursday
May 17, 2018
8:30AM–4:00PM

Acoustics and Piezoelectricity with COMSOL Multiphysics®



Ping Chu
Los Angeles, COMSOL, Inc.

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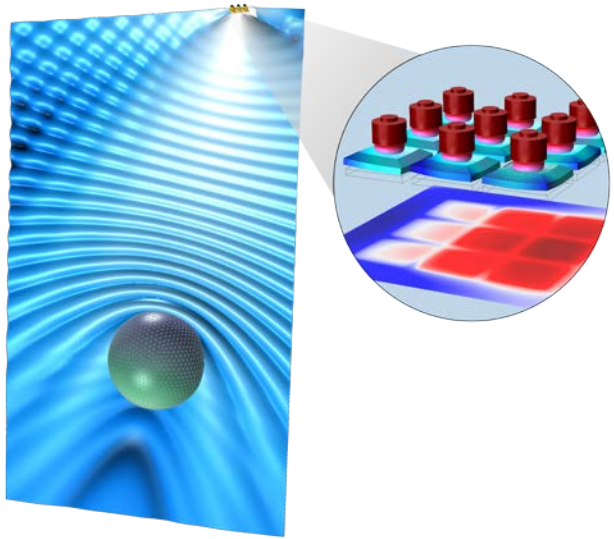
Agenda

- Acoustics Module overview
  - Application Areas
  - Modeling Capabilities
- Piezoelectricity Modeling
- Demo



Tonpilz Transducer Array for SONAR Systems, a hybrid BEM-FEM model.

https://www.comsol.com/release/5.3a/acoustics-module

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Acoustics Module Overview

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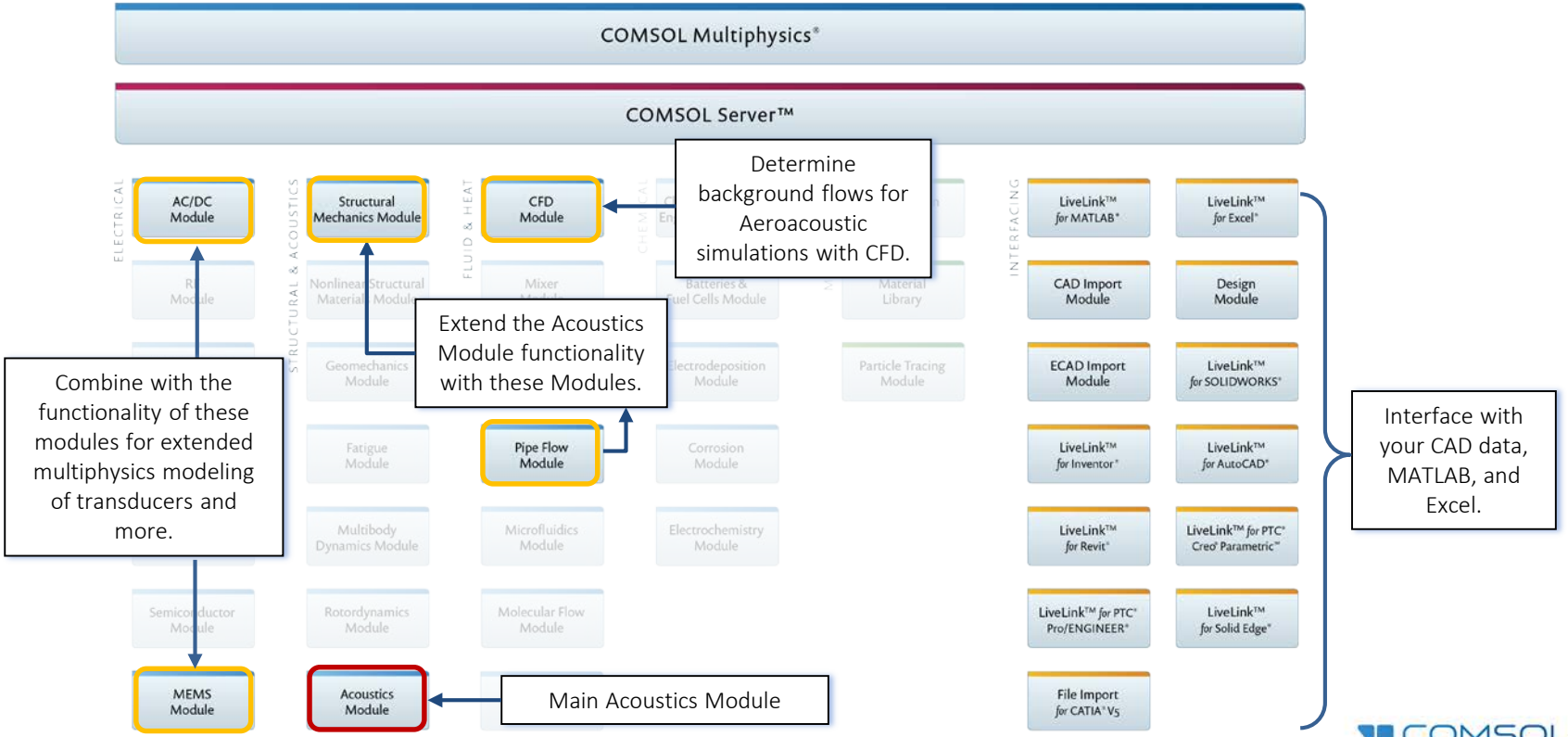
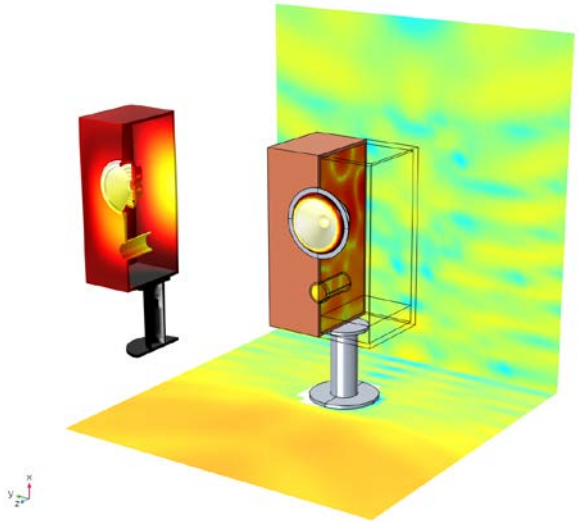
The COMSOL® Product Suite



The Acoustics Module

- Multipurpose acoustics simulations
  - All-in-one
- Multiphysics simulations
  - Vibroacoustics (acoustic-structure)
  - Piezoelectric materials
  - Aeroacoustics (flow borne sound or convected acoustics)
  - Porous materials (Biot's)
  - Electroacoustics (fully coupled or lumped)
- Multimethod
  - Finite elements (FEM)
  - Boundary elements (BEM)
  - Hybrid FEM-BEM modeling
  - Ray tracing
  - Discontinuous Galerkin (dG-FEM) time explicit



Loudspeaker cabinet modeled using a hybrid FEM-BEM approach, including structural vibrations.

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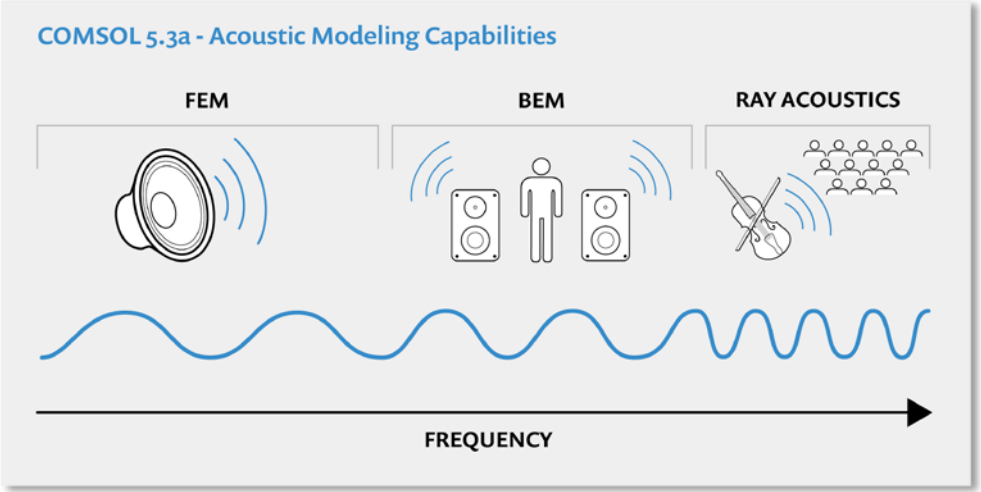
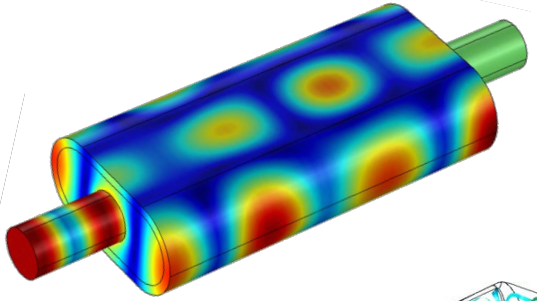
Complete Suite of Tools



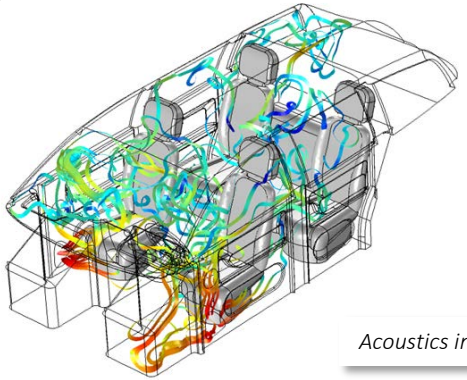
By combining boundary element, finite element, and ray acoustics analysis in a multiphysics environment, COMSOL 5.3a delivers unprecedented acoustic modeling capabilities.

Application Areas of the Acoustics Module

- Automotive industry
- Aerospace
- Civil engineering and architecture
- Room acoustics
- Transducer design
- Mobile and smart phones
- Headsets
- Flow meter applications
- Underwater acoustics
- Hearing aids
- Bioacoustic applications with ultrasound
- Musical instruments
- Advanced applications



Pressure distribution in a muffler system.



Acoustics inside a sedan.

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ACOUSTICS
MODELING CAPABILITIES

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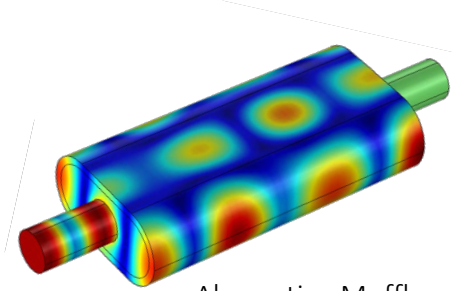
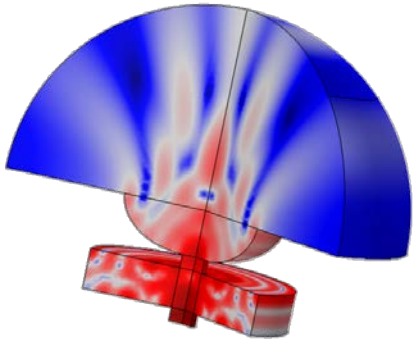
Pressure Acoustics

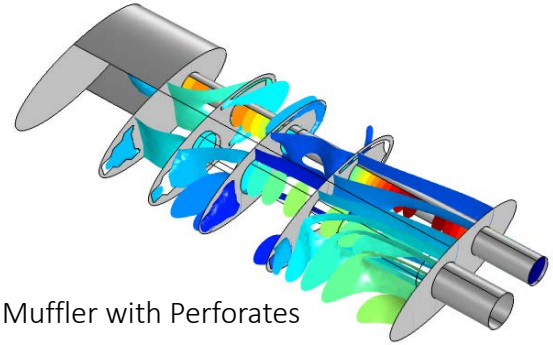
- Helmholtz equation
- Scalar wave equation
- FEM, BEM, dG-FEM



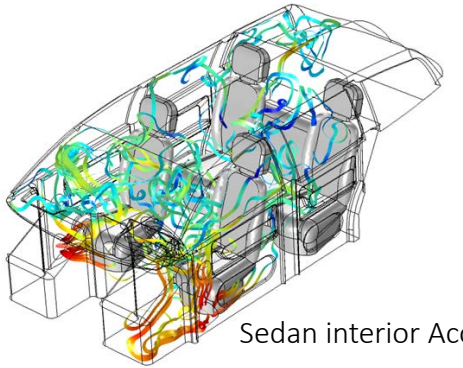
Absorptive Muffler



Shape Optimization of
a Tweeter Waveguide



Muffler with Perforates



Sedan interior Acoustics

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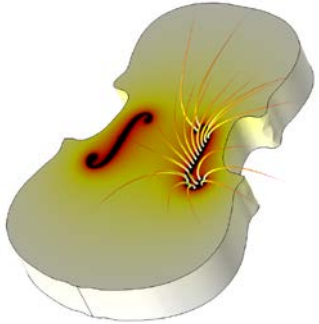
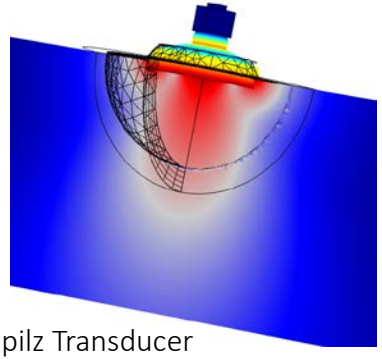
Acoustic-Structure Interaction

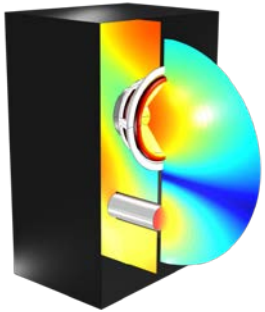
- Acoustic-solid interaction
- Acoustic-shell
- Poroelastic waves (Biot/Allard)
- Piezoelectric materials



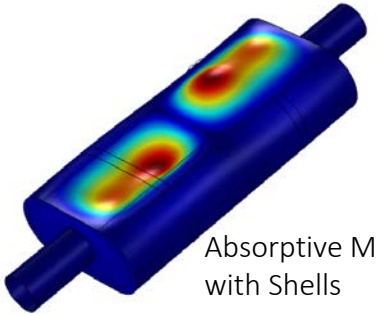
Violin design



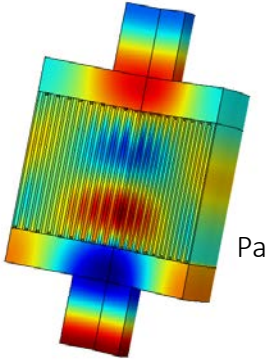
Tonpilz Transducer



Loud speaker in a vented enclosure



Absorptive Muffler with Shells



Particulate filter

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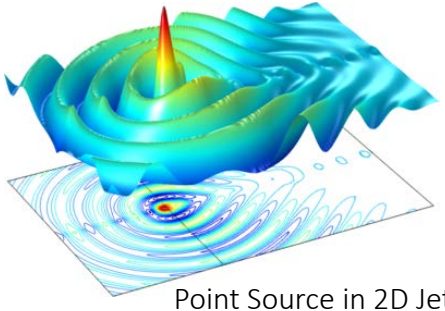
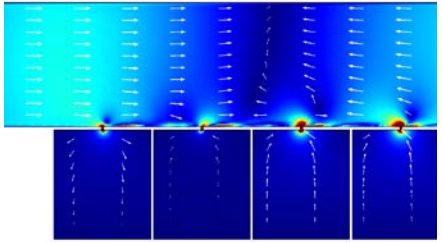
Aeroacoustics

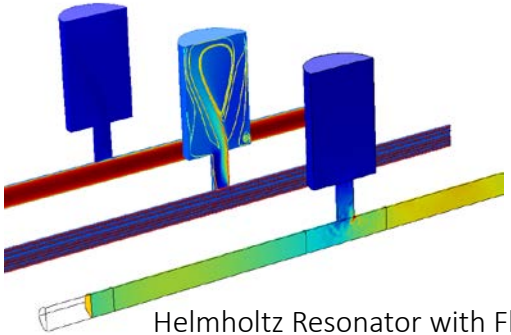
- Linearized Navier-Stokes
- Linearized Euler
- Linearized potential flow
- FSI in the frequency domain



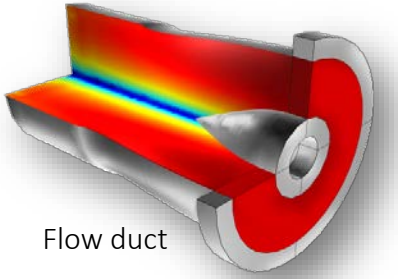
Point Source in 2D Jet



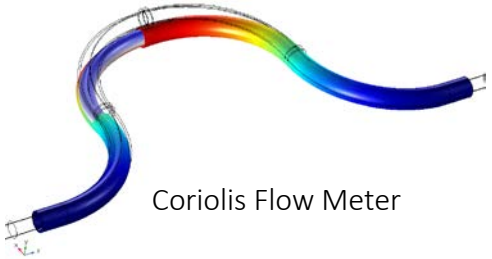
Acoustic Liner with a Grazing Background Flow



Helmholtz Resonator with Flow: Interaction of Flow and Acoustics



Flow duct



Coriolis Flow Meter

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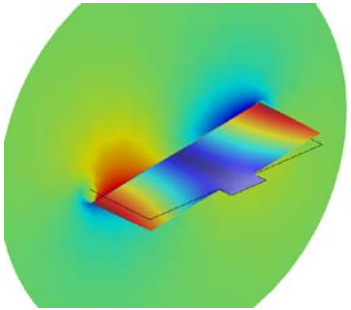
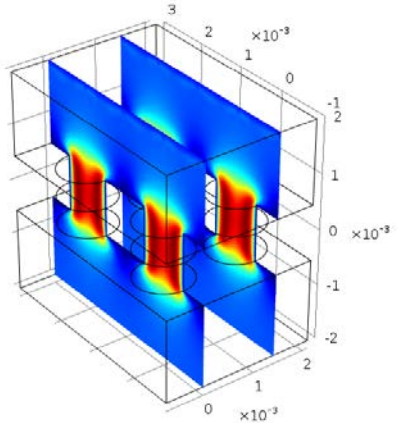
Thermoviscous Acoustics

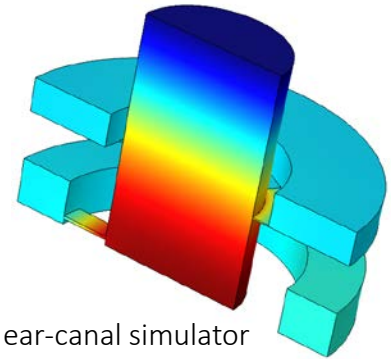
- Acoustics in small devices
- Miniature transducers
- Thermal and viscous losses
- Boundary layer losses



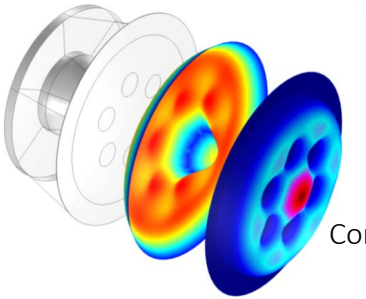
Vibrating Micromirror



Transfer Impedance of a Perforate



Occluded ear-canal simulator



Condenser microphone

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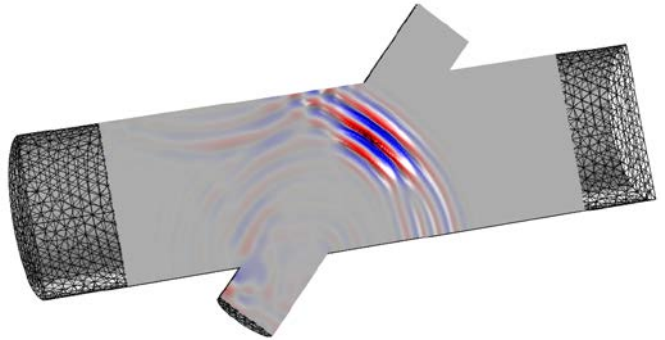
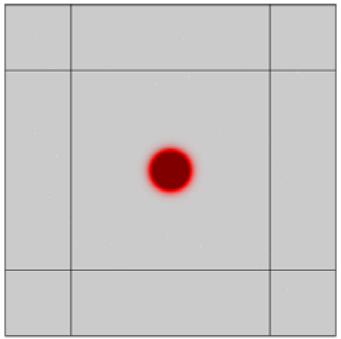
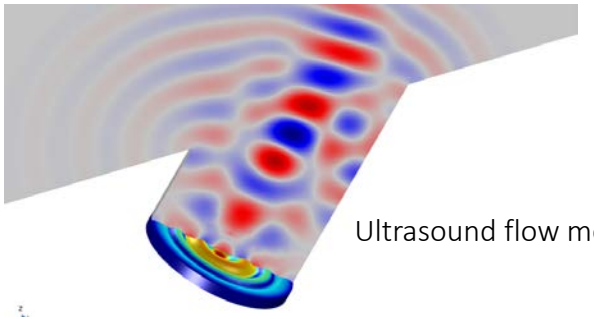
Ultrasound

- Linear ultrasound models
- With/without background flow
- Discontinuous Galerkin (dG-FEM)
- Acoustically large models





Gaussian pulse in 2D uniform flow



Ultrasound flow meter analysis

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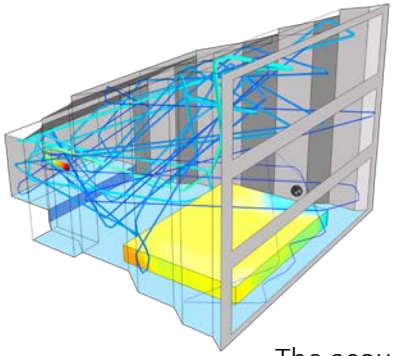
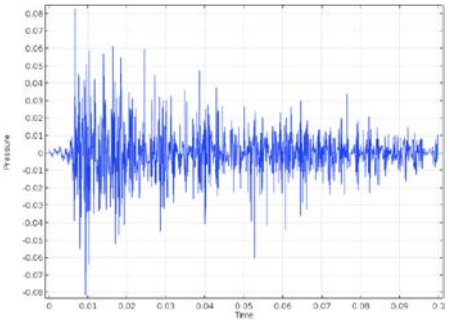
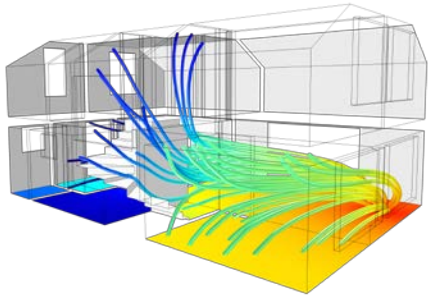
Geometrical Acoustics

- Acoustic diffusion equation
- Ray acoustics
- Room acoustics
- Underwater acoustics

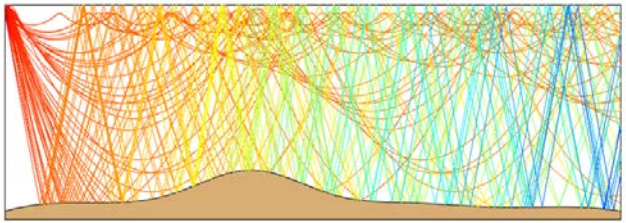




The acoustics of a small concert hall



One-Family House Acoustics



Underwater Ray Tracing

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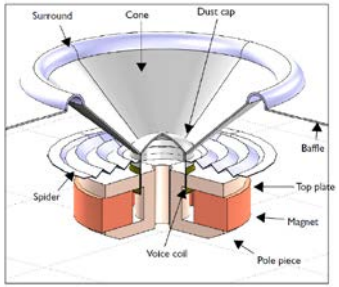
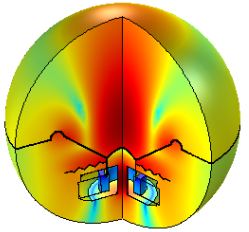
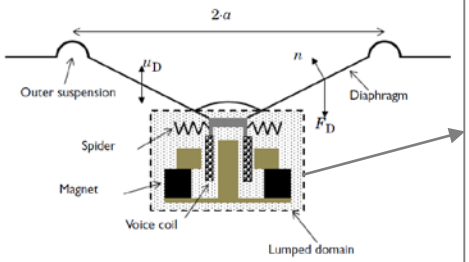
Electroacoustics

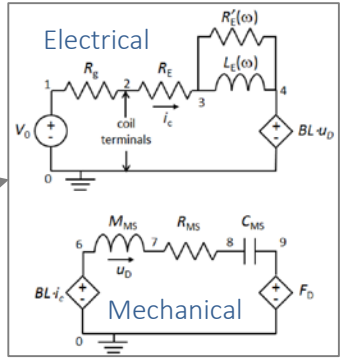
- Combine the AC/DC Module with the Acoustics Module
  - Electric and magnetic fields
  - Circuits (SPICE import)
  - Fully two-way coupled
- Create a lumped equivalent circuit that represents any part of your model and couple to an FEM model
  - Electrical
  - Mechanical
  - Acoustical
- Mechanical networks/circuits with the Multibody Dynamics Module



Sound Pressure Level







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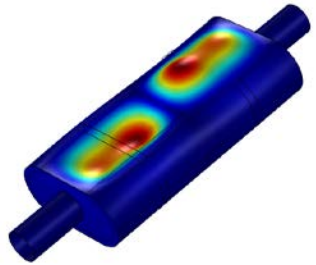
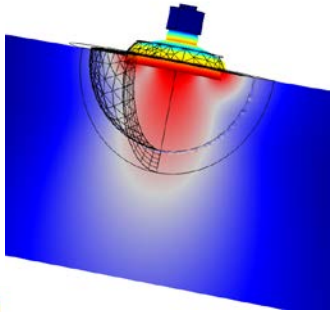
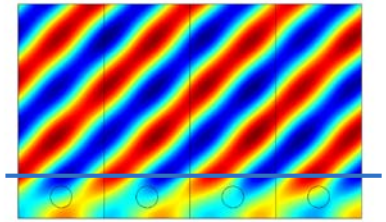
Acoustics and Vibrations

- Not only speakers and electroacoustics
- All structural vibrations
  - Solids, shell, membranes, beams
- Piezo materials
- Porous material
- Built in pre-defined couplings







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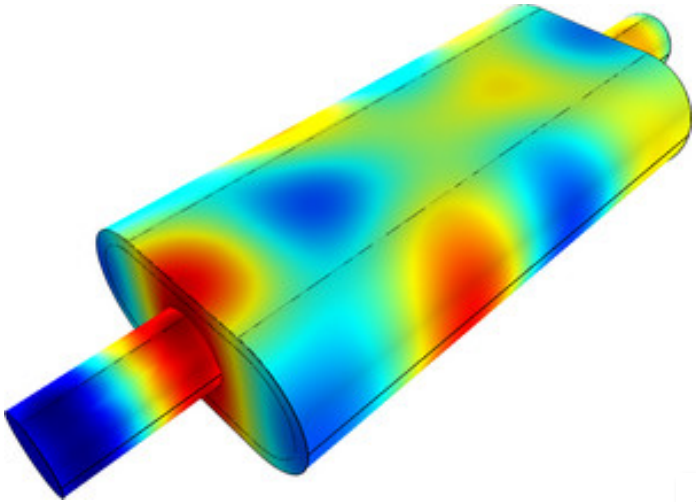
Demo: Absorptive Muffler



Absorptive Muffler: Includes an absorptive porous lining material on the inside of the muffler.

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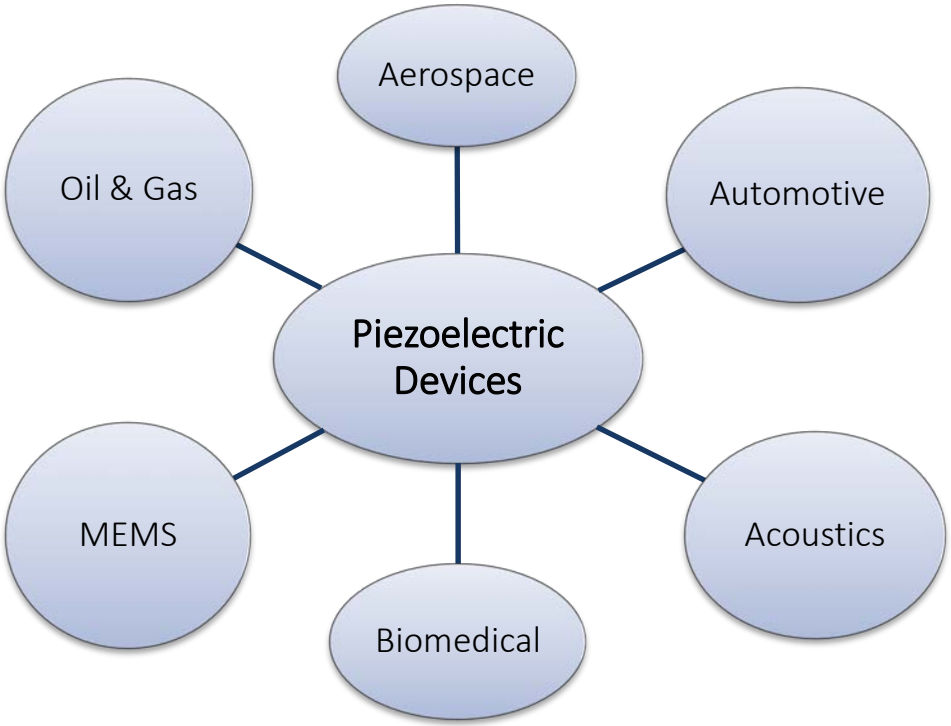
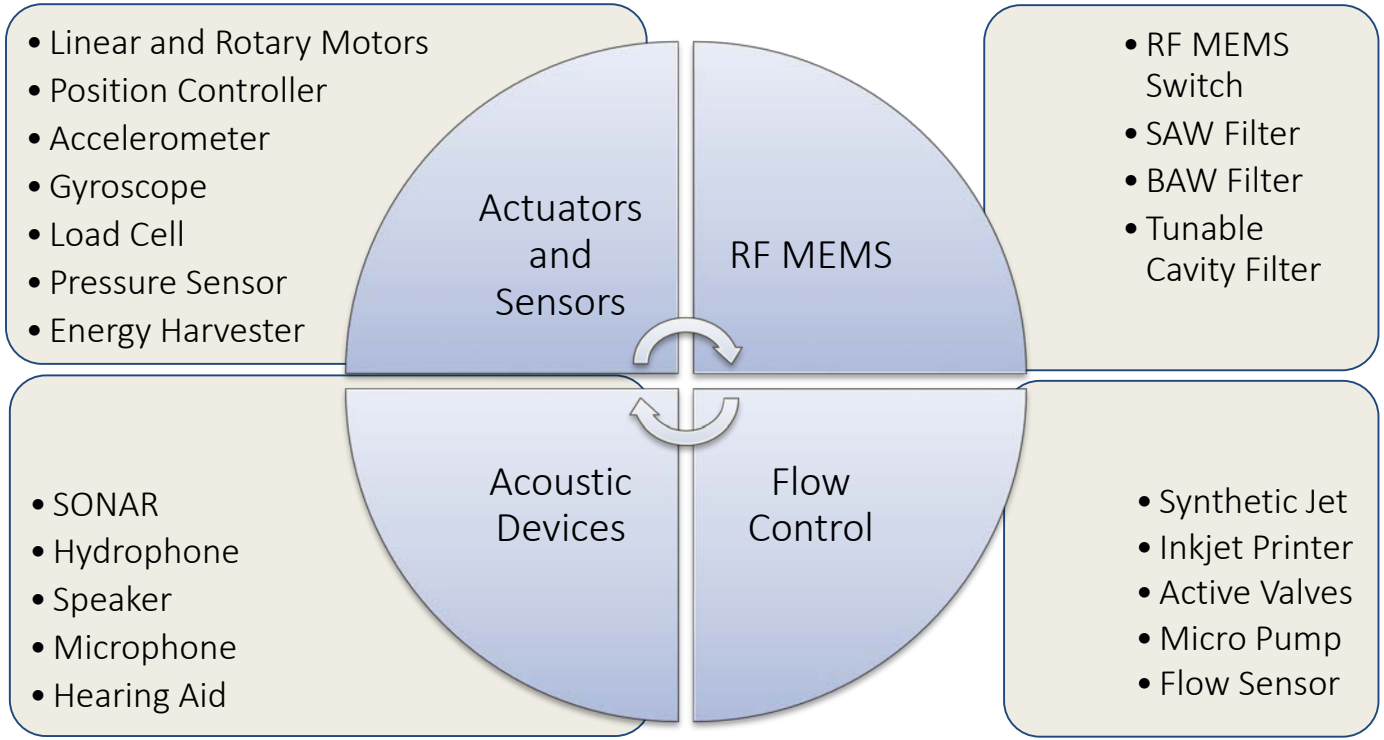
Piezoelectricity Modeling

Industries Using Piezoelectric Devices



Piezoelectric Devices



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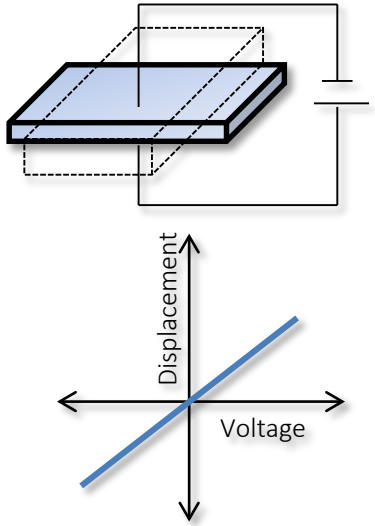
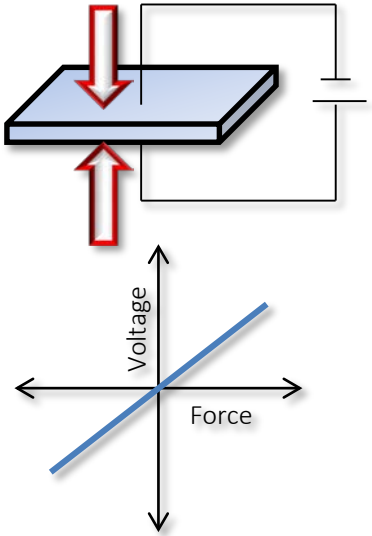
Piezoelectric Effect

Inverse effect



Direct effect



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Coupled Constitutive Equations

Stress-Charge Form

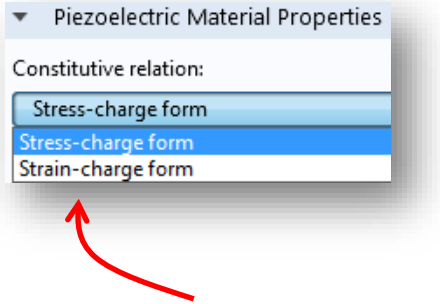
$$T = c_E S - e^T E$$

$$D = eS + \varepsilon_S E$$

Strain-Charge Form

$$S = s_E T + d^T E$$

$$D = dT + \varepsilon_T E$$



T = stress; S = strain

E = electric field

D = electric displacement

c_E = elasticity matrix (rank 4 tensor c_{ijkl})

e = coupling matrix (rank 3 tensor e_{ijk})

ε_S = permittivity matrix (rank 2 tensor ε_{ij})

$$c_E = s_E^{-1}$$

$$e = ds_E^{-1}$$

$$\varepsilon_S = \varepsilon_T - ds_E^{-1} d^T$$

In COMSOL, you can choose any one of these equation forms based on the material data you have

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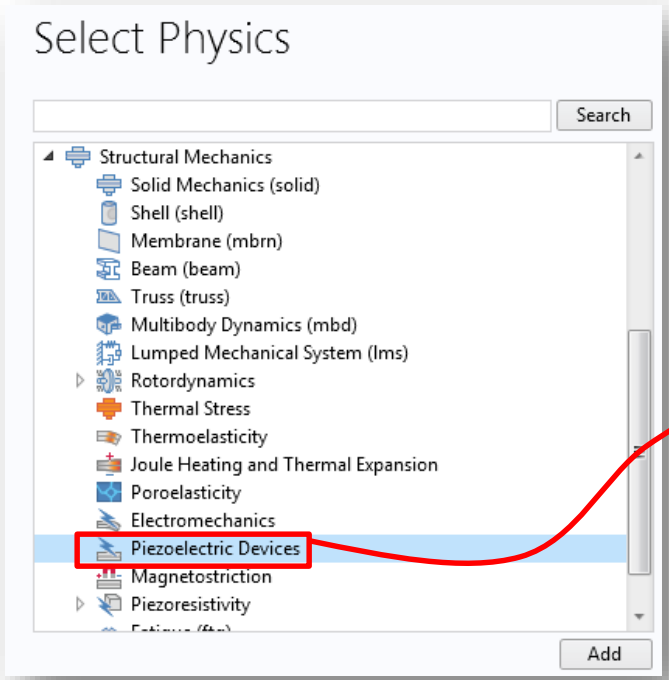
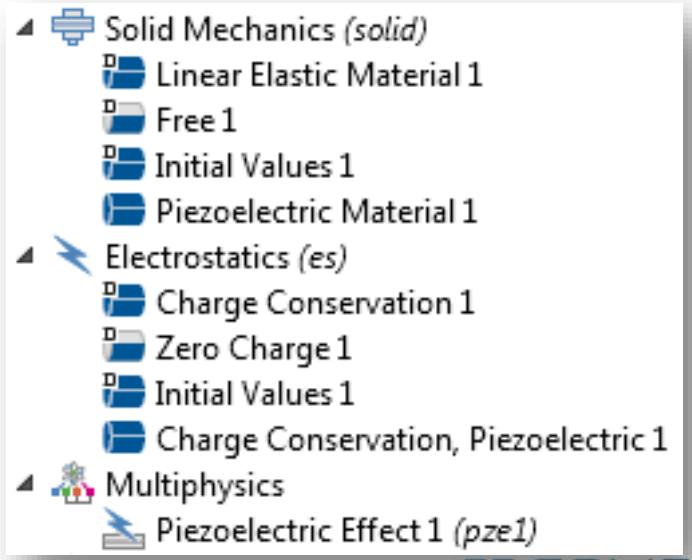
Physics Interfaces





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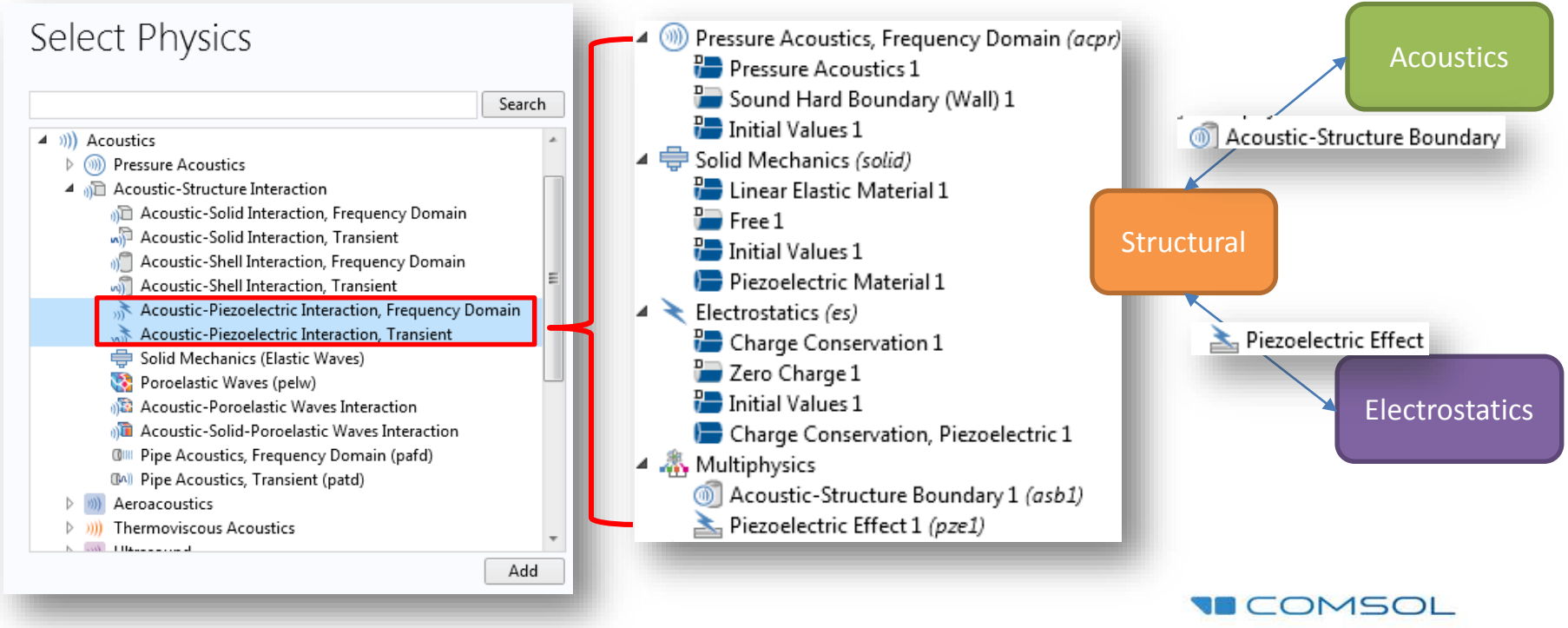
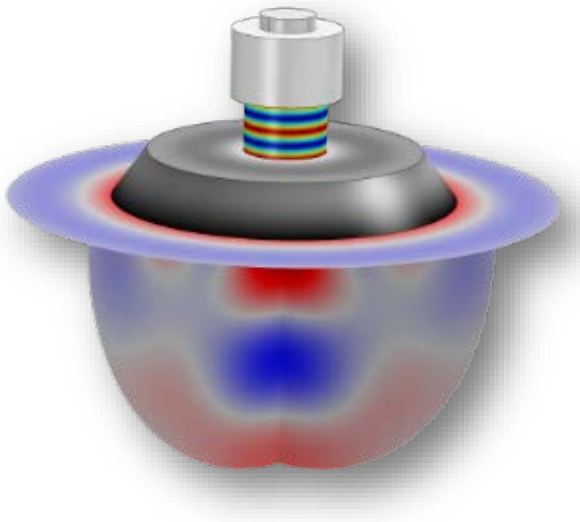
Physics Interfaces



Demo: Piezoelectric Tonpilz Transducer

A tonpilz transducer is used for relatively low frequency, high power sound emission. It is one of the popular transducer configuration for SONAR applications. The transducer consists of piezoceramic rings stacked between a head mass and a tail mass which are connected by a central bolt. In this model the frequency response of the transducer is studied to determine structural and acoustic response of the device such as deformation, stresses, radiated pressure, sound pressure level, far-field beam pattern, the transmitting voltage response (TVR) curve, and the directivity index (DI) of the sound beam.



http://www.comsol.com/model/tonpilz-piezo-transducer-11478

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COMSOL Day
Orange County

Thursday
May 17, 2018
8:30AM–4:00PM

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