COMSOL CONFERENCE 2018 LAUSANNE

T4G ENGINEERING

Prediction of Thermoacoustic Instabilities in Combustion Systems - Application to a Simplified Model of a Domestic Boiler

D. Tonon, Lausanne, 23/10/2018

Company Profile

- **T4G Engineering GmbH** has been founded in 2017 in Luzern, Switzerland
- T4G Engineering provides reliable and cost-effective **solutions** and **services** in:
  - Clean, Smart and Sustainable Energy and Power
  - Advanced Combustion Systems and Combustion Dynamics
  - Aeroacoustics
  - Technical Acoustics
  - Development of simulation and calculation software and tools
  - Training
- In particular, the team of T4G Engineering has cutting-edge skills and experience in **Aeroacoustic and Themoacoustic Coupling in Energy Processes**
- T4G Engineering helps you **solving your challenges**

Combustion Systems Development

Low pollutants emissions can be achieved with **lean-premixed combustion**, but there are **intrinsic problems** with a lean combustion zone

- Difficulties in **igniting the flame**
- High promptness to **unstable combustion** (i.e. combustion dynamics) process leading to high amplitude pressure oscillations (i.e. acoustic pulsations)
- Combustion dynamics is due to **aero-acoustic and thermo-acoustic coupling** processes
  - Aero-acoustic coupling between **flow instabilities** and acoustic pressure waves in the combustion system
  - Thermo-acoustic coupling between **heat release fluctuations** and acoustic pressure waves in the combustion system

Effect of combustor acoustic pulsations

Pressure oscillations → Structural vibrations → Pulsation Induced Damages

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Combustion Systems Development

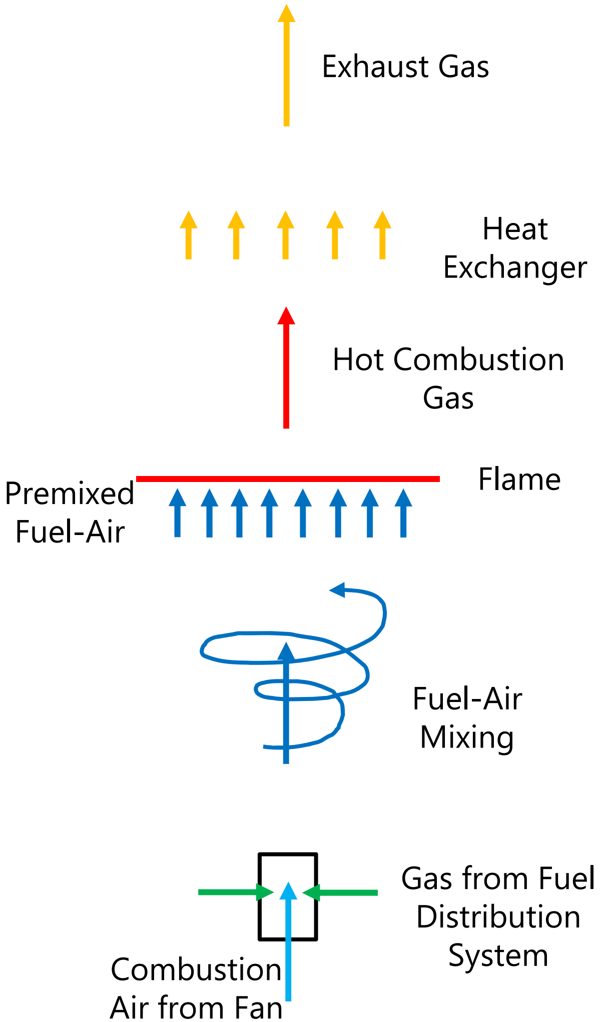
Solution to the problem of Combustion Dynamics

- Approach:
  - **Develop prediction tools of combustion dynamics** to aid the design of combustion systems
  - Use of **numerical and experimental tools** to find concepts to avoid high dynamics
  - **Monitor the combustion behavior** to precisely characterize the combustion dynamics of a combustion system
- Solution:
  - **Design optimization**: fuel streams/stages design, fuel line design, aeroacoustic design, thermoacoustic design
  - **Passive acoustic damping** solutions as integral part of the combustion system
  - **Active control** of pulsations/vibrations

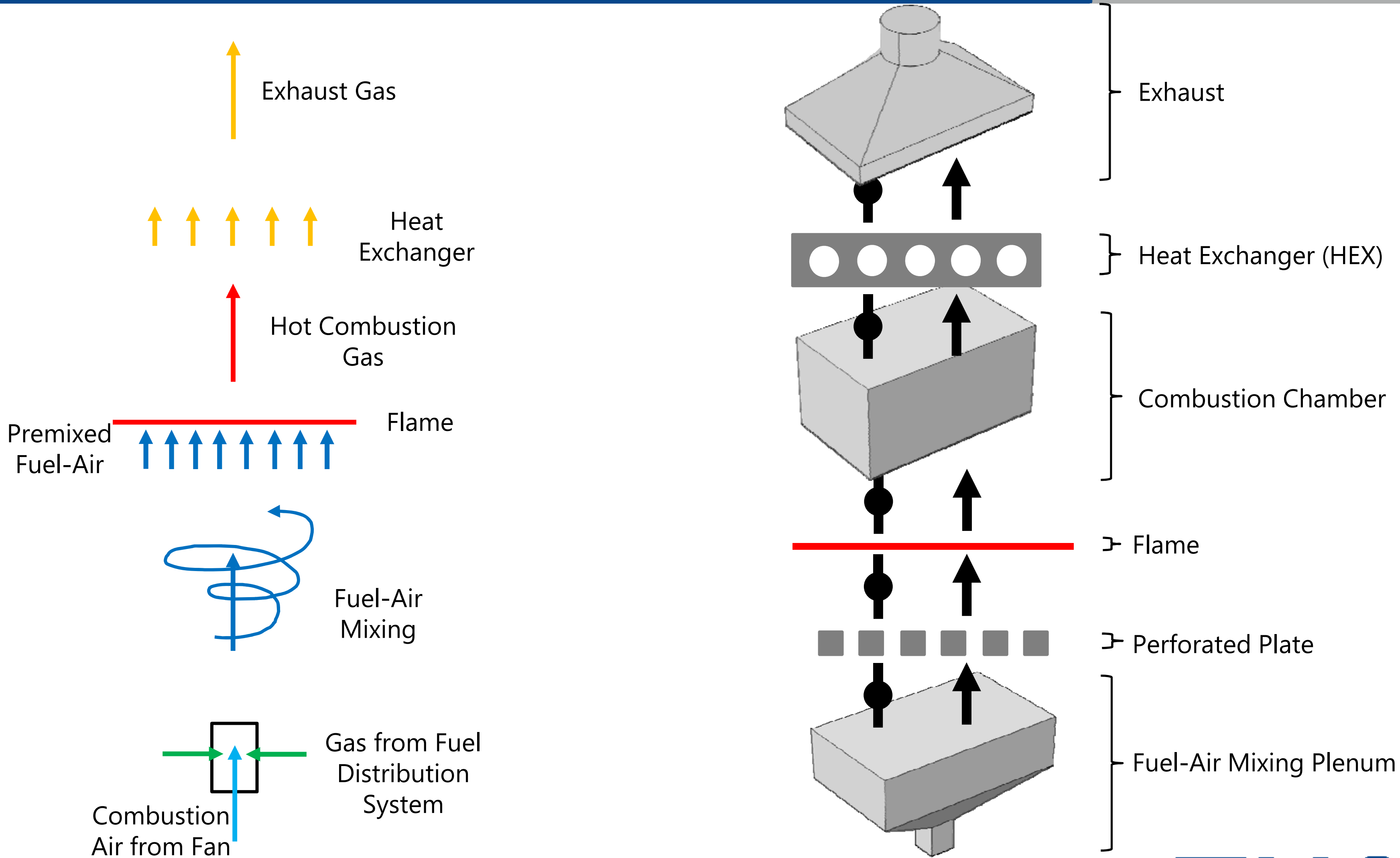
Solution to the problem

Combustion Dynamics Modelling; Design optimization; Passive damping solutions; Active control of pulsations

Domestic Boiler Example

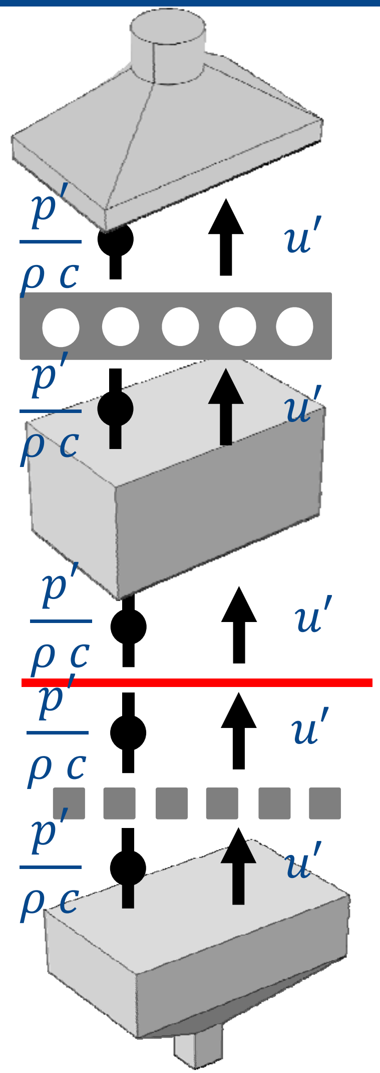


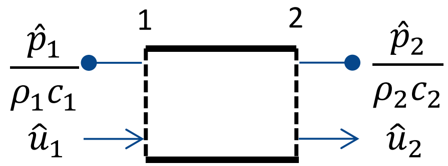
Domestic Boiler Example



Acoustic Network Model

- Network elements connected by ports
- Acoustic compactness of flame and heat exchanger
  - Flame thickens much smaller than wavelength ($\delta_{flame} \ll \lambda$)
  - Heat exchanger tubes diameter much smaller than wavelength ($D_{hex} \ll \lambda$)
- Plane waves at the network ports
- Acoustic wave propagation in network elements:
  - **Analytical models:** Perforated Plate, Flame and Heat Exchanger
  - **FEM model (COMSOL):** Fuel-Air Mixing Plenum, Combustion Chamber, Exhaust





Transfer Matrix

$$\begin{bmatrix} \frac{p'}{\rho c} \\ u' \end{bmatrix}_2 = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} \frac{p'}{\rho c} \\ u' \end{bmatrix}_1$$

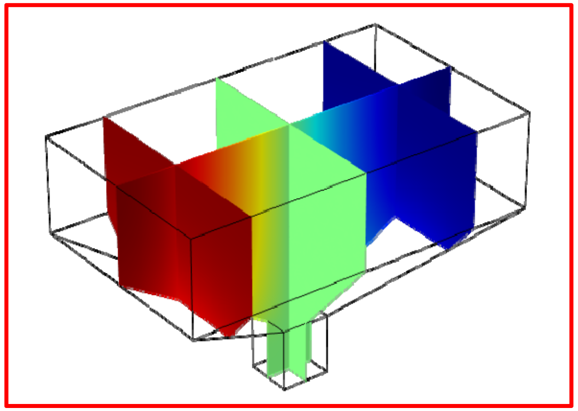
Analytical and/or FEM

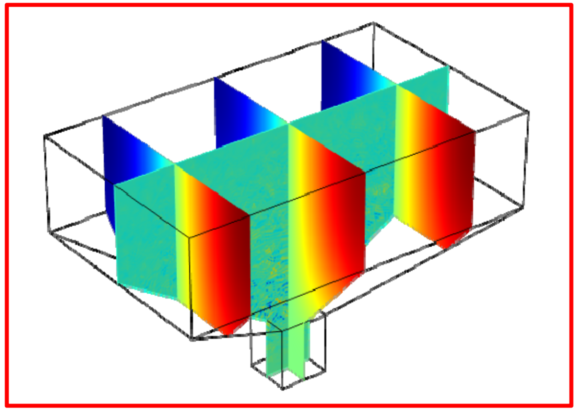
FEM Calculated Network Element Transfer Matrix

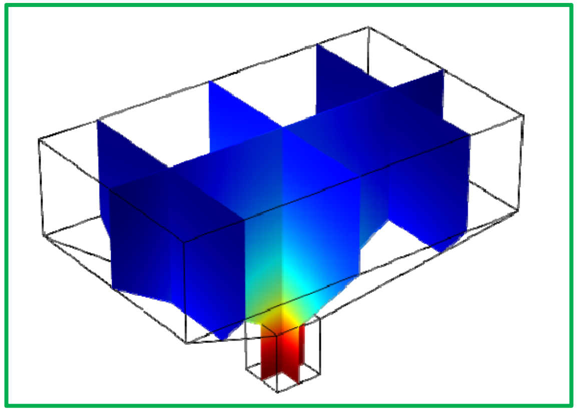
- Numerical evaluation of **acoustic transfer matrix** of network elements with **COMSOL Multiphysics**
  - *Pressure Acoustics, Frequency Domain (acpr)* physics interface with *Frequency Domain* study
  - *Pressure Acoustics, Frequency Domain (acpr)* physics interface with *Eigenfrequency* study
- Workflow to evaluate network elements transfer matrices with COMSOL Multiphysics:
  - Import geometry (CAD Import Module) in COMSOL Multiphysics
  - Divide the geometry in domains (partition objects) and save each domain (.stl binary)
  - Calculate the eigenfrequencies for each domain
  - Export mode shape at domain boundaries (corresponding to network ports) for each eigenfrequency; normalization factor of the modes; speed of sound and density in the domain
    - Take into account only modes with plane waves at the network ports
- Import COMSOL simulation results in **T4G's Acoustic Network Model**

Selection of modes with plane waves at the network ports

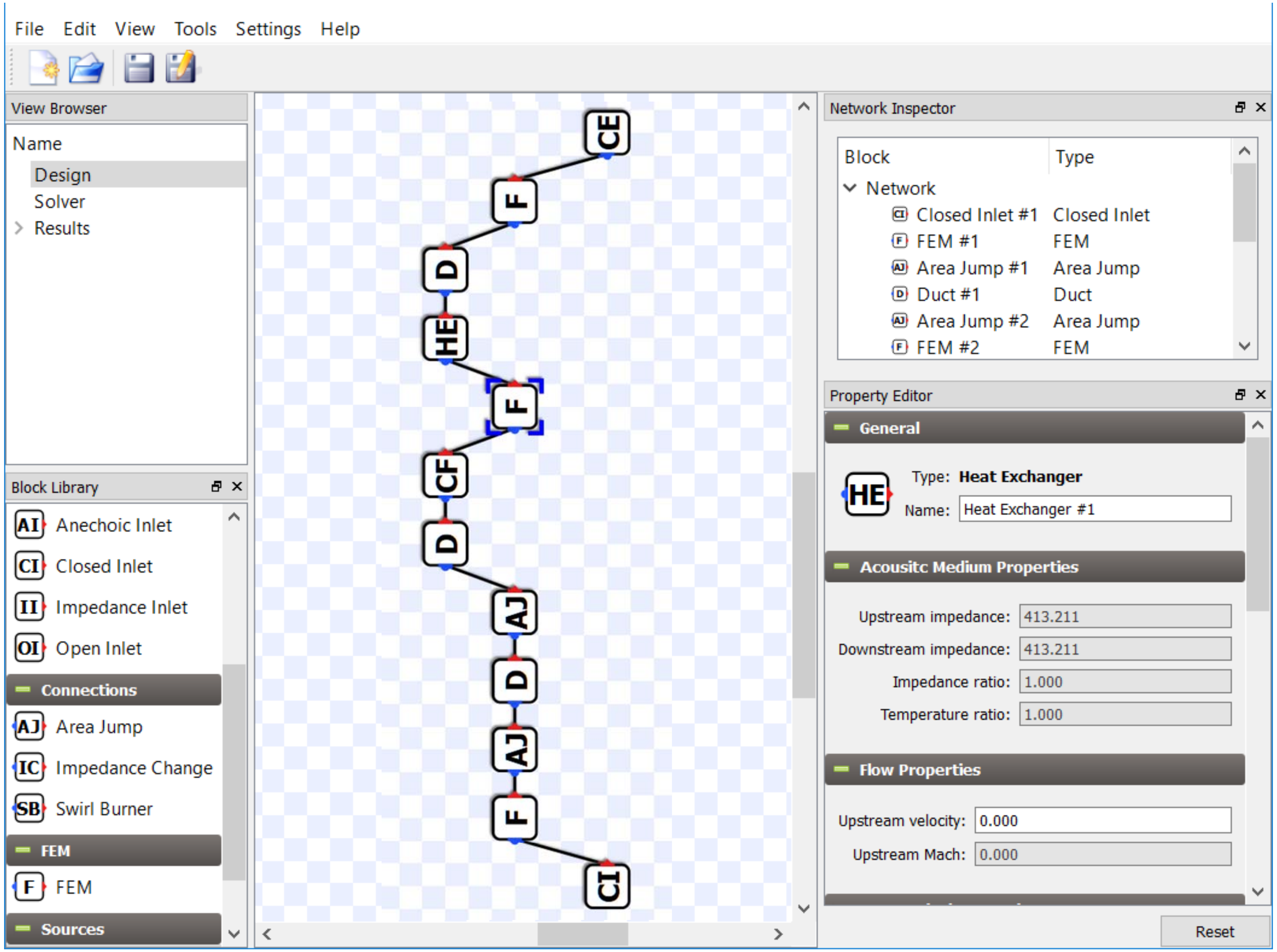
- Only modes corresponding to plane waves at the network ports should be taken into account
  - Manual selection by visual inspection
  - Automated selection in COMSOL by means of *Volume Integration*, *Volume Average*, *Surface Average*, *Surface Minimum* and *Surface Maximum* of acoustic pressure



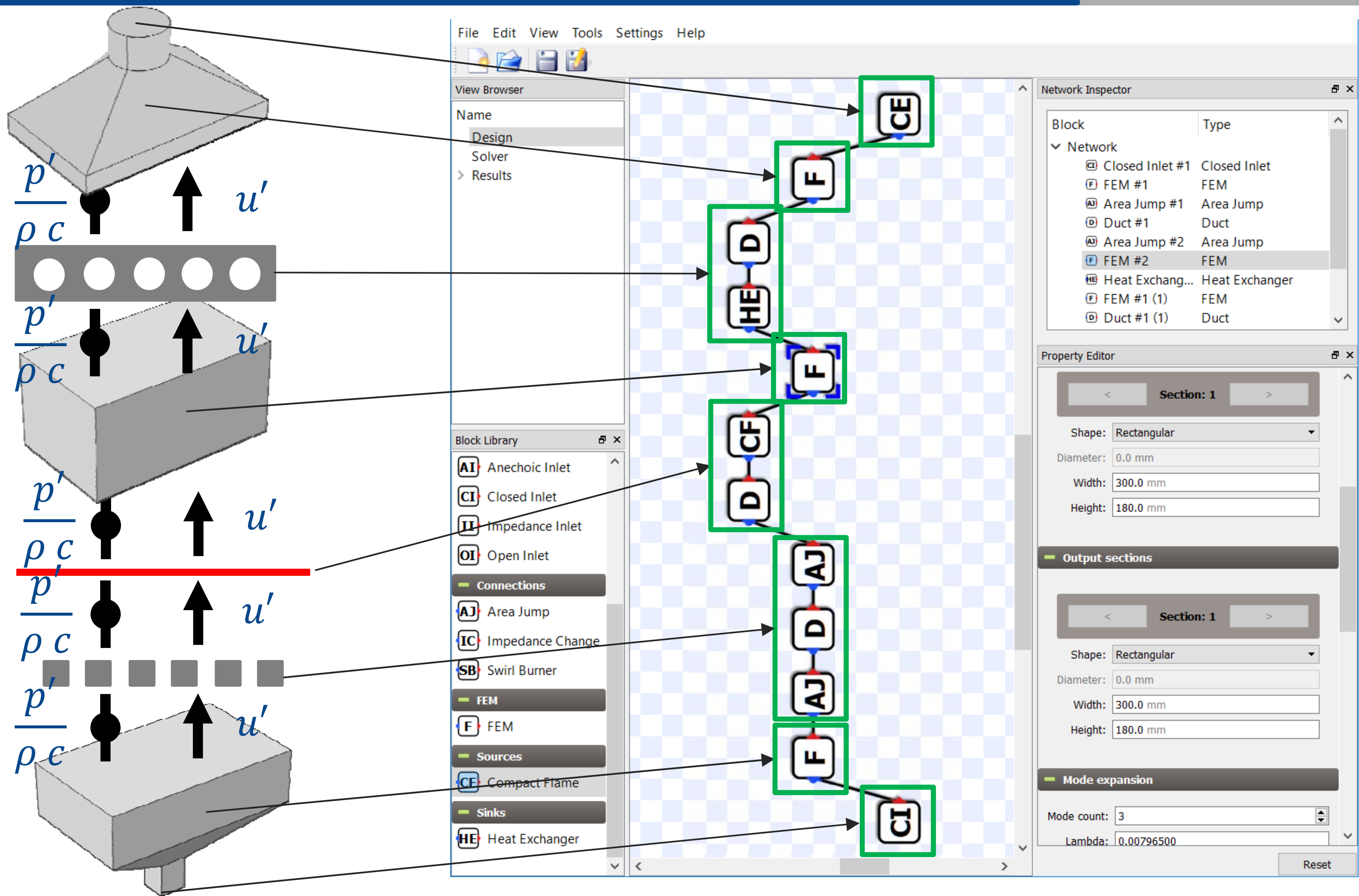




T4G’s Acoustic Network Model



T4G's Acoustic Network Model



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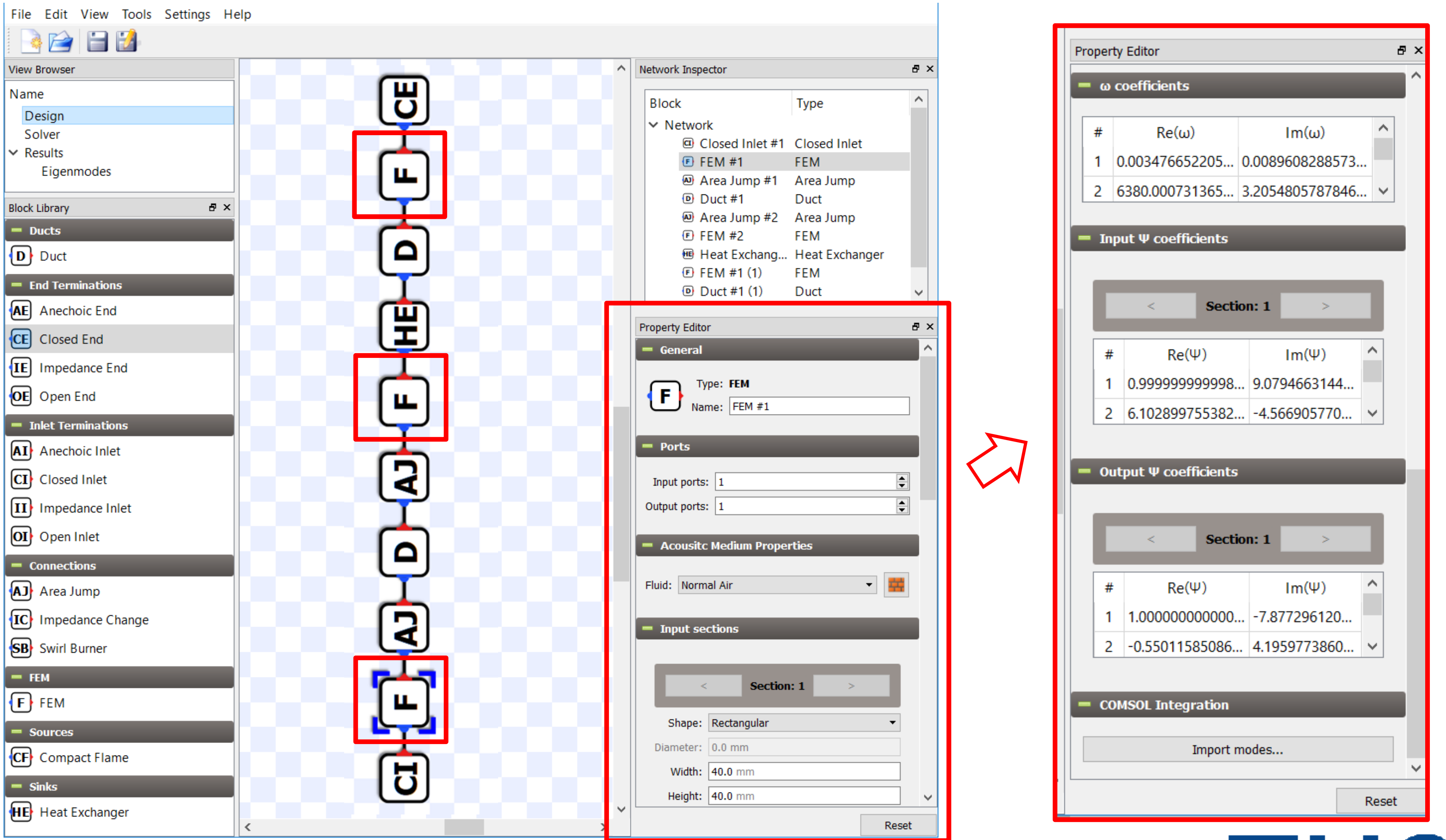
T4G's Acoustic Network Model



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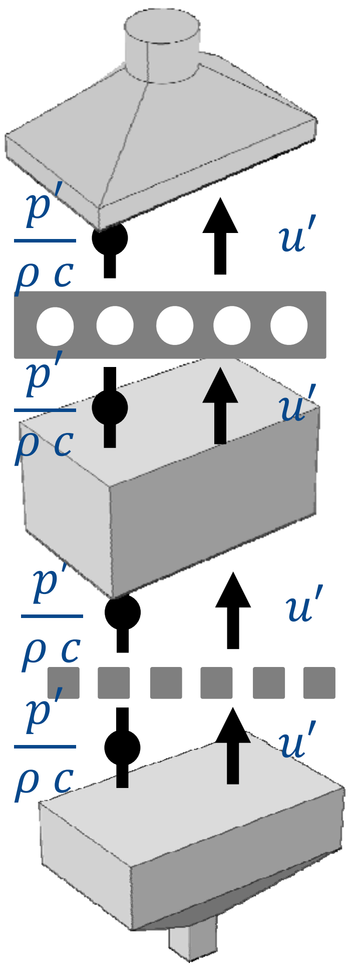
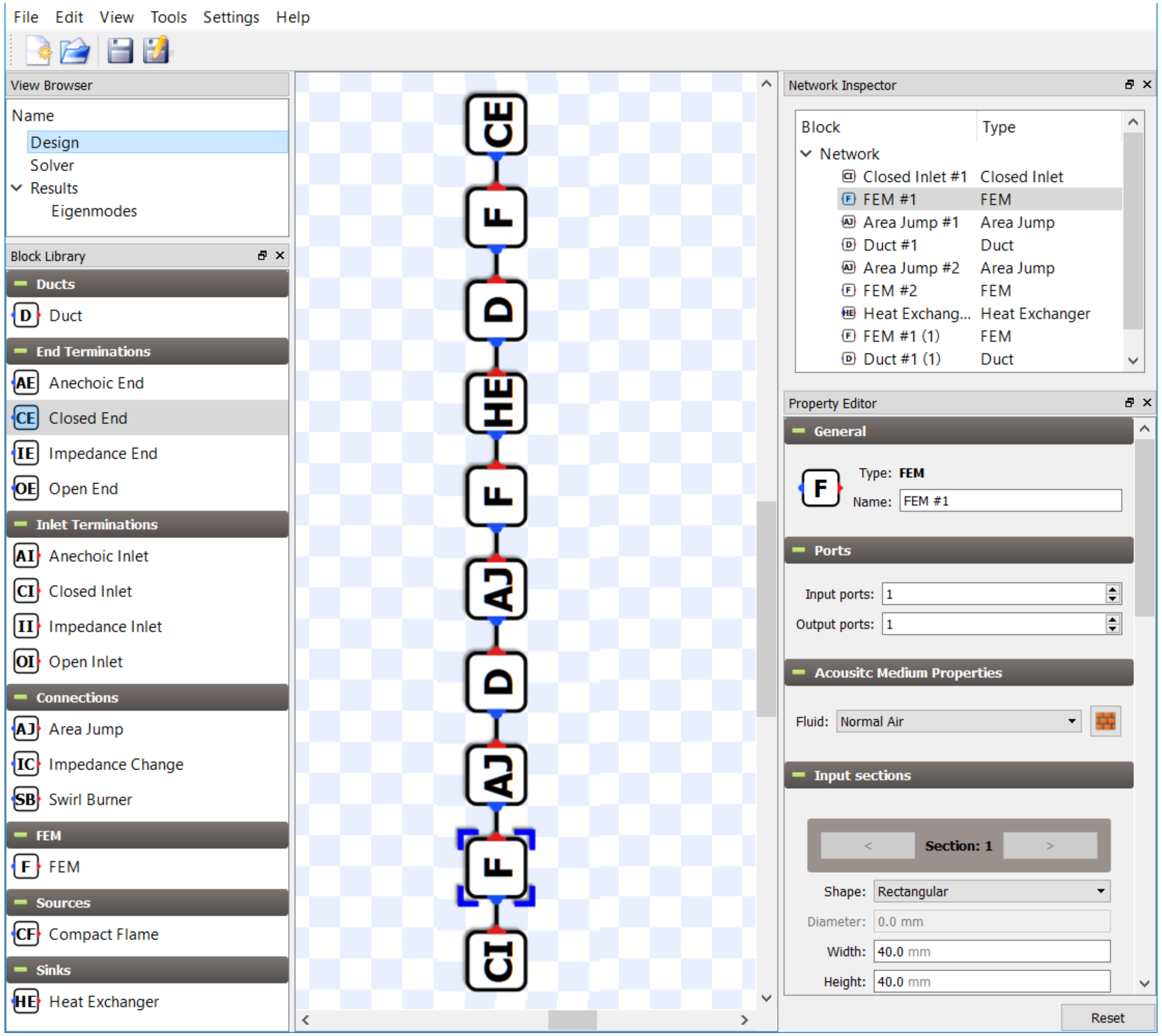
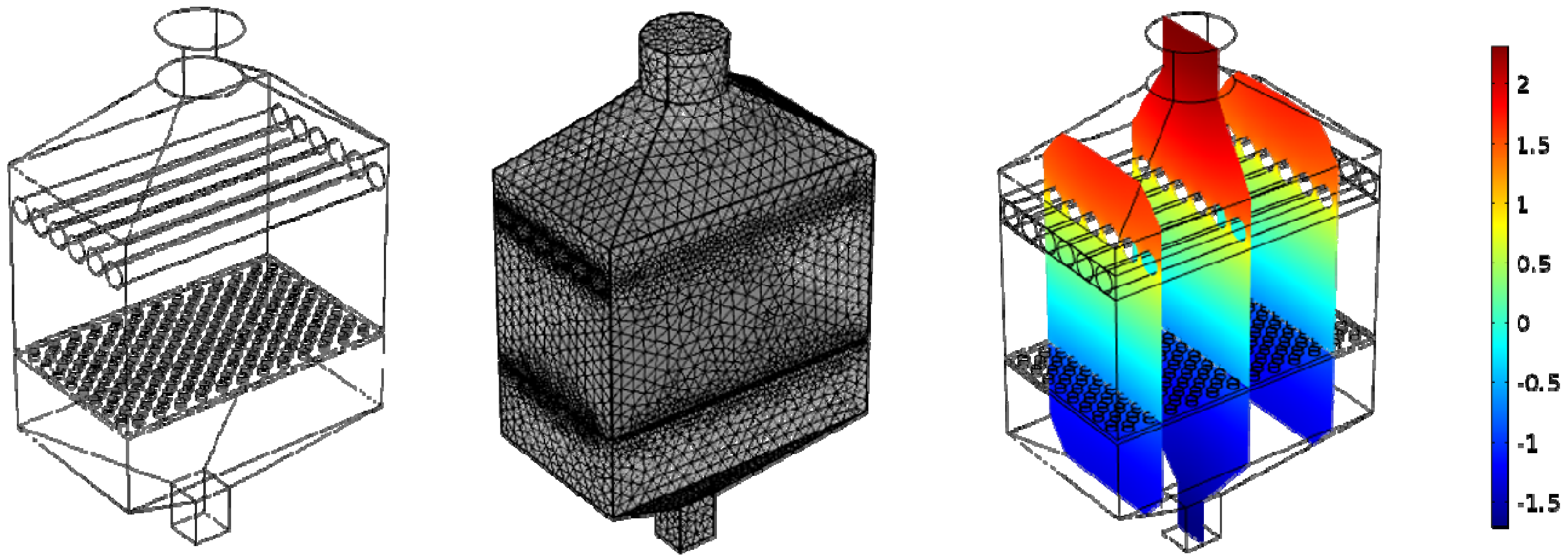
Validation Case with no acoustic sources or losses





Validation Case with no acoustic sources or losses



- Comparison of Network Model and COMSOL simulation of the full domain without acoustic sources or losses
  - *Pressure Acoustics, Frequency Domain (acpr)* physics interface with *Eigenfrequency* study
  - Validation (i.e. cross-check) of the network model results

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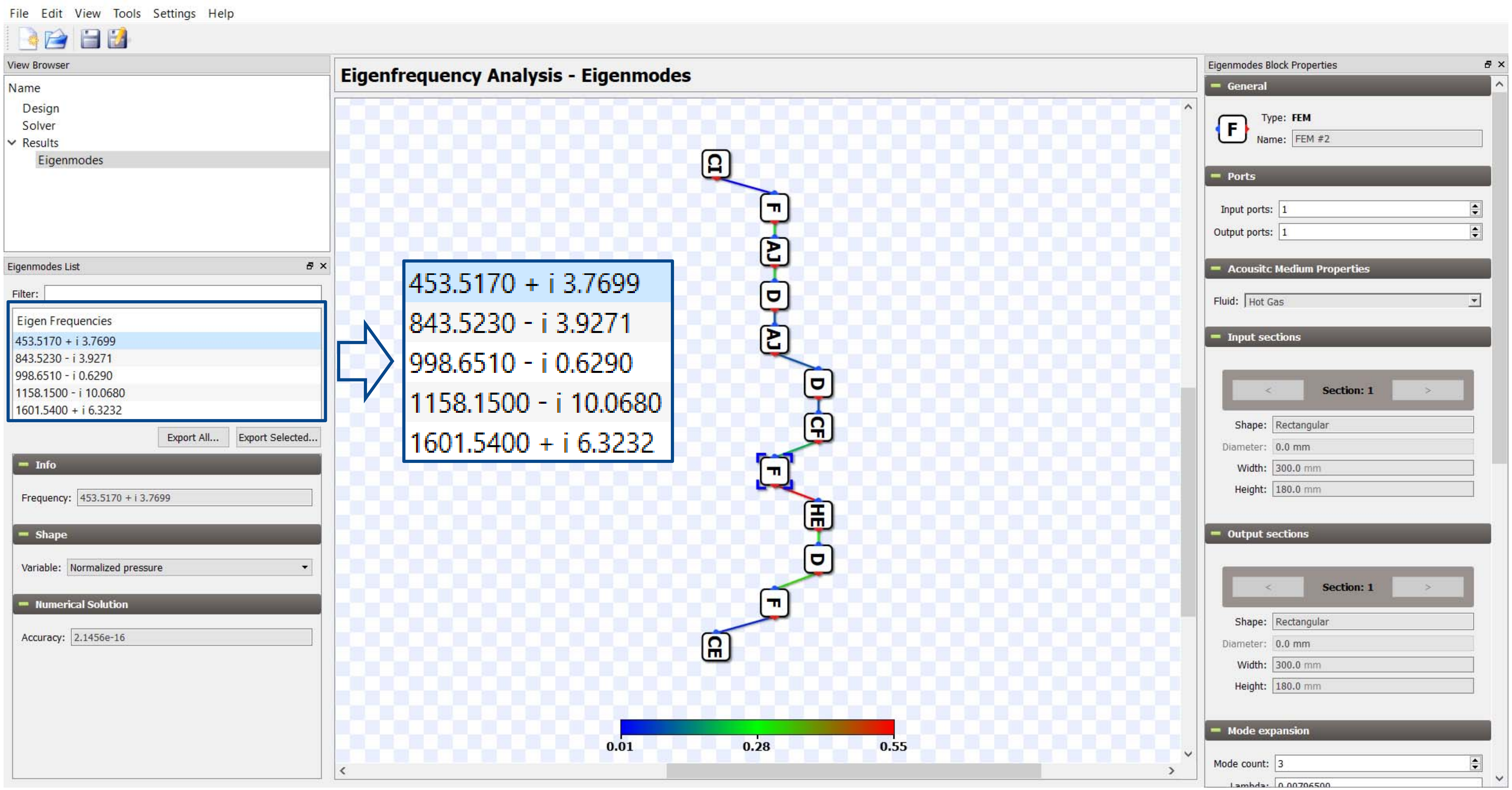
Analysis of Thermoacoustic Stability of a Simplified Model of a Domestic Boiler



Thank you for listening