SIMULATION AND OPTIMIZATION METHODS FOR ORGAN PIPE DESIGN
PhD Workshop, Dept. of Telecommunications

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Outline

Brief introduction

Optimization of chimney pipe resonators
  Optimization algorithms
  Results and further development

Simulation of the flow in a flue pipe model

Computational aeroacoustics
  Aeroacoustic simulation in Matlab environment

Progress report
  Educational activities
  Publications

Summary
Introduction and background

– Brief introduction
  • 1\textsuperscript{st} & 2\textsuperscript{nd} semesters: Numerical methods in acoustics
    Infinite element method
    Modeling various organ pipe forms
  • 3\textsuperscript{rd} – 5\textsuperscript{th} semesters: Fluid flow modeling
    Theory of fluid mechanics and turbulence
    Computer methods of flow simulation
  • 4\textsuperscript{th} & 5\textsuperscript{th} semesters: Aeroacoustics and coupled techniques
    Analogies and formulations of the problem
    Implementation in a finite element code

– Project background
  • INNOSOUND has finished in January 2011
    Sound design of labial pipes
  • ReedDesign has started in November 2011
    Reed pipes: sound generation mechanism, simulations
    Administration steps started in January 2011
    Preparations from August to November 2011
Problem description and modeling

– Problem description
  • Chimney pipes can produce special sounding
  • How to exploit this capability the most?

– Methodology
  • The resonator can amplify (depress) some partials
  • The transfer function of the resonator must be tuned

– The one-dimensional model

The model has 6 input scaling parameters
Our goal is determining some of these variables
Optimization algorithms

- Optimization goal
  - Tune to a given frequency
  - Amplify given harmonic(s)
- Simple iteration
  - Only the lengths are unknown
  - Based on reflection coefficients
  - Very fast calculation
- Global cost minimization
  - A common optimization approach
  - Applicable to all parameter sets (Only some of them are relevant)
  - Construction of a cost function (Based on frequency deviations)
  - Computationally more expensive
Results and further development

- Pipes have been built based on the optimization method
- Good match of optimization, simulation and measurement results
- Quality factors can be taken into account
- Models for different pipe types can be developed

- Publications in the topic
  - Conference paper at DAGA2012
  - Journal (JASA) paper is currently in preparation
Simulation and model setup

- Resonator
- Foot hole
- Pipe foot
- Lower lip
- Upper lip
- Pipe body
- Air jet
Flow simulation in a flue pipe model

- The pipe foot model (H. Außerlechner)
  - Precision tuning of geometry
  - Reproducable measurements
  - LDA by means of high speed camera
  - Perfect for validating simulations

- Purpose of modeling
  - Accurate computer representation
  - Explanation of interesting phenomena

- Simulation technique
  - Large Eddy Simulation (filtering NSE)
  - Implementation in OpenFOAM
  - Simulations on supercomputer system

- Difficulties
  - Mesh creation is not trivial
  - Boundary conditions of free flow
  - Numerical instabilities
Flow simulation results I.

- The nature of the flow
  - \( Re \approx 2000 \) – 3000 (transient domain)
  - Free jet profile develops
  - 3D turbulent whirls obviously detectable
  - Kármán vortex street appearing

- Comparison of measurements and simulation of the free jet case
  - Velocity and TKE profiles, different distances from lower lip
  - Hot wire anemometry measurements
  - 2D and 3D models have been compared

- Publications in the topic
  - Abstract submitted to CMFF’12 Conference (International, refereed)
Flow simulation results II.

Comparison of simulated and measured velocity profiles

- Meas. (Ausserlechner2009)
- Simulation (2D)
- Simulation (3D)

Velocity magnitude (shifted) [m/s]

X position [mm]

Y positions: y = 0.5 mm, y = 5.0 mm, y = 10.0 mm, y = 15.0 mm, y = 20.0 mm, y = 25.0 mm
Computational Aeroacoustics (CAA)

- Aeroacoustic analogies
  - Compute radiated sound from turbulent flow field
  - One-way effects (no feedback)
  - Time dependent acoustic source distribution
  - 3 types of sound sources

- Numerical formulations
  - Formulation in time domain
  - Incorporation into FEM
  - New source terms can be computed at each time step

- Difficulties of application
  - The whole 3D flow field must be known (and stored)
  - Interpolation between meshes

Pipe foot
Languid
Pipe feedback
1-pole
Upper lip
Radiated sound
Edge tone
2-pole
Shear layer: 4-pole
Lower lip
Organ pipe simulation and optimization
CAA implementation and test

– Implementation
  • Time domain FEM implementation
  • Newmark time stepping scheme
  • Infinite elements on boundaries
    Zero mass formulation needed

– Test problem
  • Academic example of 2D corotating vortex pair (Powell, 1965)
  • Sound propagation speed significantly reduced \( c \approx 1 \text{ m/s} \)
  • Flow field analytically, everything else is numerically computed

– Discussion
  • Computation of derivatives is noisy
  • Very fine mesh is required
  • Computational effort limitations
PhD course and requirements

- Subjects
  - 3 obligatory and 3 facultative subjects accomplished
  - Lectures on fluid dynamics

- Languages
  - English advanced, complex (C1)
  - Spanish intermediate, complex (B2) (summer, 2011)
  - Latin intermediate, complex (B2)
  - Currently learning German and Spanish
  - Language criteria are fulfilled

- Participation in projects
  - Key tasks in the ReedDesign project
  - Some smaller tasks in the COSMA project

- Recent travelings
  - Two weeks at Fraunhofer IBP, October 2011
Educational activities

– 2010/11 2\textsuperscript{nd} semester
  Laboratory 2. measurements \hspace{1cm} 12 \times 4 \text{ hrs.}
  Audio technology laboratory \hspace{1cm} 4 \times 3 \text{ hrs.}
  Audio engineering laboratory \hspace{1cm} 6 \times 3 \text{ hrs.}
  Project laboratory consultations \hspace{1cm} 14 \times 1.5 \text{ hrs.}
  Laboratory demonstrations \hspace{1cm} 4 \times 4 \text{ hrs.}
  Preparation time \hspace{1cm} \approx 30 \text{ hrs.}
  \textbf{Total} \hspace{1cm} 10 \text{ hrs. / week}

– 2011/12 1\textsuperscript{st} semester
  Software laboratory 1. \hspace{1cm} 14 \times 2 \text{ hrs.}
  Measurement laboratory \hspace{1cm} 4 \times 4 \text{ hrs.}
  Project laboratory consultations \hspace{1cm} 14 \times 1 \text{ hrs.}
  Thesis consultations \hspace{1cm} 14 \times 3 \text{ hrs.}
  Preparation time \hspace{1cm} \approx 20 \text{ hrs.}
  \textbf{Total} \hspace{1cm} 8.6 \text{ hrs. / week}

• My student, Bence Olteán has won 3\textsuperscript{rd} prize at the TDK
## Publications

– Summary of publication points

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– Achievements

- Huszty Dénes award, 2011
- BMe research grant publicity award, 2011
- Our last project, **INNOSOUND** was selected by the European Comission as a success story
Summary

1. I have shown how simulation and optimization techniques can be applied to sound design of organ pipes
   - Development of an optimization algorithm for chimney pipes
   - Numerical modeling and optimization of pipes with tuning slot

(2.) I have developed a coupled numerical model that is capable of reproducing the edge tone of a flue organ pipe
   - Proper numerical fluid flow and acoustic model with coupling
   - Validation by comparison to precise measurements

- Obligatory, facultative and some other subjects accomplished
- Language criteria fulfilled
- Various educational activities
- Active participation in the ReedDesign project
Thank you for your attention!

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