SONIFICATION OF A COMPLEX COMPUTATIONAL PROCESS: COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

A live demonstration of the real-time sonification of a complex numerical calculation of a computational fluid dynamics (CFD) simulation is to be performed. The CFD process is implemented in a Java programming environment using JSyn [1] as the sound synthesis tool. A FM Formant Instrument (3 oscillators) is used as the main unit generator (a total of 26 instruments are used to represent computational cells in the domain). All parameters of the instruments, together with the envelopes of each sound event, are mapped directly from the computational process in real time. The computational process is iterative in nature, hence the listener experiences the unfolding of lengthy “phrases” which pan from left to right and represent the “marching” of the solver through the computational domain.

1. INTRODUCTION

Computational Fluid Dynamics (CFD) is a complex numerical process whereby the motion of fluids in a discretized space (i.e. a grid) is simulated by solving the Navier-Stokes equations of fluid motion numerically in some specified physical domain.

An example of an extremely simple physical domain is shown as Fig. 1.

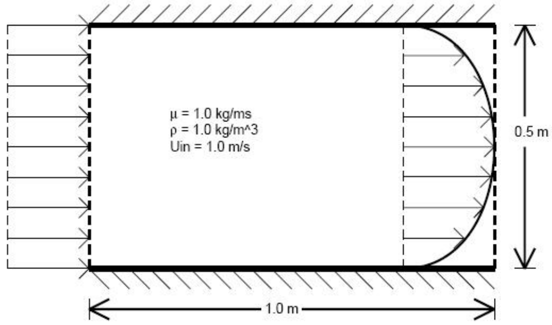


Figure 1. *Fluid Flow in a 2D Horizontal Duct*

Fluid enters a horizontal duct at the left with a uniform velocity distribution and leaves at the right with a parabolic (fully developed) distribution. While the flow situation is disarmingly simple, the calculations of the transition from the uniform profile (left) to the parabolic profile (right) are mathematically complex.

A simplified rendition of the computational domain is shown as Fig. 2.

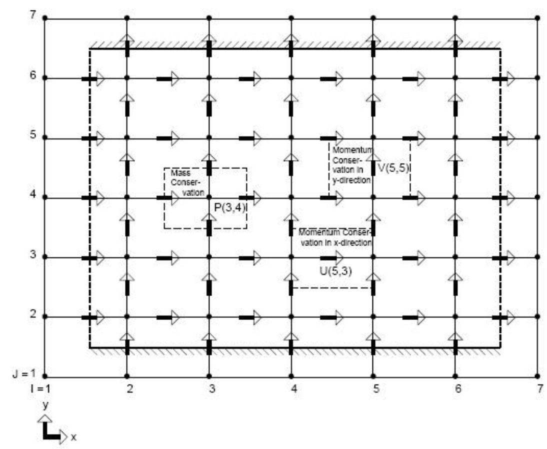


Figure 2. *2D Horizontal Duct Computational Domain*

The arrows and dots illustrate that discrete values of velocity components (arrows) and pressures (dots) are stored at specific locations in a grid (lines) on which control volumes (dashed lines) for the conservation of mass and momentum are constructed. This construct results in a set of simultaneous equations (i.e. a matrix) which is solved iteratively, beginning with an initial “guess” of component velocities and pressures at each point.

2. TECHNICAL SOUND DETAILS

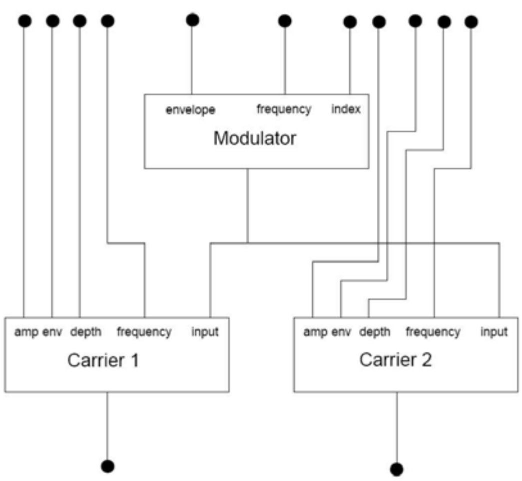
The computational component of the sound synthesis was ported to Java from a FORTRAN academic CFD code [2]. The calculation iterates based on imposed boundary conditions and an initial guess of the flow field. The iteration moves through the computational domain from left to right, and that motion is mirrored by the panning of the sound from left to right. At each “step” through the domain, the current values of all available numerical data at that step are used to drive the characteristics of the 26 FM instruments. A schematic of the instrument is shown as Fig. 3.

The basic scheme is a follows:

1. The inputs to Carrier 1, Carrier 2 and Modulator are controlled by the x-direction velocity, y-direction velocity and pressure, respectively.
2. The x (horizontal) direction velocity is the most prominent component (since the general direction of flow is in the horizontal direction). The predominant pitch content of the sonification is

therefore driven by the magnitude of this component. The mean pitch is 440 Hz.

3. The y (vertical) direction velocity is a very weak component, which vanishes completely at the exit (right) end of the duct. It manifests itself by the overtone content of the predominant x direction pitches. The mean pitch of this component is 8400 Hz. The presence of this overtone is much more predominant at the left hand side of the duct (stereo field).
4. The pressure field in CFD is strongly related to the conservation of mass. While the calculation of the x and y components of velocity is driven by Newton's Second Law of Acceleration, the calculation of pressure is regarded as the "correction" needed to force the velocities to conserve mass in every control volume in the domain. The poorer the mass conservation, the higher the modulation index, which is heard as a "scratch" sound.
5. The envelope of each note is controlled by the matrix coefficients from each equation variable. Among other things, the smoothness of attach and decay is controlled by the "smoothness" of the flow field.



In this demonstration about 50 iterations are used. The general expectation of this type of calculation is that the solution will "converge" on a unique answer. In terms of sonification, this convergence may be "heard" towards the end, as each new iteration sound similar to the last.

3. RELATED WORK

A sine oscillator version of this sonification was presented by the author at ICAD 2001 [3]. The FM Formant Instrument was used demonstrated in a hail storm sonification presented at ICAD 2003 [4].

4. TECHNICAL REQUIREMENTS

The demonstration will be run off of a laptop computer. The only equipment required would be a stereo amplifier/speaker combination which can be driven by the headphone output jack on a laptop computer.

5. REFERENCES

[1] http://www.softsynth.com/jsyn/

[2] A. Gosman, B. Launder, F. Lockwood and G. Reece, "National Development Program in Computer-Assisted Learning," Mechanical Engineering Dept., Imperial College of Science and Technology, London SW7 2BT, UK

[3] Edward Childs, "The Sonification of Numerical Fluid Flow Simulations," *Proc. 2001 International Conference on Auditory Display*, Espoo, Finland, July 29 – Aug. 1, 2001.

[4] Edward Childs, "Using Multi-channel Spatialization in Sonification: A Case Study Using Meteorological Data," *Proc. 2003 International Conference on Auditory Display*, Boston, MA, USA, July 6 – 9, 2003.