Estimation of Speech Intelligibility for Room Reverberation

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ABSTRACT: *We studied the estimation of speech intelligibility for room reverberation for which we deployed experimentation. With the use of MOS text and test sentence application from SMST base we did the estimation of subjective intelligibility. We have presented the results extensively. Further we compare the intelligibility analysis. This process measured the degradation level of the speech intelligibility with reverberation effect.*

Keywords: Telecommunications, Power Engineering, Cochlea, Fluid Dynamics, Signal Processing, Fluent, Mechanical APDL

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1. Introduction

The purpose of the study is to show the benefits of interdisciplinary approach of fluid dynamics and telecommunications in the field of signal processing. They both show the multidisciplinary point of view being put into practice in cochlea mechanism and the design of human cochlea implants and tuning.

In order to explain the process of design and simulation of the cochlea the geometry and functions of this organ are explained below.

The cochlea is filled with a watery liquid, the perilymph, which moves in response to the vibrations coming from the middle ear via the oval window. As the fluid moves, the cochlea partition (basilar membrane and organ of Corti) moves; thousands ofhair cells sense the motion via their stereocilia, and convert that motion to electrical signals.These signals are communicated via neurotransmitters to many thousands of nerve cells. These primary auditory neurons transform the signals into electrochemical impulses known as action potentials, which travel along the auditory nerve to structures in the brainstem for further processing.

The cochlea originally has the shape like spiral [1]; precisely ‘snail’ as cochlea is Latin for the snail. The main cochlea parts are round window, oval window, the perilymph fluid and Basilar Membrane (BM) as shown in Figure 1 [2]. The BM is most important element of inner ear as the deformation of BM due to sound pressure waves aftermaths in the motion of hair cells and the neural signals are generated before delivering it to the brain. The mechanics of the basilar membrane is reason for ear to hear the fine frequency ranges. When the stapes exerts force on the oval window in rhythmic pattern, the perilymph fluid acts as a medium to carry those pressure waves around the BM. Since the stiffness decreases along the length towards apex, it deflects in the particular frequency in the particular region of the length. The deformation due to the travelling waves is proportional to the passive material parameters i.e. elasticity, density and damping properties. The basilar membrane has a detailed frequency map as shown in Figure 2 [3].

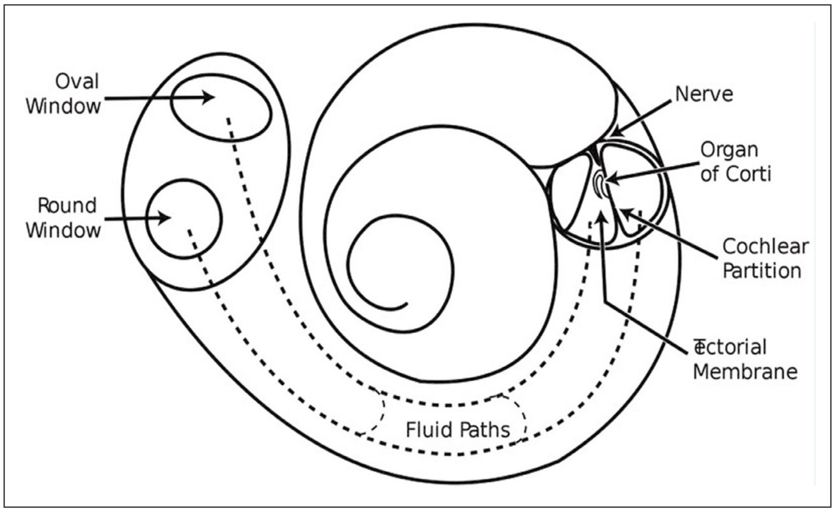


Figure 1. Cochlea natural geometry representation

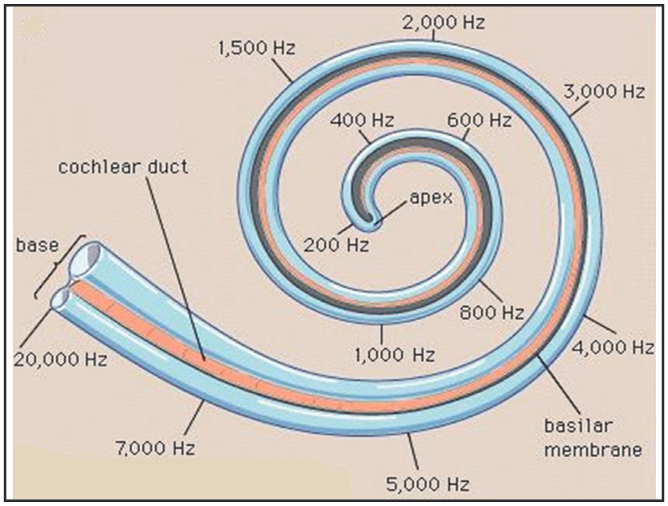


Figure 2. Frequency map for basilar membrane

2. Geometrical And Material Design

2.1. Geometrical And Material Parameters

With initial consideration of cochlea materials and the geometric proportions, original dimensions are considered. The model has been simplified in this work and elements are defined accordingly. The simplification was done since the computational resources were limited. Therefore, instead of the spiral model a simple box model was designed. The geometry and material properties are as mentioned in the Table 1 [8].

Element structure	Data
Oval window	
Geometric parameters	
Major axis(mm)	2.24
Minor axis(mm)	1.4
Thickness(mm)	0.2
Materials parameters	
Density(kg/m3)	$2.3x10^3$
Elastic modulus (N/m2)	$1.71x10^{10}$
Round Window	
Geometric parameters	
Diameter(mm)	1.2
Thickness(mm)	0.05
Materials parameters	
Density(kg/m3)	$1.2x10^3$
Elastic modulus (N/m2)	$3.5x10^5$
Basilar Membrane	
Geometric parameters	
Base width(mm)	0.1
Apex width(mm)	0.5
Base Thickness(mm)	7.5
Apex Thickness(mm)	2.5
Length(mm)	31.9
Materials parameters	
Density(kg/m3)	$1.2x10^3$
Youngs modulus (N/m2)	
Base	$5x10^7$
Middle	$1.5x10^7$
Apex	$3x10^6$

Table 1

2.2 Design Software

The model of cochlea was simplified and designed using SOLIDWORKS. User friendly design features was the primary reason for using the above mentioned software. The simplified model and their dimensions are mentioned in the Figures 3 and 4 and Table 2. The ‘Assembly’ feature was used to design the solid model. The basilar membrane and the outer casing (Figure 4) were designed separately. Both the components were joined using the ‘Assembly’ operation in SOLIDWORKS.

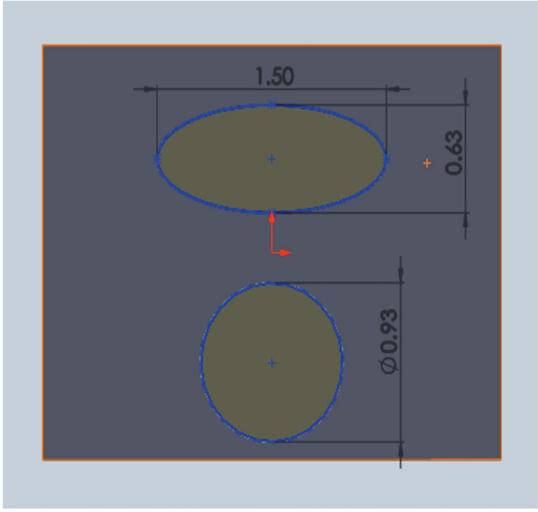


Figure 3. Dimension of 2 windows

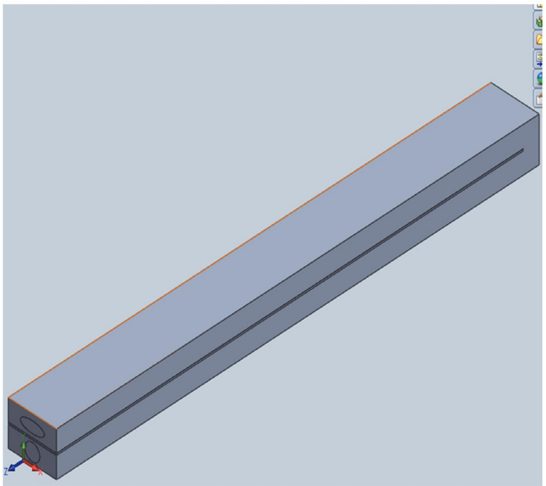


Figure 4. Final solid model

Parts	Dimensions(mm)
Basilar Membrane	3x0.1x29
Round Window	Diameter=0.93
Oval Window	Major=1.5, Minor=0.63

Table 2. Solid Model Dimensions

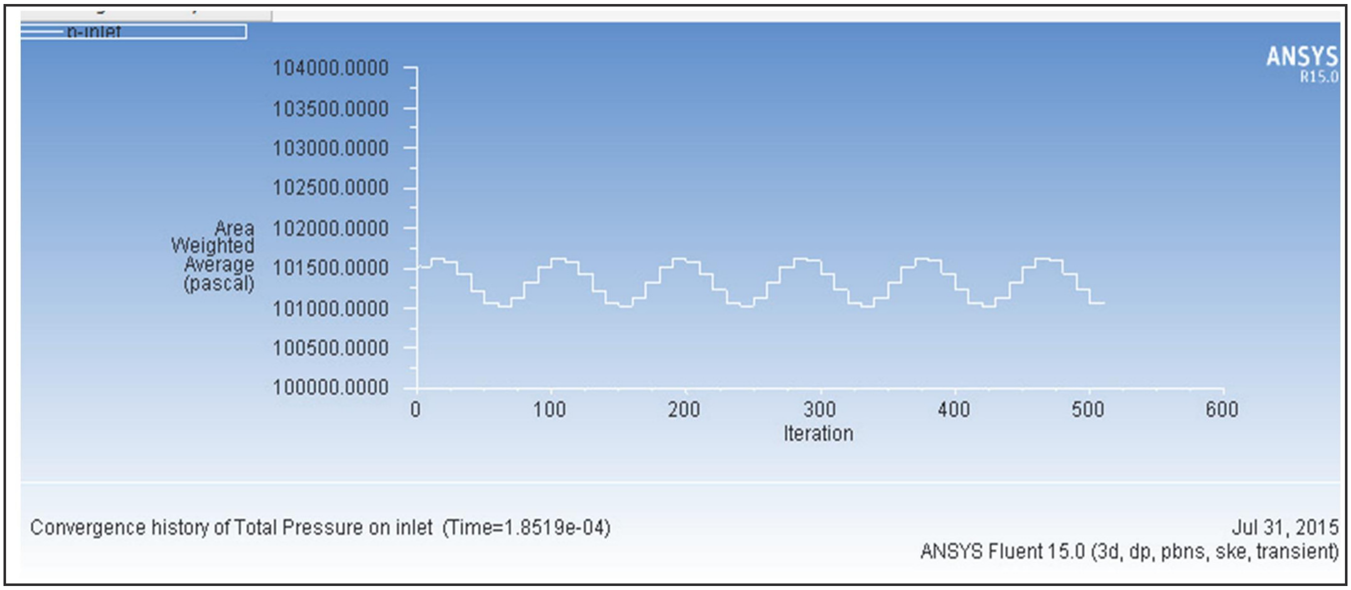
2. Fluid and Mechanical Simulations of the Model

2.1 Fluid Simulations

The fluid simulation for the above mentioned model was done in ANSYS FLUENT. The sound wave input at the oval window was given in the form of pressure wave [1]. The simulation was carried out for two frequencies viz. 600 Hz and 12 kHz. The Table 3 shows the parameters considered for the UDF (User-defined function). UDF is a feature of ANSYS FLUENT in which we can vary the input signal. Here, the input signal is pressure, which is varied as a sinusoid. The number of points to be plotted on the sinusoid mentioned in first column in Table 3 was decided based on the computation resources available. The graphical representation for the input signal is shown in the Figure 5. The simulation was carried out using the k-upsilon turbulence model [4], [5]. This model was used since the fluid in our case is incompressible.

Frequency	**600HZ**	**12000HZ**
No. of points for one sinusoid	9	9
Simulation period	0.1s	0.05s
No. of time steps	540	5400
Time-step size	0.000185s	9.529×10^{-6}
No. of iterations\timestep	10	10
Maximum no. of iterations	5400	54000

Table 3. Parameters of the UDF



Convergence history of Total Pressure on inlet (Time=1.8519e-04)

Jul 31, 2015
ANSYS Fluent 15.0 (3d, dp, pbns, ske, transient)

Figure 5. Input Signal

After post-processing, the pressure contours were obtained for both the frequencies on the upper as well as lower part of the basilar membrane. As the pressure on the upper surface is higher than the pressure on the lower surface the basilar membrane will bend in the downward direction. This deforming effect is shown in the section of Mechanical Simulation. Consider Fig. 6 and 7 which shows the cutout of the pressure contour on the basilar membrane for 600Hz. The colour map on the left side of the Figs. 6, 7, 8 and 9 show decreasing value of pressure in the downward direction. The figures show that the upper surface has higher pressure (colour contours) and that is why the basilar membrane will deform downwards.

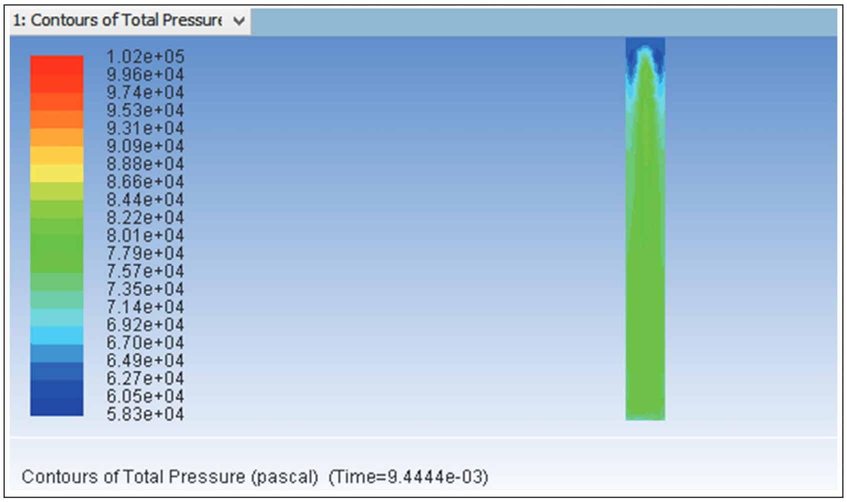


Figure 6. Pressure contour on upper surface of BM for 600 Hz

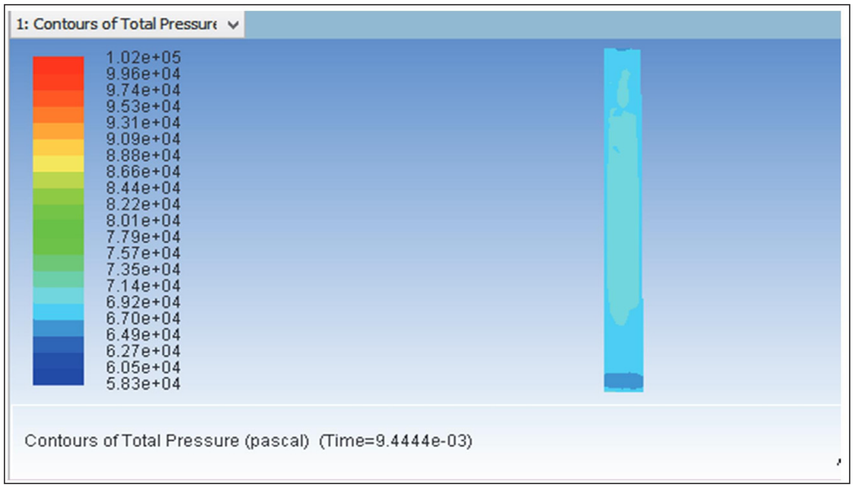


Figure 7. Pressure contour on lower surface of BMfor 600 Hz

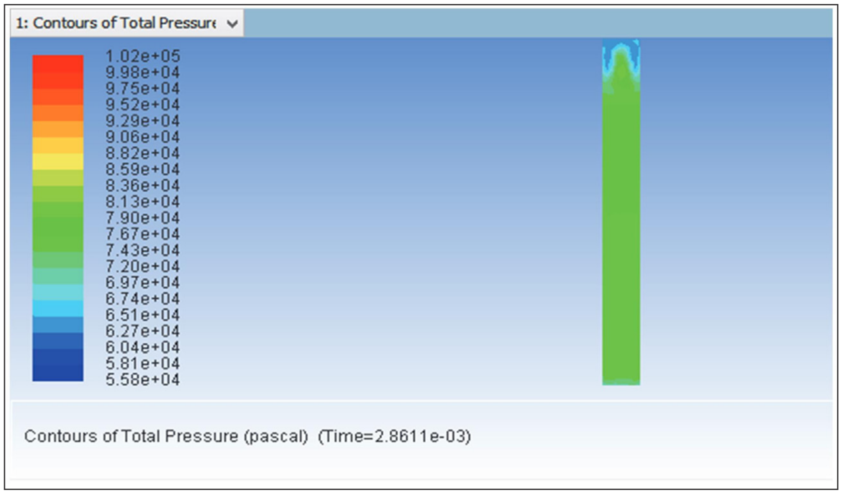


Figure 8. Pressure contour on upper surface of BM for 12kHz

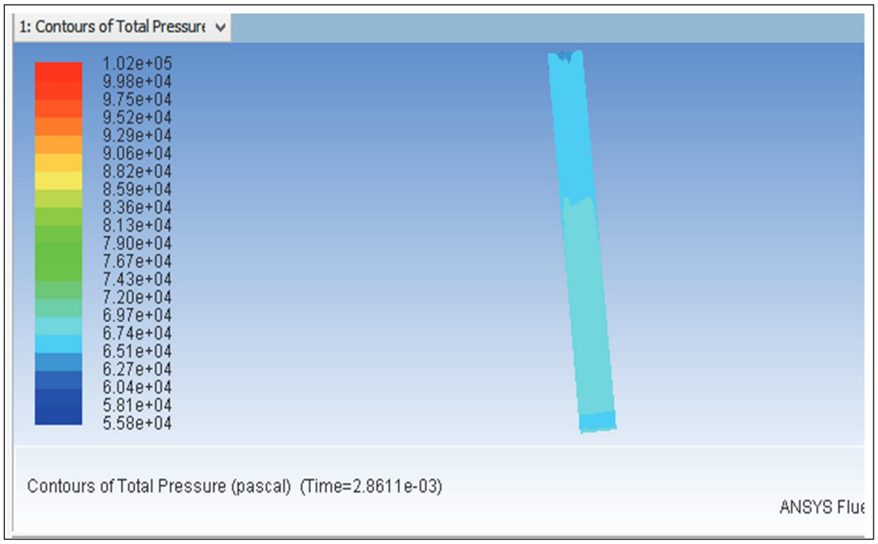


Figure 9. Pressure contour on lower surface of BM for 12kHz

2.2. Mechanical Simulation

To observe the deflection and obtain the value of deflection a scaled up model of basilar membrane was designed in ANSYS Mechanical APDL. The dimension was scaled up by a value of 100. The actual size of the cochlea is very small. Of course the results obtained were very small in 10-5micron range. To get a better idea about the numbers related to the results the dimensions were scaled up. The material properties of polyamide-6-titanium dioxide were used for the membrane. The deflection values for this material were approximately the same as that of the original basilar membrane. The pressure values from ANSYS FLUENT on the upper and lower surface of the membrane were taken and averaged out. The force was applied in APDL and the deflection was observed. The maximum deflection for the scaled up model at 600Hz was0.0053m (Fig. 10) and for 12 kHz was 0.004057m (Figure 11). This deflection was observed in the area where the basilar membrane is reactive to the respective frequency shown in figure 2.

As we can see in the Fig. 2 the frequency range of the cochlea ranges from 200 Hz to 20 kHz. The simulation time for one result took around 40 Hours on an Intel 4th Gen i7 processor. So we decided to cut short to two intermediate frequencies for time saving. We did not have enough processing power while we were actually simulating.

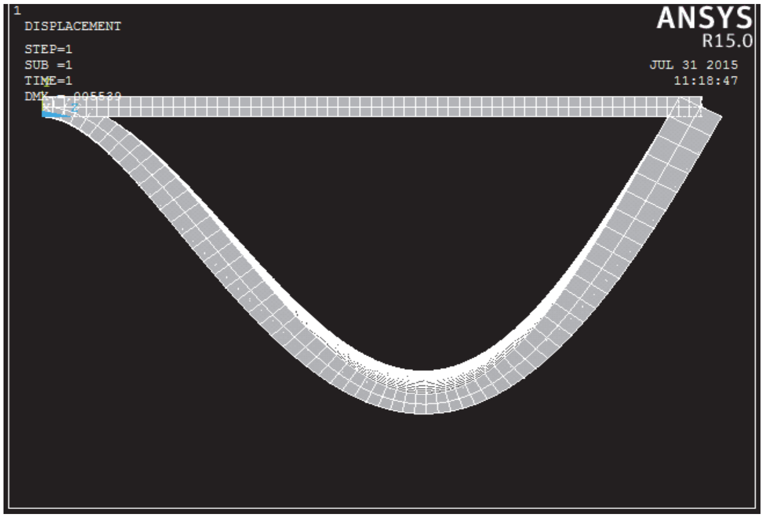


Figure 10. Deflection for 600 Hz

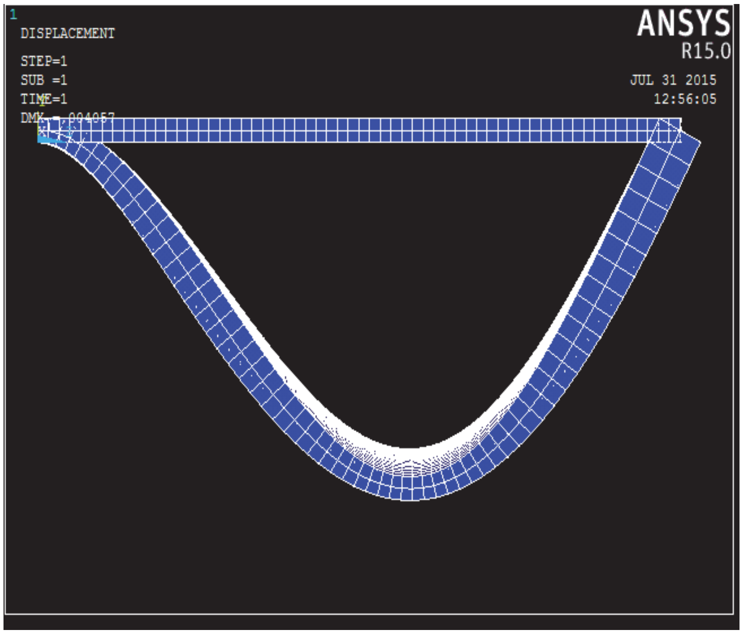


Figure 11. Deflection for 12 kHz

3. Conclusion

In this paper is shown how the use of two different subjects as fluid dynamics and signal processing help to solve successfullyan interdisciplinary problem related to the both engineering and medicine spheres. Mixing the both lead to better understanding and putting into practice the theory in engineering. The results shows that education and design in multidisciplinary approach leads to solving an engineering problem concerning even to a medical topic. The study of materials was carried out and a suitable material was found out. The simulations were carried to see which part of the membrane reacts to which frequencies and the results almost matched. This is just a start of 3D simulations in this multidisciplinary approach of fluid mechanics and telecommunications. It is just a crude start in this field which can made smooth further with inclusion of finer grids and animations for the pressure wave on the basilar membrane.

An interdisciplinary approachleads to improved student knowledge and better understanding of the given task.

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