Finite Element Analysis on Sound Wave Propagation into Human Head

The overall goal of this project is to develop an acoustic propagation model using well-understood and documented computational techniques that will model propagated acoustic signals around and in the human head. This model will serve as a valuable tool to understand the acoustic wave propagation around and inside human head, which is an inhomogeneous scatterer (bone, fat, soft tissues in inner skull) with multiple openings (ears, eyes, nose, mouth), irregular geometry, various coatings (skin layer, hairs). Our specific interest is to study the reception and conduction of sound by hard and soft tissues through the computational approach.

This study uses finite-element analysis (FEA) to model the acoustic propagation around and in human head. The acoustic analysis available in ANSYS, an industry standard used for FEA, is capable of modeling the fluid medium and the surrounding structure, studying the pressure distribution in the fluid at different frequencies, pressure gradient, particle velocity, the sound pressure level, as well as, scattering, diffraction, transmission, radiation, attenuation, and dispersion of acoustic waves. With properly developed code, it is very promising for us to build the proposed human head model using ANSYS.

At the first stage, we would like to demonstrate the feasibility of using ANSYS FEA to model acoustic wave propagation phenomena in fluid-solid media, which involves solving the coupled acoustic/mechanic equation in one simulation process to obtain pressure in fluid medium and particle velocity in solid medium. The fluid-solid media is an abstract of the scenario where a human head (containing both fluid and solid materials such as soft tissues and bones) is surrounded by air.

In frequency domain, we did harmonic analysis on the scattering of 2D rigid cylinder, 2D rigid shell, 3D rigid sphere, and 3D soft sphere in plane wave field. Figure 1 show two example models generated in ANSYS.

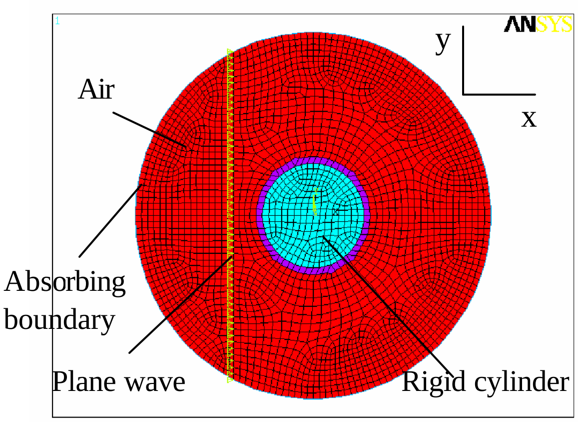


Figure 1(a): The 2D rigid cylinder FEM model generated by ANSYS

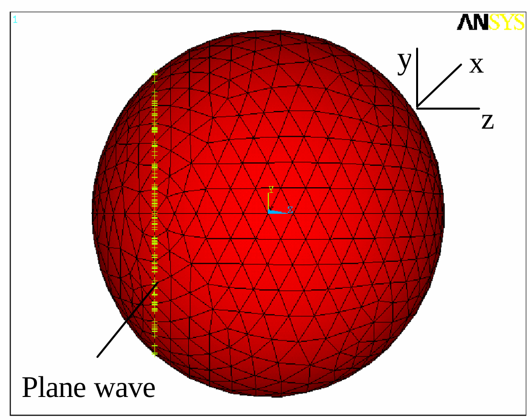


Figure 1(b): The 3D Rigid sphere FEM model; the incident wave is applied on the circular cross face (as the line in the figure)

In Figure 2 and 3, the ANSYS simulation results of the pressure distribution on the targets (cylinder, shell, and sphere) surface are compared with the analytical solutions (*Theoretical Acoustics,* Philip M. Morse and K. Uno Ingard, 1968). Reasonable agreements were achieved.

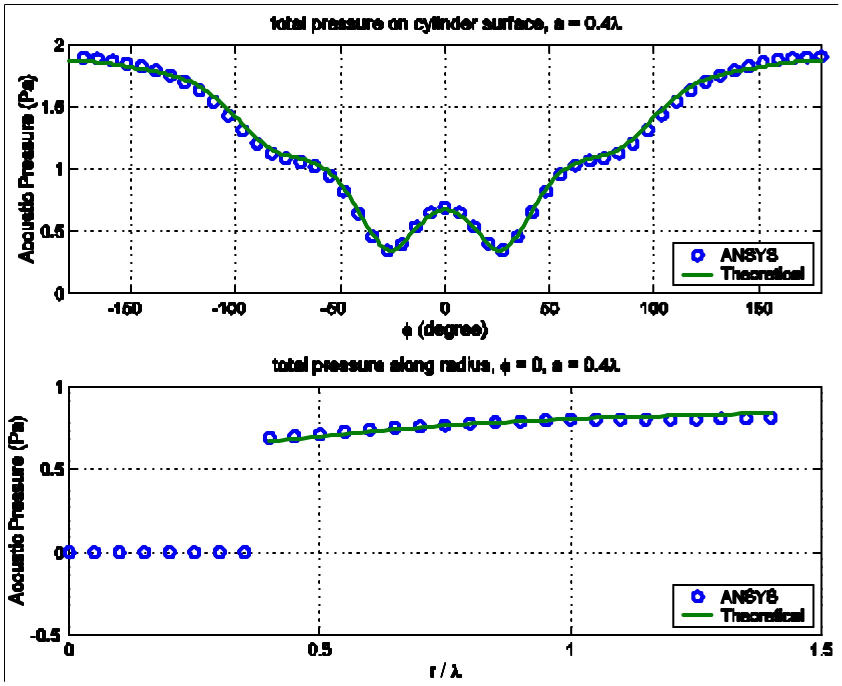


Figure 2: The rigid cylinder simulation results vs. analytical solutions

1) total pressure on cylinder surface (note that the point ϕ= 0 is the point farthest away from the source of the sound)
2) total pressure along radius, observation angle ϕ = 0 degree (note that r = radial distance from the center of the cylinder)

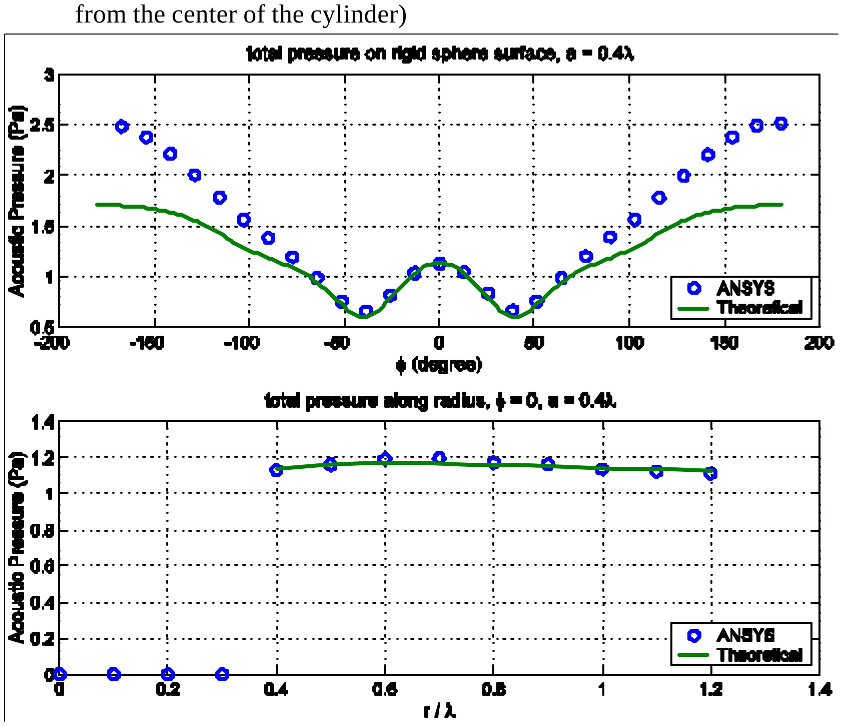
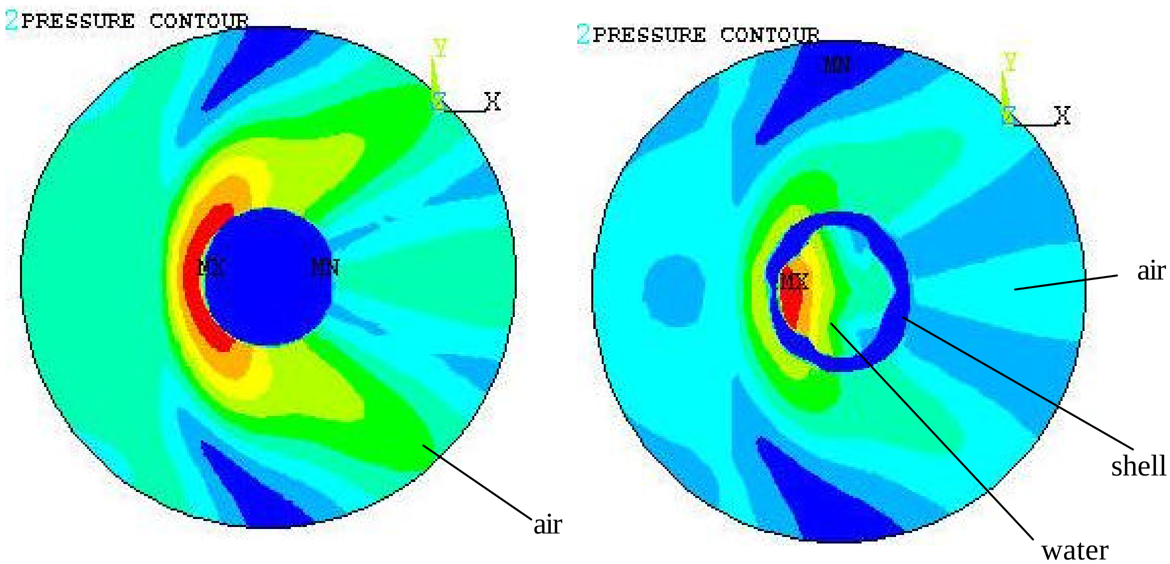


Figure 3: the rigid shell simulation results vs. analytical solutions

1) total pressure on the surface of the center sphere cross section (note that the point ϕ= 0 is the point farthest away from the source of the sound)
2) total pressure along +z axis, observation angle ϕ= 0 degree (note that r = radial distance from the center of the sphere)

Being much closer to human head case, simulations of a 2D soft shell in plane wave field were also implemented to build a 2D fluid-solid-fluid propagation model. We compare the pressure contour plots generated in the ANSYS simulations for the rigid shell and the soft shell (Figure 4). We can see that the soft shell (Figure 4(b)) allows acoustic pressure penetrating into it while not in the rigid shell case (Figure 4(a)).



(a) (b)

Figure 4: The pressure contour of
(a) rigid shell
(b) soft shell
Shell: Thickness = 0.15 λ_{zir}, Density = 2000 kg/m^3, Young's Module = 2e-8 Pa
Shell Interior Medium: Water (Speed of Sound = 1500 m/s, Density = 1000 kg/m^3)
Shell Exterior Medium: Air (Speed of Sound = 340 m/s, Density = 1.2 kg/m^3)

In time domain, we did several transient analyses in ANSYS. Below are two simulation videos generated in ANSYS which shows the wave propagation in homogeneous air with (Figure 6) and without 2D rigid cylinder (Figure 5). In these case studies, a sinusoidal wave is applied in the air medium and propagates along the x+ axis into the air medium.

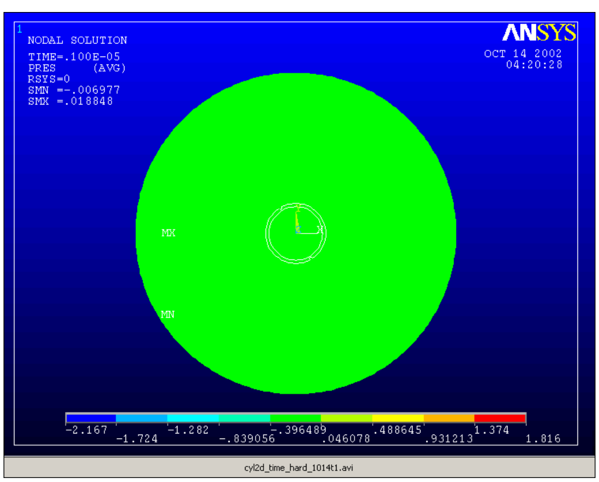


Figure (5)

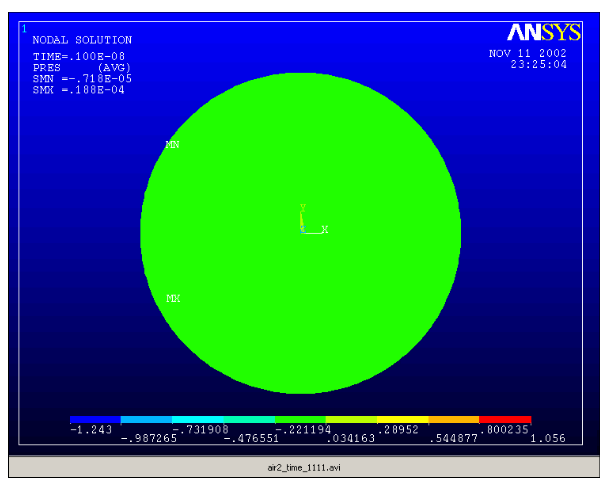


Figure 6

Furthermore, a 2D contour slice of the male human head was imported into ANSYS to study the wave propagation phenomena with regard to different frequencies and incidence angles. The image data set is provided by the National Library of Medicine's Visible Human Project http://www.nlm.nih.gov/pubs/factsheets/visible_human.html.

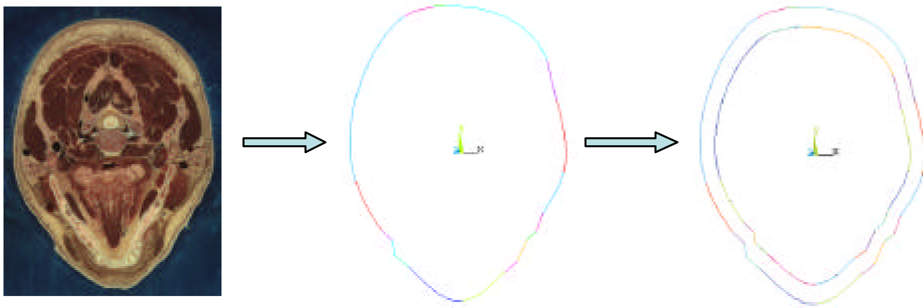
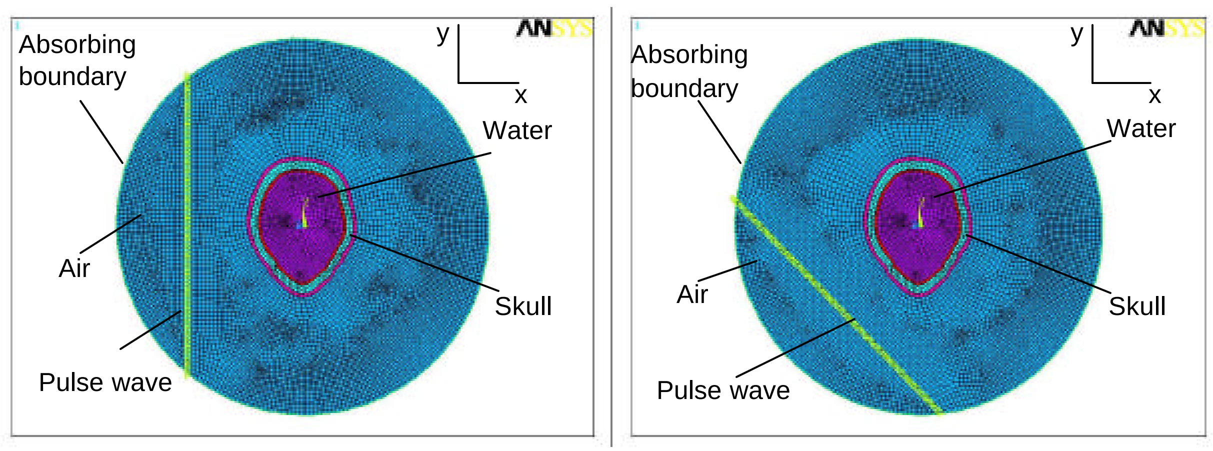


Figure 7: the 2D head contour retrieved by Adobe Illustrator



incident angle = 0 degree **incident angle = 45 degree**

Figure 8: the FEM head model with two incident angles generated in ANSYS

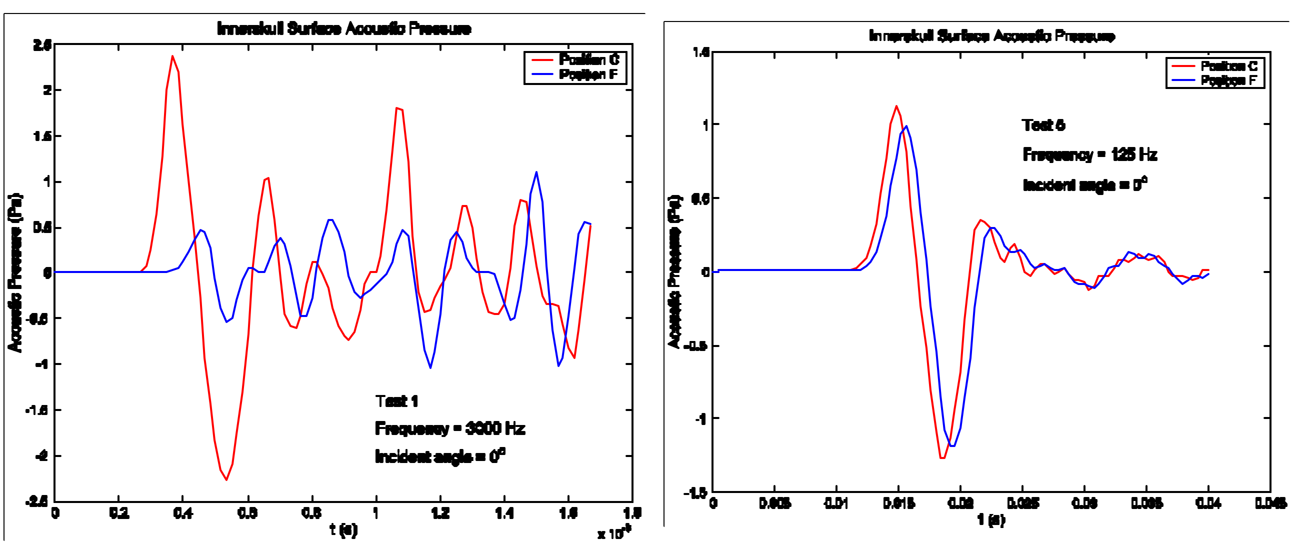


Figure 9: head inner pressure plot under different frequencies

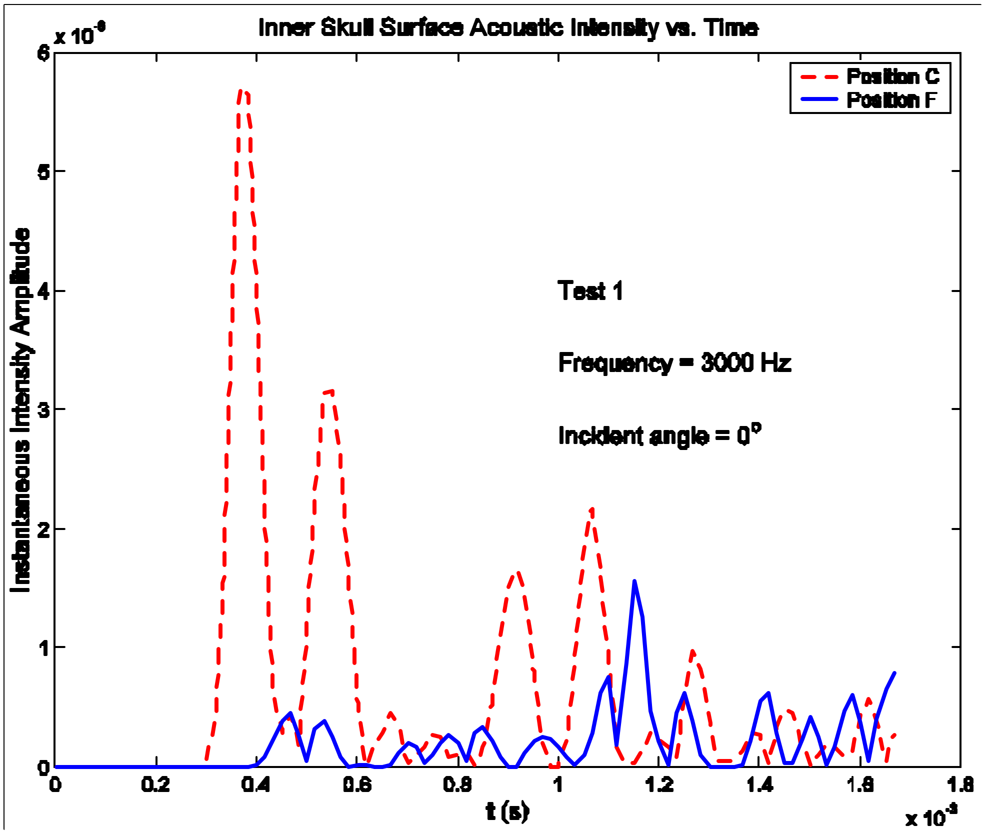


Figure 10: head inner acoustic intensity plot

The animation vedios below give us a better visualization of the wave propagation.

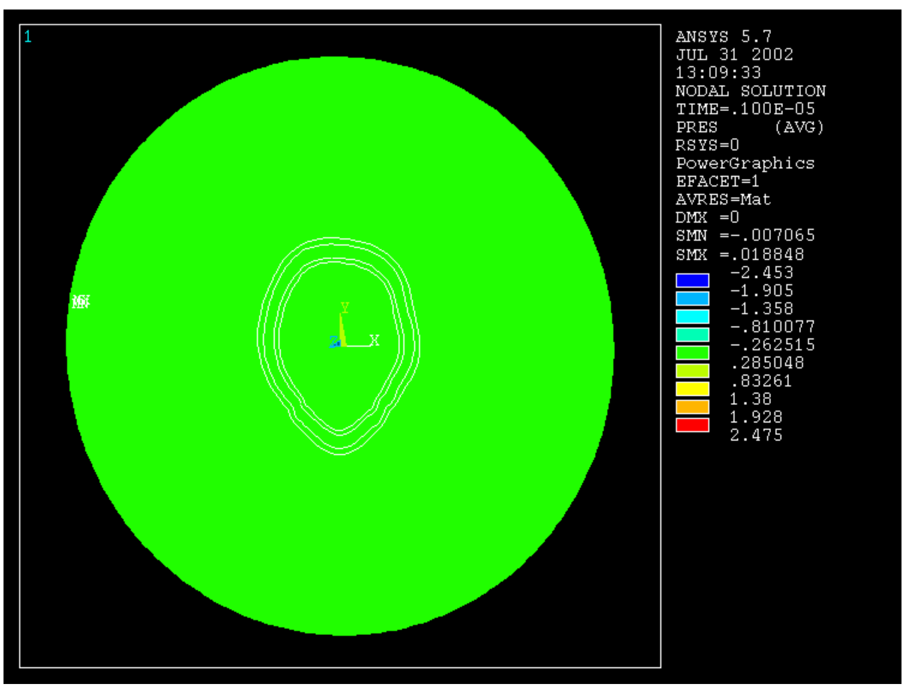


Figure 11: transient analysis on human head (frequency = 3 khz, incident angle = 45 degree)