Acoustics
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Lecture 1
Module 1
Concept review
Intro, Sound wave versus Vibration, Different Types of Ways, Octaves, Music Scales, Sense of SPL

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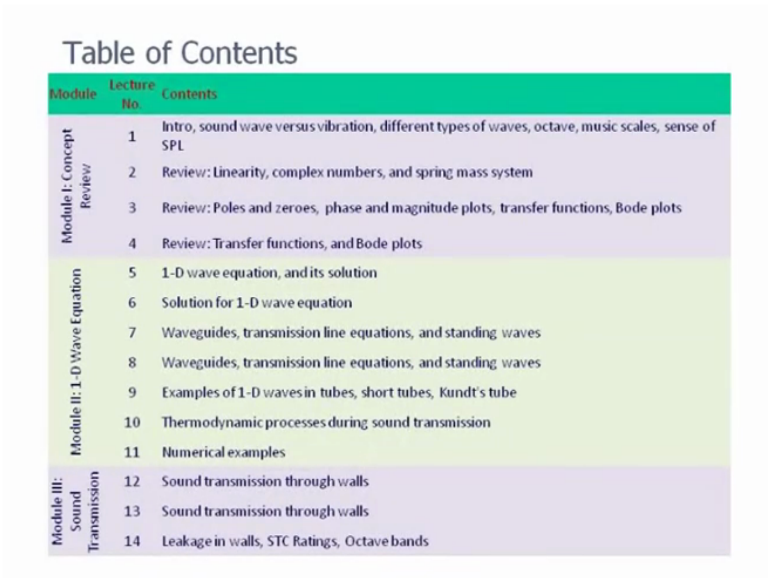

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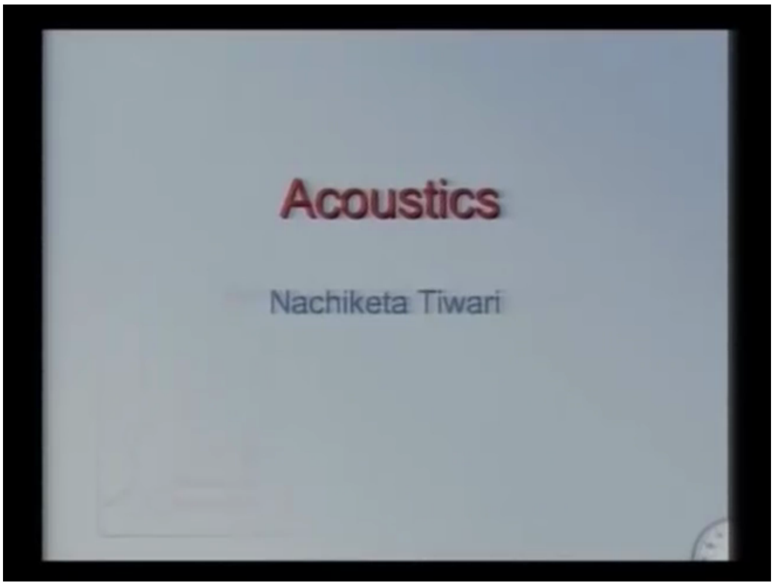

Good afternoon what we are going to start is a series of lectures in the area of acoustics and today this is an introductory lecture, so I will be introducing the topic of acoustics in the whole of lecture I will be showing you some examples how acoustics and the knowledge of acoustics is used in diverse areas what I will also try to cover is the some of the key application areas and some of the key deviations if you may call them or categories of knowledge which relate to acoustics, classification of acoustics knowledge and then also in addition to all this I will also introduced few concepts like decibel, power intensity and so on and so forth. So that will be the overall synopsis of today's lecture.

So what I will like to start with is a small video which I found on YouTube and it shows, the video is fairly powerful in the sense that it shows what sound waves which are supposedly in common understanding not damaging they can do, so that is what I wanted to start the lecture with.

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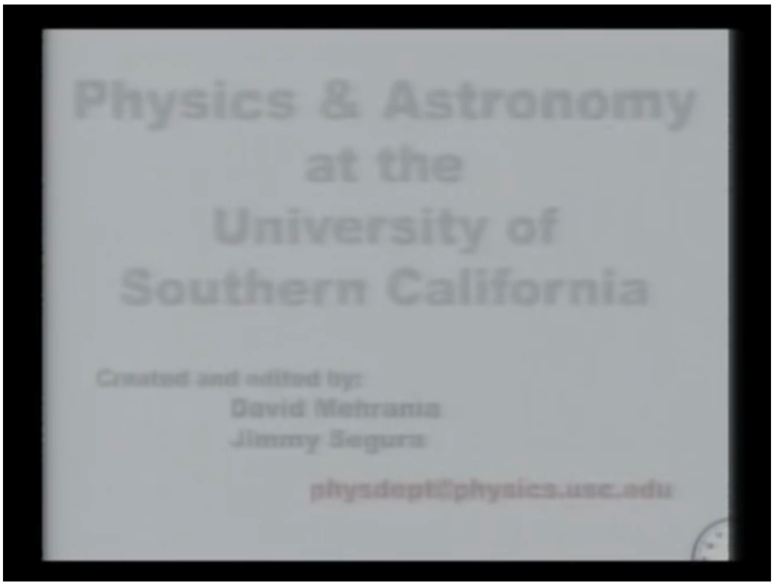

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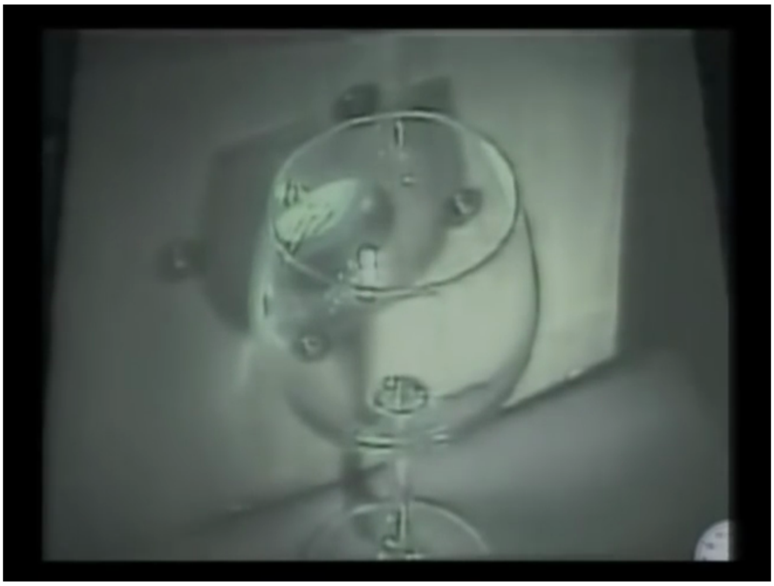

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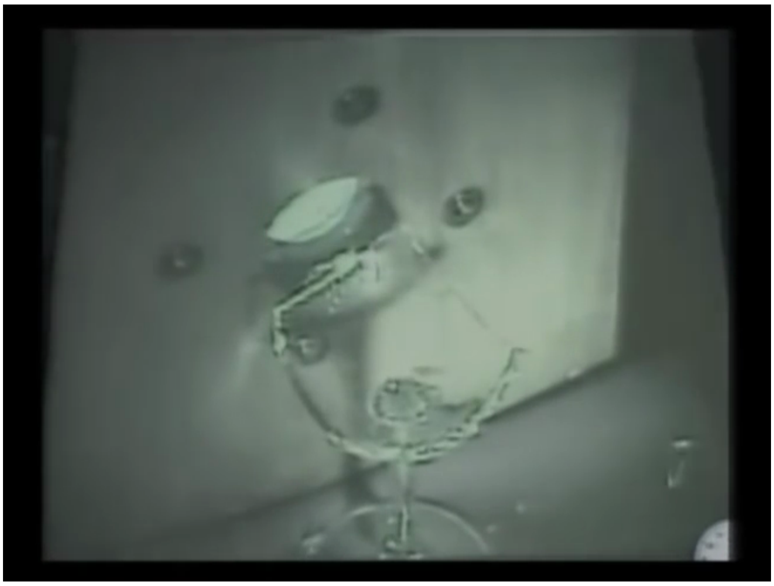

So what you have seen here is a wine glass and it is going to be excited with specific frequency of some and that sound frequency matches the resonance frequency of the glass and after few seconds of getting excited the glass shatters. So it will take about maybe 5 at the most maybe 10 more seconds as you see now the amplitude is growing and there you have it.

So just by exciting a particular frequency which matches the resonance frequency of a glass you were able to shatter the glass. So that is a small demonstration which I wanted to share with you I will go back to my PowerPoint and I wanted to introduce 2 terms, one is transverse waves and the other one is longitudinal waves but before I start speaking about transverse and longitudinal waves we should understand what is the difference between a sound wave or a wave and vibration.

So in case of vibration you can have a particle oscillating about a mean position back and forth. So when there is vibration happening it can happen in time around the mean position but when you have a wave, the wave travels not only in time but it also travels in space, so you drop a piece of stone in a lake and you have waves right starting from where the stone plunges into Ocean or water body and waves start travelling in a circular fashion and they reach shores after a period of time.

So waves have a temporal dimensional that is they have a motion associated with time and they also have motion associated in space so again I will show you one good illustration of wave motion and again I am pulling it from Internet and what you see here are 2 types of waves.

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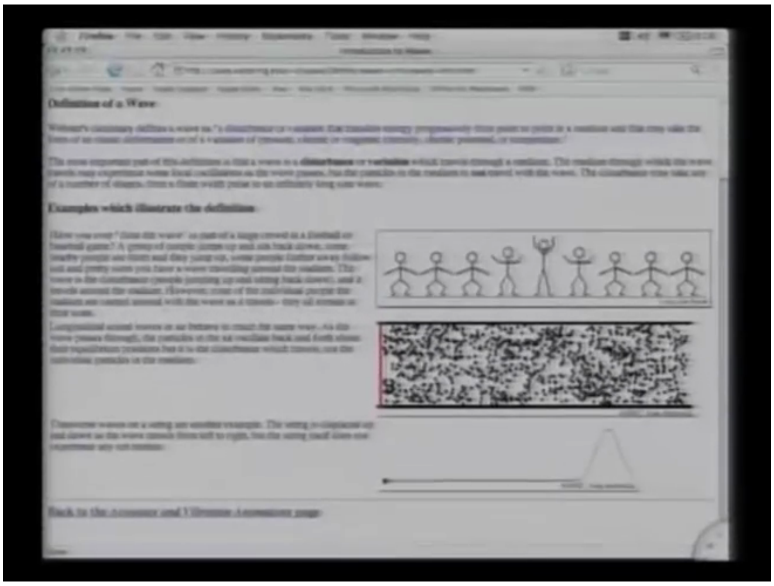

So the waves which is on the top basically where men are jumping up and down there the particle motion is normal or perpendicular to the direction of the wave and those types of waves are called transverse waves. The second categories of waves are longitudinal and that corresponds to the picture where you have lot of air particles and they are being compressed by a red piston.

So when the piston gets excited you have disturbance in the particles wave is travelling that direction is same as the direction of the particle motion and these types of waves are called longitudinal waves. So most of the waves which we encounter in our day-to-day experiences you take a rope and you oscillate one end of it and the other and is tied to a tree or you have waves in ocean, more a lot of these waves along to transverse category because the particle motion is normal to the direction of the wave propagation.

In case of sound waves these are longitudinal waves because the air particles they move in the direction of the motion of the wave. So I had mentioned that wave has 2 dimensions it has a motion associated with a dimensional, special dimensional and also motion associated with time and that is very nicely captured in this, pretty simple but powerful animation.

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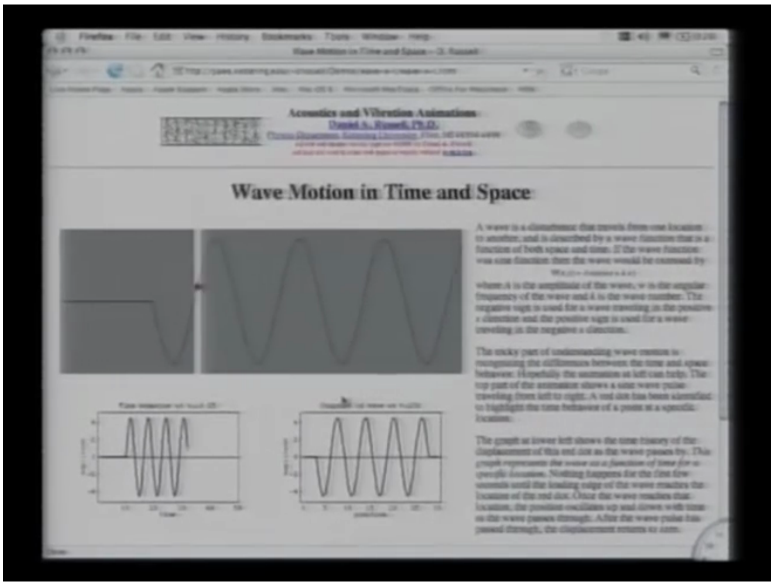

So what you have here is a red dot which is illustrative of particle and when wave motion starts at one end and it hits the particle, the particle moves up and down. So please note that the particle itself is not moving with the wave to the extreme right end of the picture but when the wave hits the particle, the particle moves up and down and while the wave keeps on continuing moving along in the spatial dimensional.

So again if very simply but powerfully illustrates that there is a time dimension to wave and there is a space dimension to wave vibrations may have both of these then they happen to become waves but most of the vibrations we talk about for instance you have a mass and a spring system there only in the time dimension, so the wave does not propagate along the x-axis.

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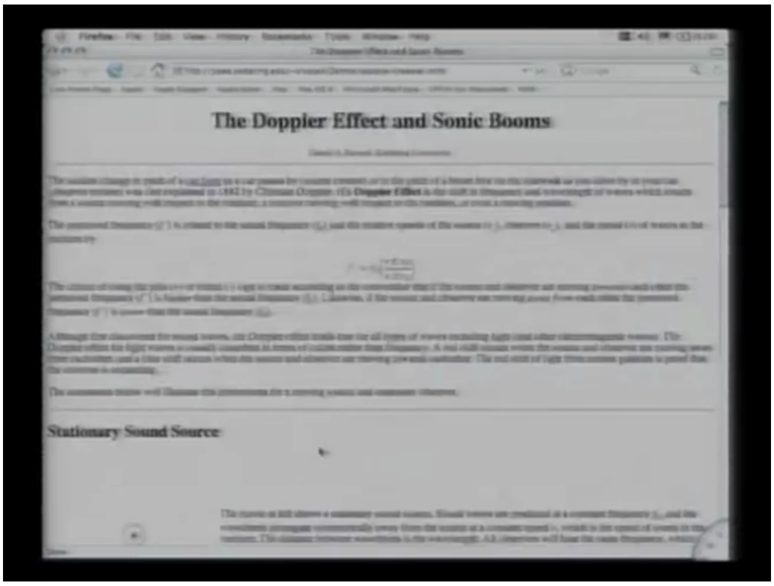

So that is 1 important thing to remember, I also wanted to share some another interesting feature of wave and this is also pretty powerful. So in our high school physics classes or in first or second year of bachelors program in engineering we have read about Doppler effect and essentially what Doppler effect is that if you have a source of wave and that source is moving or the observer is moving while the source is stationary than the apparent wavelength of the wave either gets reduced or it gets enhanced depending on whether you are moving towards the source or you are moving away from the source that is shown very nicely here.

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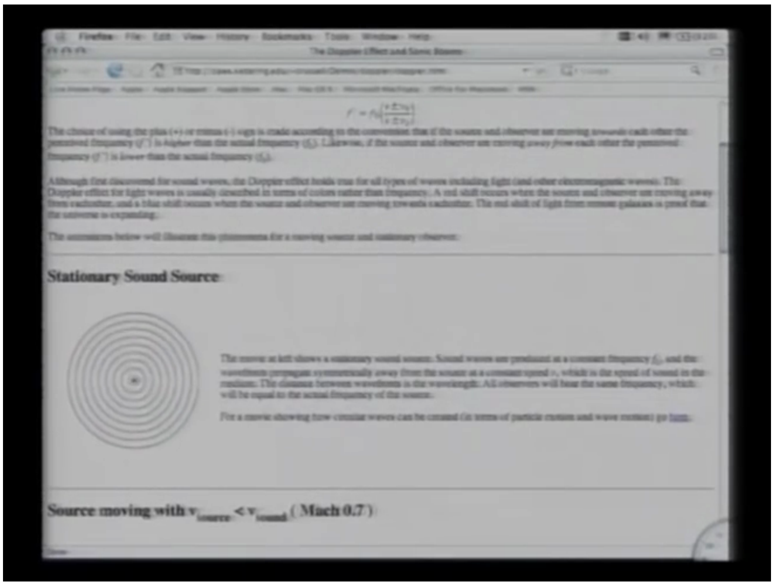

So consider a small dot, a pulsating dot and it is generating sound waves. So and the source is a stationary and also the observer is stationary. So what you are seeing here is wave propagation in a spherical front. So you have concentric circles slowly growing with a period of time. Now consider a case when this is happening and also the dot in the middle which is the source of the excitation is also moving in a particular direction that is what you see here.

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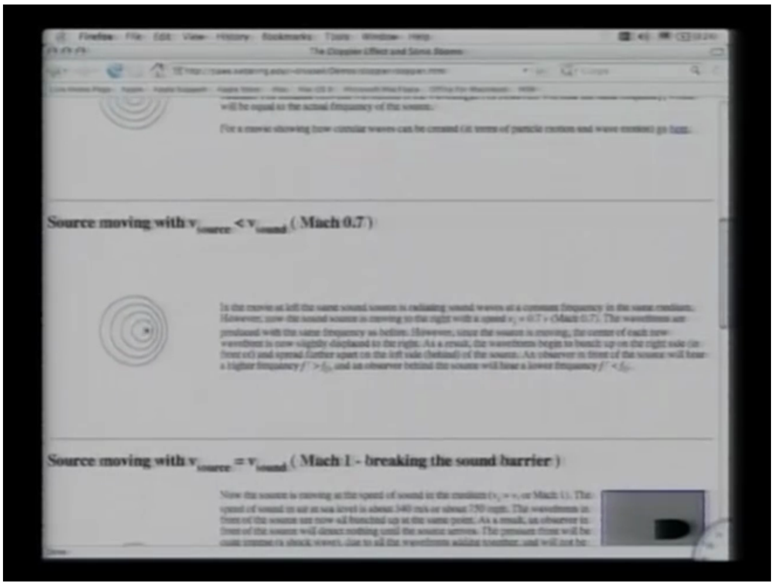

So you have a dot which is moving rightwards to the in the (()) (9:09) and it is also generating waves and as this is happening the waves in front of the front they are getting compressed. So the the wavelength of the wave is getting reduced or in other words those waves which are in front of the source they tend to have higher frequencies while waves on the backside of the source as the front is as the point is moving front rightwards they happen to have lesser frequencies.

The same source exciting the same frequency but just because it is moving in a particular direction the frequency in front of the source and frequency on the backside of the source they start. Now this is the situation when you have the velocity of the source less than the velocity of the sound wave itself.

Now what happens when the velocity of the source equals velocity of sound and that is illustrated in this picture? So here the source is moving as fast as the sound wave itself, so right at the tip essentially theoretically the frequency of the sound almost approaches infinity in a theoretical sense.

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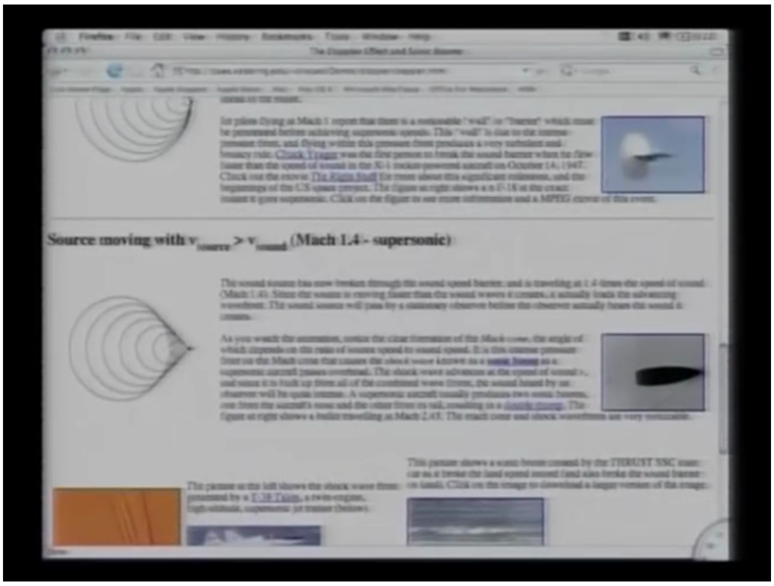

And once you break this sound barrier that is the velocity of the source exceeds the velocity of sound then this is the type of pattern you get and this is what we commonly encounter when you have aeroplanes travelling faster than sound. So an aeroplane is travelling faster than sound you see the aeroplane first you hit the aeroplane first that moving object first and after that you hear a big sonic boom.

So I just wanted to share some of these animations they are publicly available and it will be really educative for you all to go visit some of these sites and see what does sound do in different types of situations and scenarios. So Internet is a powerful tool and you should use the power of Internet to your advantage. So with this I will talk a little bit about what are the different areas of acoustics and how is the science of acoustics classified?

So let us consider a sound system which is receiving electrical energy, it amplifies the recording of a CD and generates sound from there. So there is a body of knowledge which deals with conversion of a particular type of energy into sound or sound in getting converted into say electricity or some other form of energy. So that body of knowledge where these transformations happen is called electromechanical acoustics there are people who also call the same body as electroacoustic.

So if you are trying to understand the inner workings of a microphone which basically converts sound energy into electricity or a loudspeaker which converts electrical energy into sound in that is the body electro acoustics or electromechanical acoustics is the body which deals with this particular specialization then once you have generated the sound in a sound system sound propagates from the Speaker to my ear the understanding of this transmission, propagation, attenuation is called physical acoustics.

So in the (()) (13:33) of physical acoustics a lot of focus is placed on wave equations, how sound strength attenuates especially if there are spherical sources as sound moves away from the source, how its strength attenuates? Because of dampening effects and also because we are further and further away from the source. So all this body of knowledge is termed as physical acoustics.

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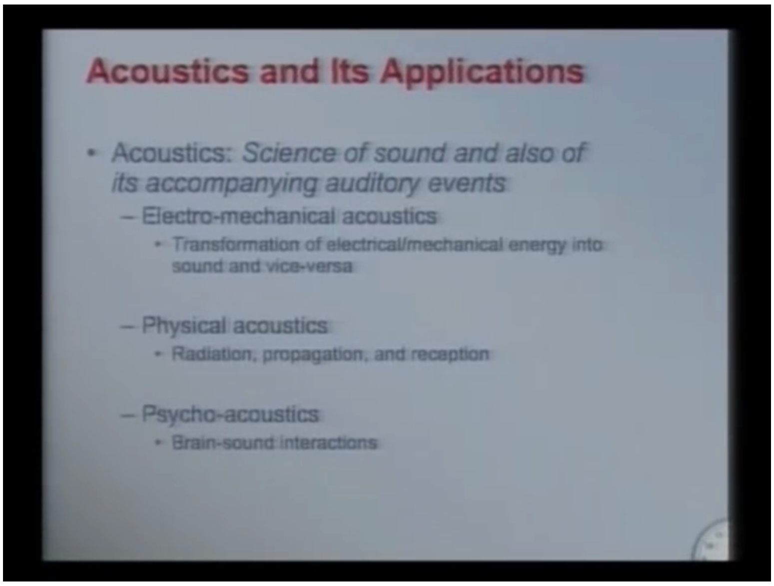

And finally sound comes and hits my eardrums my eardrums are essentially pressure sensing devices, so the sense fluctuations in the air pressure and that pressure fluctuation is converted into electrical signals and then my brain interprets those signals and how this brain interpret these sound waves is called psycho acoustics . So we have 3 key categorisations electro-acoustic, physical acoustics and psychoacoustics.

In this course will talk very little about psycho acoustics but we will capture some of the key things as they relate to physical acoustics and also the electromechanical acoustics.

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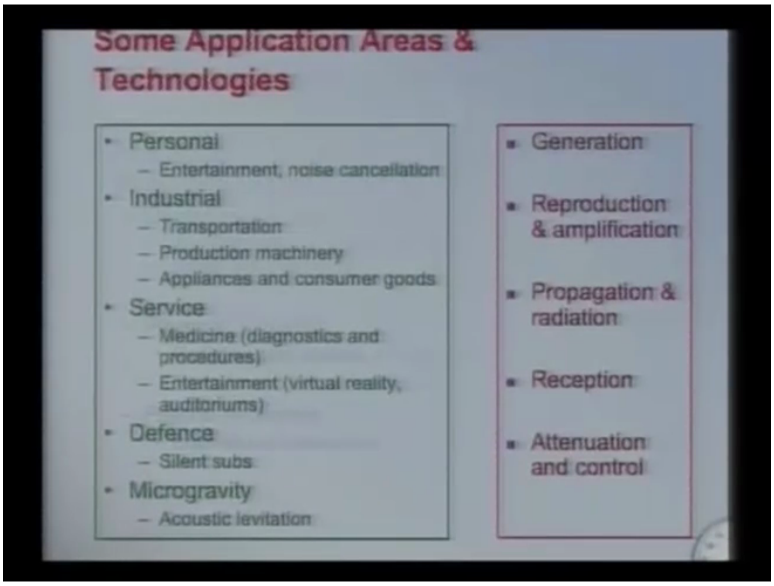

What are different areas where sound is important? So we all use entertainment systems we also have now some of the in the entertainment industry itself we have some noise cancelling headsets, noise cancelling mechanisms or methodologies are also used in automobiles, so that the engine noise gets cancelled. So that is one big area where sound and science of sound is used then in industrial sectors we have transportation trains, planes, automobiles, cars of the challenge is how to make them silent while ensuring that they are as light as possible.

Traditionally a lot of effort has been made to make these things sound less or less noisy if you may call it by relying heavily on a lot of usage of dampening materials and expensive methodologies. So that is one very big area where better understanding of sound is needed to make things lighter especially now that small cars are becoming common and ensuring simultaneously that the system remains less noisy and sounds pleasing enough.

On shop floors we have production machinery and they again are very noisy, so there are governmental standards, environmental standards so that is another big area where application of acoustics is critical for good designs. Every home has appliances and consumer goods, grinders, food processors, washing machines, vacuum cleaners and in all these areas understanding of sound is critical to ensure that their sound characteristics, noise levels are below government regulations and also their pleasing to the human ear.

Then there is another very big area and especially in the service sector where sound is used for diagnostic process, ultrasound scans nowadays people have started using sound for conduct some medical procedures breaking small cysts in the body, so these are some other areas where sound and the science of sound is utilized for human benefit.

In the area of defence acoustics has very very large number of applications one big area where it is used is to ensure that the submarine as they travel below the ocean remain silent, it just happens that below the surface of ocean the propagation of sound waves at lower frequency levels is more or less not at all attenuated and a small sound pressure level gets conducted more or less without any attenuation over thousands of miles of distance.

So if you have a submarine which is generating very small you know very low levels of sound it can be detected at a faraway distance by the enemy, so a big challenge is how to make submarines is quite as possible. interestingly the same feature or same properties sound that it is able to travel underwater at very low frequencies over very large distances is utilized by Whales to communicate with their (()) (19:08) over very large distances.

So that is the big area defence and then there are more some exotic areas also where acoustics are used typical example is microgravity experiments and we will see small animation of this experiment later in the presentation where you have small pieces of matter floating in air more or less immune to the effects of gravity and how pieces small drops of fluids or molten metal's, how they behave and how they form themselves that understanding is enhanced by usage of acoustic levitation techniques.

So you are able to suspend small pieces of fluid or matter in the air and observe them under virtually 0 gravity conditions. So that is another big area of research, so that is another application. So these are the key areas where acoustics is utilized and to have a good understanding of some of these areas what we need is a good understanding of how sound gets generated?

How it is reproduced and amplified? And there in comes a lot of expertise from the electronics side and signal processing and computational mechanic sites. How does sound get propagated over distances? So when I am speaking how does it get propagated to the listeners ear or to a microphone which is capturing my voice? what is the role of reflections as sound is coming out of my mouth and it gets reflected from all sorts of surfaces and is received by the microphone or the human ear?

So that relates to propagation and reception and then also how is sound attenuated and how can we attenuate or reduce sound levels and control to desirable levels based on specific applications need. So those are key areas of technologies which relates to acoustics are the science of acoustics. So and all of these areas relating some way or the other to some of these application areas which we talked about.

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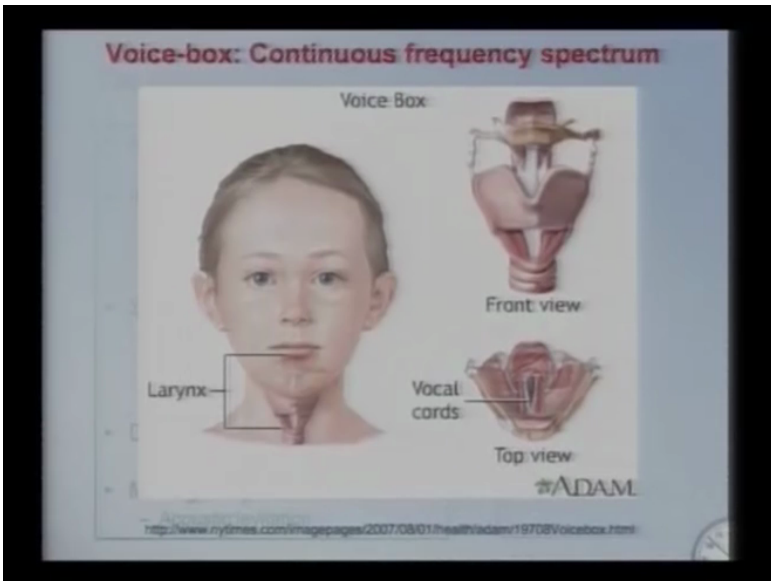

So I also wanted to give a very quick overview of how sound is produced in the human body and why I wanted to share it is because some of this also has to do with our understanding of sound and some of the terms which we have created in acoustic terminology later. So every human body when it produces sound it has 2 vocal cords in the throat area and a picture of that is shown in the slide you are seeing right now.

Now what happens is that these 2 vocal cords they vibrate and this vibration generates a sound. Now if you have a string of a fixed length it will produce a set of frequencies only but a human voice has a continuous frequency spectrum. So it is able to generate a very large number of frequencies not discrete number of frequencies and the way it happens is that let us say I have my vocal cords at their nominal situation this long and if I have to produce a little higher pitch what happens is that the muscles they tend to pull the vocal cord and when they become longer there is more tension in the vocal cords.

So they tend to produce higher pitch sounds, similarly when I have to produce lower frequency sounds then the tension on the vocal cords is relaxed and because of relaxed tension the pitch of the sound generated by vocal cord comes down. So it is a very smart mechanism and it's controlled in a very precise way by our audio sensory system, the brain and also how it is controlled and how it is related the tensions in the vocal cords and through this elaborate mechanism we have a continuous frequency spectrum coming out of our mouth.

So we talked about how sound is produced by human body and how is sound received by the human body and that is that in our ear. So typically what happens is you have sound waves that are generated through a speaker or through a person who is speaking or singing and all these vibrations in form of pressure waves they come and hit our eardrums. The eardrums are extremely sensitive devices.

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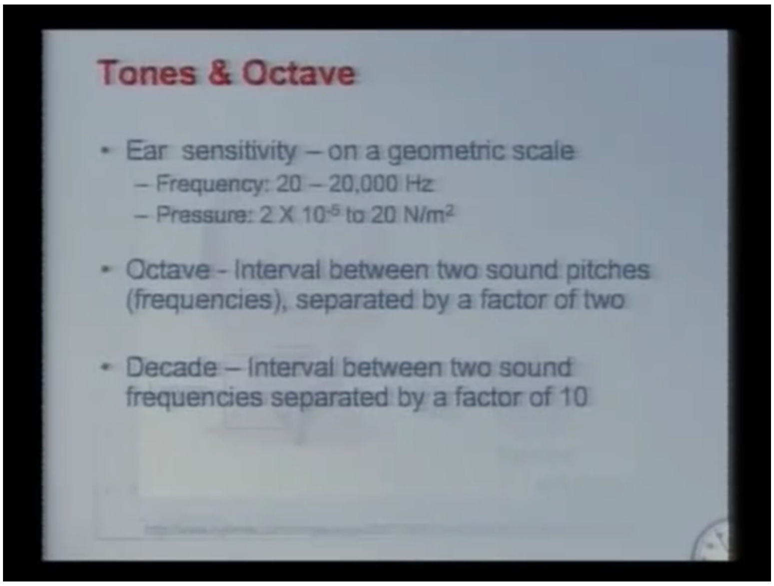

So they can sense vibrations which have a pressure level as low as 2e minus 5 Pascal, provide you a perspective the pressure 1 atmosphere is 10 to the power of 5 Newtons per meter square. So they can sense pleasures 10 order of magnitudes lower than one standard atmospheric pressure. In other words if you do some math they can sense vibrations which are as minute as a couple of hydrogen atoms thick. So they are extremely sensitive (()) (25:48).

On the upper side they can go 20 Newtons per meter square, so there are very few pressure sensors built by human beings which are more sensitive than the human ear. So that is the range of sensitivity in terms of pressure and also in terms of frequency they can go as low as 20 hertz and they can go something up to 20,000 hertz. Another interesting feature is of our ears is that if I have a frequency, let us say an instrument is playing at 100 hertz?

Some music and it is playing at hundred hertz and there is something about the year and how our brain perceives it that the perception of 100 hertz sound by the ear is similar in nature to the perception of sound being played at 200 hertz because they are off by a factor of 2. Physically what is happening is that 100 hertz sound has the same the peak points and the lows.

The peak points and the lows of the vibration profile happen at the same time as they happen at 2x or twice the frequency. So the fundamental and its second harmonic they have similar at same points of time they have highs and lows. Now the second harmonic will have some extra highs and lows also but it will also have the same highs and lows which are also happening at 100 hertz.

So for some reason at least not clear to humans, the human ear or the human brain perceives a frequency at F hertz and a frequency at 2F hertz to be similar in nature and because of this perception Human beings have created this idea called an octave. So an octave is the interval between 2 sound frequencies which are off by a factor of 2. So the idea of octave is rooted in human perception and human psychology.

Now as mathematicians we use a base 10 system. So there is a physical basis for octave, a decade has been created based on mathematical principles that if there is a frequency F and if there is a frequency 10F because we are using a decimal system then it is called a decade. So 2 frequencies if they are separated by a factor of 10 that that interval is called a decade. So you have octave which is an interval separating 2 pitches by a factor of 2 and you have a decade which is an interval between 2 sound frequencies separated by a factor of 10.

So now we try to map this in the area of music. So we have Indian classical music system and we have seen classical music system and in both these musical systems we use the notion of octane. So we will start with Western classical music system and it is good to know and be grounded in some of these things. So in Western classical music system you have 7 nodes and the first node starts with C.

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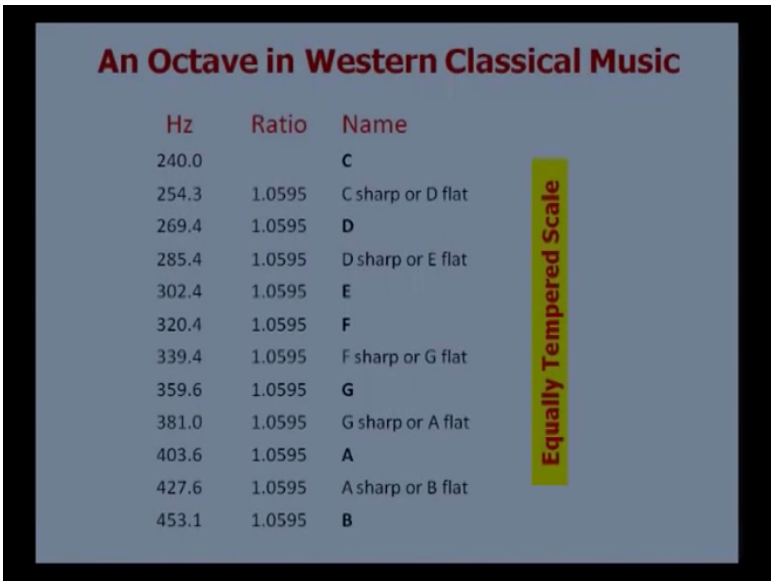

So you have seen C, E, F and G and then you go to A and then we go to B. So between C and the next C, so after B you get the next octave, so between C and A the ratio of frequencies always happens to be 2, a factor of 2. So let us say C note is 240 hertz than the 400 hertz note will be B and after that the next octave will start. If you consider Piano it has a bunch of white keys and black keys.

The white key is typically are C, D, E, F, G, A and B and then between 2 white keys there is a black key and that is called either a C sharp or D flat depending if it is between C and D, if it is between D and E there you can call it either a D sharp or you call it an E flat. If it is between G and A view call it G sharp or you call it A flat. The other interesting feature about Western classical music scale is that not only the nodes between 2 octaves are separated by a fact of 2 but also the intermediate points are in a geometric series.

So in this, on the screen you are seeing C, C sharp, D, D sharp and so on and so forth LB. So that makes one, 2, 3, 4, 5 6, 7, 8, 9, 10, 11, 12 rows which means there are 12 intervals. So the ratio of 2 adjacent notes is 12th root of root which is about 1.0595, if I multiply 240 by 1.0595, I get 254.3 which is assumption. If I again multiply that number by 1.0595 I get D note and so on and so forth.

And because these notes separated by equal ratios not equal numbers but the ratios are equal because this music scale equally tempered scale. After B then you will have the second octave which will again have C then you will like to start again from C, D and F. So you have sometimes you say that Oh! This person can sing his sound spread over a period of 3 octaves which means that, that person can sing let us say my starting frequency is 100 hertz, 3 octaves means 100 to 200, 200 to 400, 400 to 800, so his sound range extends from hundred hertz to 800 hertz, okay.

So again because the ratios of these frequency nodes frequencies are equal it is called equally tempered scale. Now there is nothing musical about this equally tempered scale is just that it is a convenient number you know you take the twelfth root of 2 and then you separate the frequencies by that and you develop a scale but there is nothing musically significant about these ratios.

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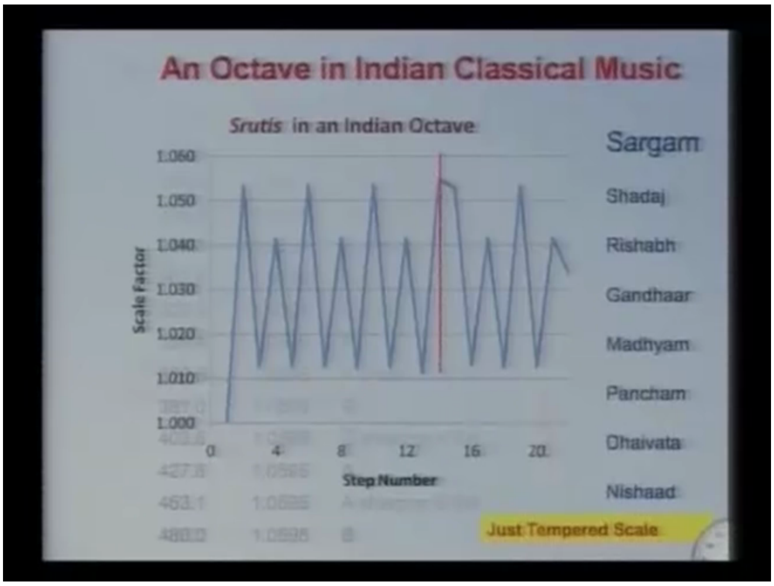

The musically significant aspect is only the factor of 2 which we talked earlier but nothing about 1 over twelfth root of 2. So in Indian classical music Indian classical music system and this applies to both Hindustani as well as Karnataka music system there is this notion called Sruti's. So instead of 12 notes different notes the number of Srutis over an octave is much larger I think it is something like 22.

Let us count 1, 2, 3, 4, 5, 6, 7, is, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 notes and each of these ratios is calibrated to what sounds and that is a qualitative judgement but over several years people mastered and this is about several thousand years back they figured out that oh! This ratio is optimal between let us say if I have to compare starting from C note, this ratio is the first optimal note then this ratio is the second optimal and so on and so forth.

So it just happens that when you plot them the first ratio is about 1.055 I am just approximating then you go down the second ratio is about a little lower 1.01 and the third ratio is a little over 1.04 then the fourth ratio is again comes down to 1.01 then the fifth ratio is again 1.05 something.

“Professor-Student conversation starts”

Student: And the piston 1 began at 240.

Professor: It begins at 240.

Student: And what about the Indian one?

Professor: So we do not have in our traditional instruments we do not have specific keys, right? We do not have keyboards in it.

Student: So music is like relative arrangements of frequency.

Professor: Right.

Student: Arrangements of frequency.

Professor: Yes.

Student: It does not depend from where we start.

Professor: No, I am not a music specialist, a musicologist.

Student: I am just asking technically and even I am not interested in music.

Professor: Yes, but there are no set frequencies in the Indian but the ratios are important.

Student: Yes.

Professor: And based on those ratios these peak ratios, so you start with Sa in the Indian music system and that is called Shadaj or just Sha than the second high is Re, Sa Re Ga Ma, right? So second high is Re and there is called Rishab then the third high the third peak which is this one is Ga and the actual name is Gandhaar.

So you get Sa Re Ga Ma, Pa and then Dha this is again adjacent Ni and then it comes Sa and then you again start the next cycle and these notes are called Srutis. So in most of the situations they break it into 22 but there are some people who break it even at finer levels. So because it is not equally tempered this type of a musical scale is called just tempered scale, okay.

“Professor-student conversation ends”

So we talked about music and how music has influenced some of the terminology in the science of acoustics. So this idea of octave essentially comes from the area of music. I also wanted to share one very interesting experience, so in the nineteenth century America had a big civil war and in this civil war there were 2 sides. One was the Confederate side and the other side was called the Unionist they wanted one single America, Confederate wanted to break up America into different pieces for some reasons.

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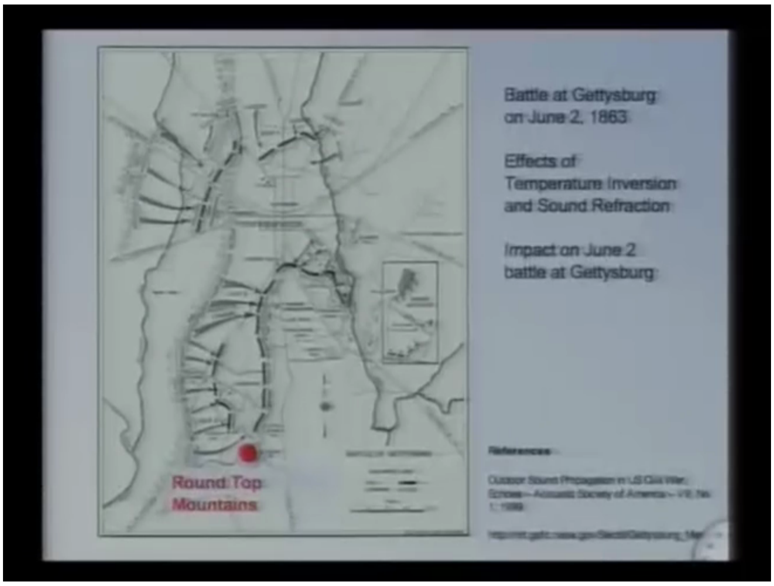

So they were having this war and on July 2, 1863 one of the battles happened in a place in United States is called Gettysburg. Actually there were series of battles over 4 to 5 days in Gettysburg but this was one of the battles and on July 2 this battle happened. On July 1 or before that in Gettysburg Unionist was kind of winning not conclusively but the Confederate, no I am sorry.

Confederates were on the stronger side but the union forces had captured good chunk of some of them (()) (38:17) mountains in that area. So in this picture what you are seeing is this dark black line this line, so this is a series of mountains and the big red dot is a bunch of mountains called round top mountains and that is a part of mountain range called ridge.

So on July 2 the confederates thought about a plan that on July 2 they will execute a specific plan through which they will be able to capture some of the top of the mountains and that will hit them advantages position. So they said that what we will do is we will break our whole Armed Forces into 2 groups. One group will go far from the mountains and they will engage with Unionist.

And the other group will remain focused around round top mountains because they saw that the strength of Unionists near the round top mountain was not strong. So they said, okay group 1 you go little further away and you fight, start fighting with Unionist and once they are engaged in the fight they will not be able to easily support people who are guarding the round top mountains and number of soldiers on around top mountain was not significantly large.

So then we will be able to capture some of these strategic mountains which will help us to further down the road in our battles and the clue was, not the clue they said that group 2 will attack round top mountains only once we hear that group 1 has started fighting with the Unionist far away and the way we will know it is that once we fire your artillery, cannons and guns and all, we will hear the sound and we will figure out that the fight has start, for now you can start trying to capture the round up mountain.

So this was the plan and it looked reasonable just happened that group 1 started the fight and they started firing the artillery and all that but group 2 never heard the sound of group ones artillery they were about 10 or 12 miles away from group one, the sound of the same artillery was heard about 150 miles away in a place called Pittsburgh but these guys they were only 12 miles away and they did not hear the sound and it is not just one person to persons the whole unit did not hear. So something was strange about it.

So people tried to understand and in 1999 an article was published in a magazine called Echoes, it is a publication of acoustic Society of America and the way they explain this was that they had some data on what kind of temperatures were there in that area, what was the humidity and based on that they figured out that on that day it was very hot, it was very humid, so the air near the surface of Earth had relatively less density, it was less dense, so you had less dense air above it there was fairly normal air with normal density and then you go up further and the atmosphere then again the density of the air was less.

And the way the situation has been explained is that cannons were being fired sound was coming out of those Canons and it would go through medium which was rarer density wise it had lower density and as a consequence because waves refract, so they will refract go up, so the guys who are near the round top mountain which is group 2 they never got to hear those sounds but the same sound travelled and then it went up to higher levels of atmosphere and there again you have a thinner air, so it will refract back downwards and then people far away 150 miles they were able to hear the sound but these people who were closed to did not hear it.

So this is an interesting phenomena, so sound is a wave and by virtue of being a wave it gets reflected, it gets refracted, it interferes, it gets refractions you have acoustic shadows, so any phenomena which is in a light wave you will see something equivalent happening in area of sounds. So I wanted to share this interesting feature and explain that all wave related phenomena are also exhibited area of acoustics.

So now over next 2 to 3 slides what we will do is, we will try to understand some fundamental quantities at a very cursory level because we will dig deeper into the details as we move further down the course and subsequent courses we will learn more about these things.

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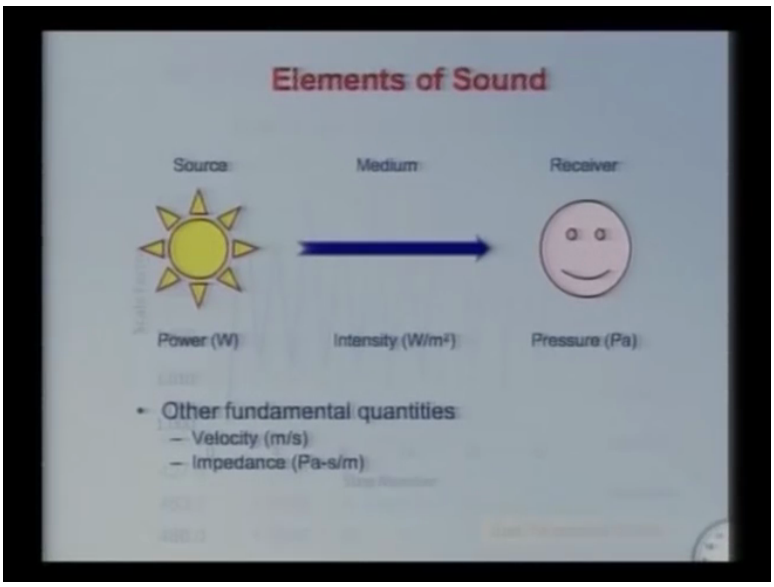

So in a very broad sense you have 3 elements in a sound (()) (44:11) generated, you have some place where sound is getting generated then that sound travels through medium and then at the final destination it is being received. So the sound gets generated maybe through a human ear or through an animal, through a child or a through a music system or through an engine it gets transmitted through air or oil or water or whatever and then you have a receiver which could be a machine or it could be a human being or it could be an animal or whomsoever.

So in general the characterization at the level of source happens in terms of power and that is measured in watts. As sound travels through the medium we try to characterize it through a term called intensity and which is essentially power per unit area. So if my unit for power is watts and unit for area is square meters then the unit of intensity would be watts per square meter.

And then finally you have a recipient which could be a microphone or it could be a human ear and a lot of receiving devices they sense pressure and some receiving devices also sense velocity. So at the receiver end we try to characterize sound through pressure and in some cases through velocity you will see oh! This sound is this loud because it's the pressure is extra generating at my ear or in the microphone is so much.

In the medium I tried to characterize sounds through this motion called intensity and at the source I tried to characterize sound by how much energy it is (()) (46:17) into the environment. So if I have to how good a sound system is, one way of characterizing it is how much energy it is receiving through electricity let us say 100 watts of energy and how much it is generating sound? Then let say it is 2 watts, so then it is 2 percent efficient.

As a side note most of the sound systems have fairly low efficiency. If you have 3 percent efficient, sound system you have a fairly good system. So a lot of times you see in media, in newspapers, in magazine that they will some commercial vendors of sound system will try to sell you a system which produces 1000 watts of sound. So that is marketing number.

Probably what it means is that it is eating 1000 watts of energy because 1000 watts of pure sound if you generate that can rob the whole I mean a very big area. So 1000 watts is a very big number. Other fundamental quantities are velocity of the particle. Again the unit could be meters per second and impedance it is analogous to impedance which we use in electrical circuits and we will talk much more about this term impedance later in the class.

“Professor-Student conversation starts”

Student: Sir, I just wanted to know clearly why pressure is used at the receiver I mean why is pressure used to measure things at the receiver.

Professor: So typically when you receive sound you will try to sense what is happening in the medium there will be pressure fluctuations and there will be particles moving back and forth. So they will have pressure fluctuations and also they will have velocity changes. So those are the 2 changes you will sense and then he will try to figure out what is the type of sound, right? And that is how ear senses it, it senses pressure fluctuation. So again other fundamental quantities are velocity and impedance.

“Professor- Student conversation ends”

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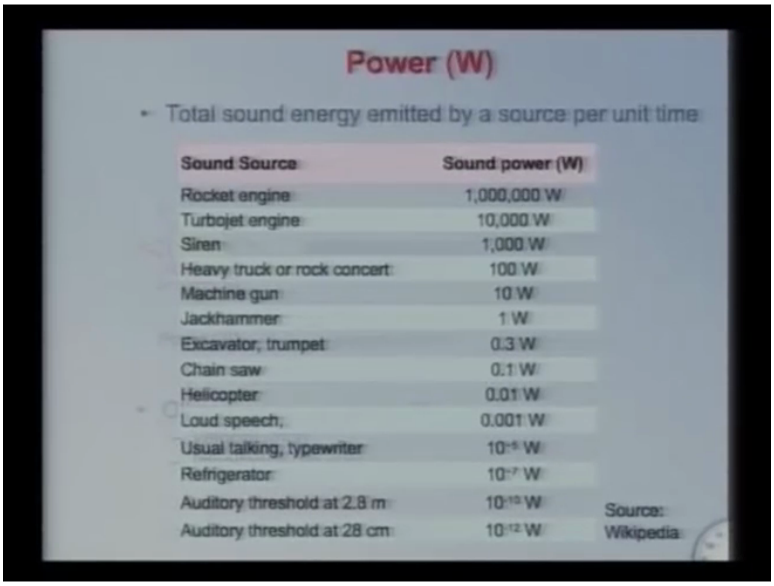

So we talked about power and I wanted to show some of the numbers. How much power do different sound sources generate? So a rocket engine is a very powerful device in terms of being able to produce some it generates about 1 million watts of power. So that is one extreme end and then the other extreme end, let us imagine you have some source which generates (()) (49:16) amount of sound which the human ear can hear and it is 28 centimetres away.

28 centimetres would be something like a little less than a foot, foot away. So all it has to generate is 10 to the power minus 12 watts and that is the faintest sound the human would be

able to hear. If the same source is 2.8 meters away then it has to generate 10 to the power of minus 10 watts. When I am talking normally loud speech not this speech, not loud speech all I am generating is a 1000 watt.

A helicopter which is very loud generates about 10,000 watt, a machine generates about 10 watts. So again I wanted to re-emphasize, a lot of marketing stuff which happens and you go try to go, you go to a shop and you try to buy a sound system and is a this is 1000 PMPO or pure what is it? Pure musical power out thousand watts is something like a very loud siren which can be heard at very large distance is in a city also.

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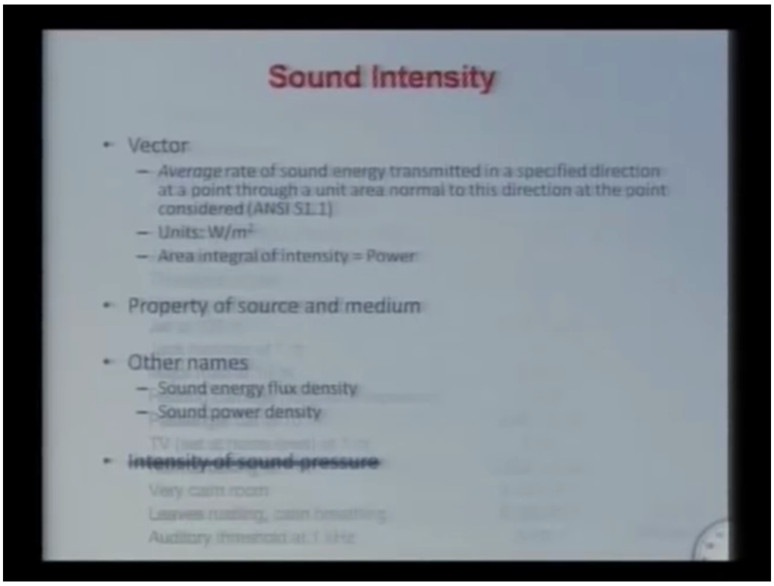

So again we talked about power, now in terms of sound intensity first thing we have to understand is that it is a vector. So it is a vector because it is sound energy being transmitted per unit area and that transmission has to happen normal to that area. So then it is a vector and there is an industry standard definition average rate of sound energy transmitted in a specific direction at a point through a unit area normal to this direction. Watts per square meter could be its unit and if I integrate this whole term this quantity over a sphere then I get power back.

So I have a source which is generating let us say W watts of power and sound is travelling and let us say at this point I am trying to measure the intensity and if I integrate the sound intensity around the whole sphere then I get that W watts of power back assuming there is no dissipation of energy happening as sound is travelling through the medium which in reality is not the case but the dampening in ear is fairly small. So I will get fairly close to the original watts which are being generated at the source.

“Professor-Student conversation starts”

Student: What exactly is dissipation means in the sense that there is loss in terms of heat?

Professor: Heat. So as long as the transformation is happening between kinetic and potential energy is not getting dissipated but there will be some losses because of heat (()) (52:34). So also sound intensity is a property of source and the medium we will see how it is influenced by properties of the medium and of course if the source is stronger than sound influence will be higher and back and vice versa.

“Professor- Student conversation ends”

Sound intensity is also known by some other names, some people call it sound energy flux density, it is also called Sound power density, some people also use the term intensity of sound pressure but that is a wrong term to use intensity of sound pressure because what essentially it is this intensity of power, so it is not intensity of pressure. So we have to be careful.

So bit of about power than through the medium we try to characterize it in terms of sound intensity and when it reaches the instrument or the receiving end we try to sense pressure or velocity and pressure is the typical norm or the metric through which we try to characterize sound at the destination or the receiving point.

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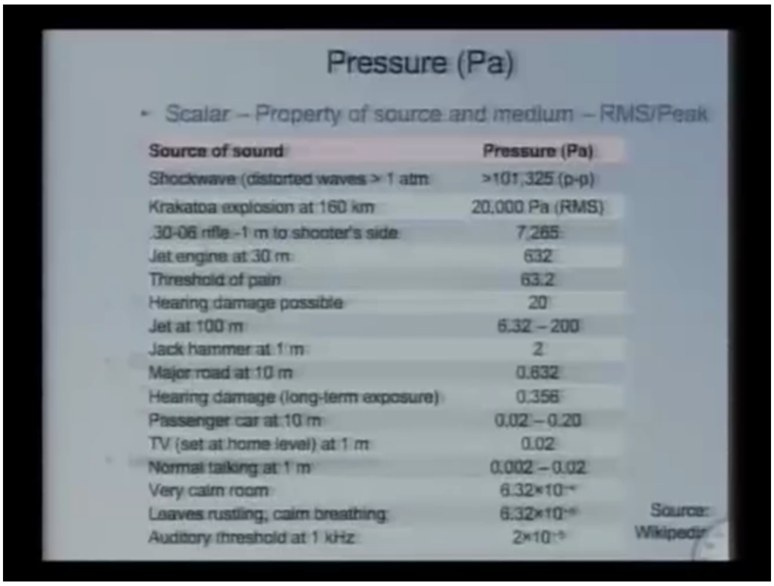

So again this is an elaborate table I pulled it from Wikipedia and it shows a whole range of pressures for different sound sources. So auditory threshold at 1 kilohertz is about 2e minus 5 Pascal so that is the faintest sound human ear can perceive to give you a perspective it will be something like a mosquito about 1 meter away that level and that generate vibrations on my eardrum which are similar in order of magnitude compared to that of some of the smaller molecules. So the eardrum can sense very small perturbation pressure.

If there is a very calm room, nothing is happening, no motors no air conditioning and then I hear something like 6.32e minus 4 Pascal then I go further again passenger car it is about 0.02 to 0.20. If the pressure exceeds 0.356 Pascal then I can have long-term damage to my ear if I get exposed to this level on the longer and if I exceed this number 20 Pascal then I can have immediate damage even though the exposure to this sound maybe per small interval like damage to my ear.

So typically we say that the human ear can hear sound pressure levels from 2e minus 5 to 20 Pascal then you have other numbers threshold of pain is 63.2 Pascal ear start physically perceiving pain and shock waves are over hundred thousand Pascal. So even at shockwave level which is the hundred thousand Pascal at that level we start getting close to one atmospheric pressure.

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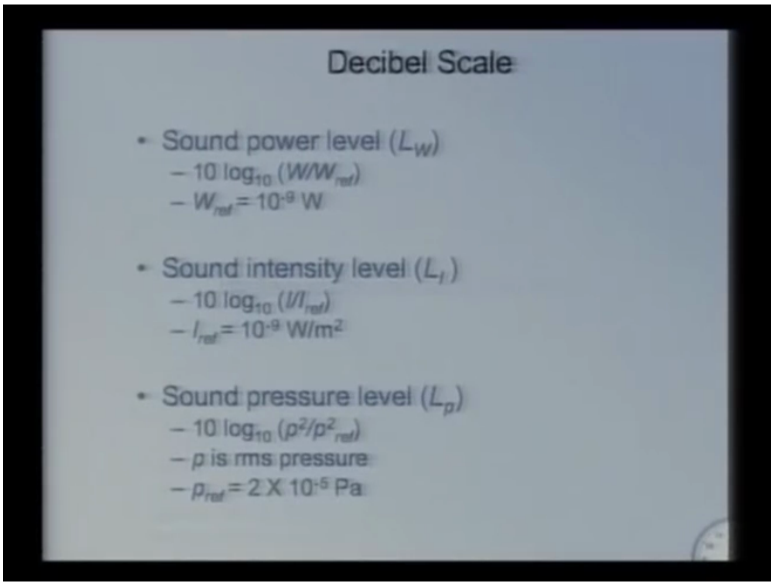

So this is one technical term I am introducing in the first lecture, we will learn more and we will do lot of mathematics around us. So we use a decibels scale in acoustics primarily because the range of pressures which we have to deal with starts from e minus 5 minute was up to 20 and sometimes even above that. So to manage a whole range of pressures which spans several orders of magnitude is we use decibel as a unit.

So the definition of a decibel for sound pressure level is 10 log W which is what is over referential watts then you have similarly decibel scale for sound intensity level and then finally we also have a db SPL level or the decibel level for sound pressure level as 10log pressure square divided by pressure square reference and we square it because the square of pressure is dimensionally similar to power.

So decibel helps us understand at a power level how are different sound levels combine into each other. So I would like to close this with another very interesting video which I pulled up from YouTube and what you will see here is acoustic levitation and this is the technique which is used in microgravity experiments and it is fun to watch, so I thought I will show it view and hopefully you will find it interesting and try to learn more about it.

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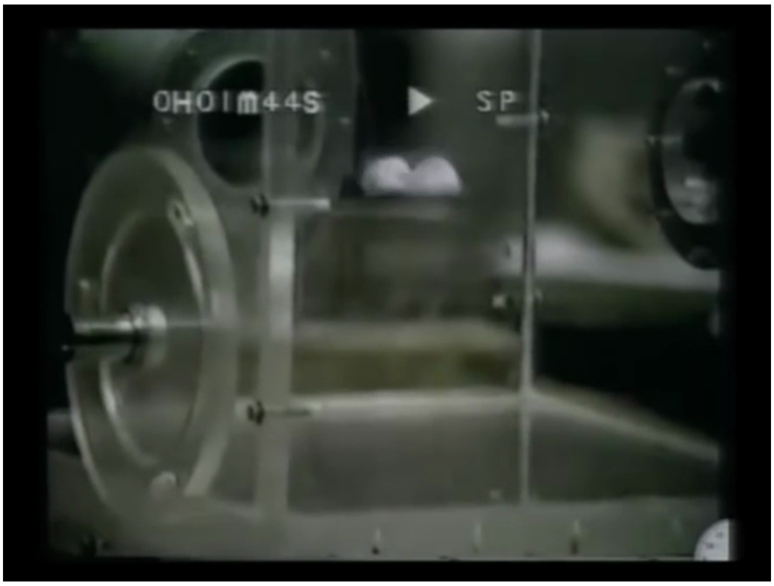

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So what you have here is closed transparent box and it is a rectangular box and in that box you have 3 speakers which you see here so they are firing from 3 different directions and there are phase relationships between frequency coming from one speaker vis-a-vis other speaker and depending on how you play with the frequency and the phase difference between different sources.

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You can raise light object in air and they do not have to be supported and if you play with some of these parameters smartly enough sometimes the object will rotate, sometimes the object will not rotate but it will just stand still.

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So you see that the object is not rotating earlier it was rotating and this approach.

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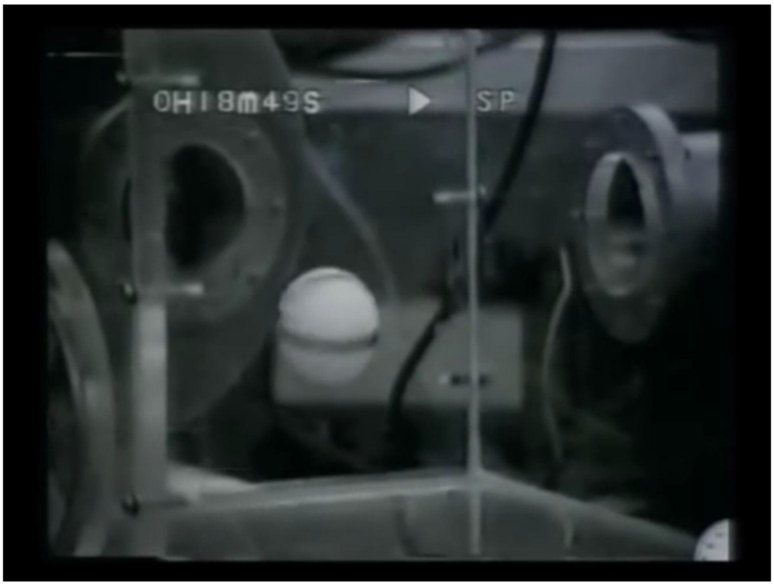

So now they changed some of the parameters and now it has start, so it is a very controllable method to manipulate solid and liquid objects in air and see how they behave in virtually no gravity conditions. So with that I conclude my lecture and we will meet next week, thanks.

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