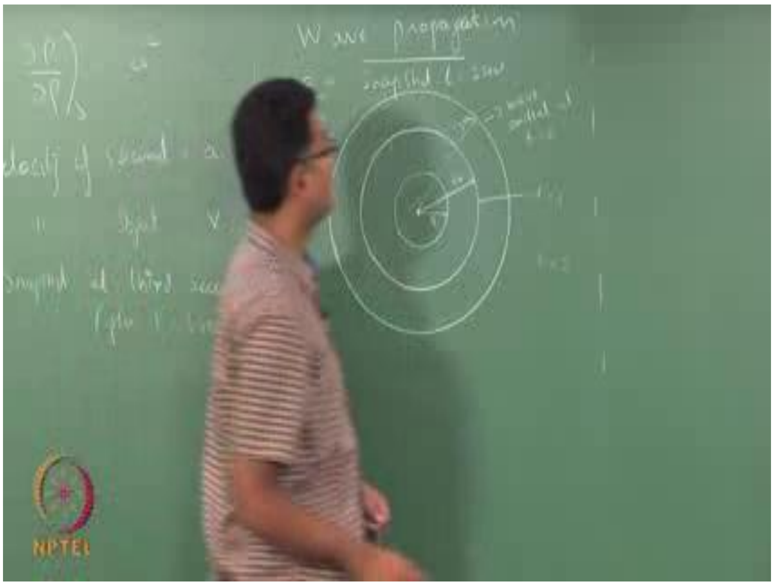
Fundamentals of Gas Dynamics

Dr. A. Sameen
Department of Aerospace Engineering
Indian Institute of Technology, Madras

Week – 03
Lecture – 08
Wave Propagation

In the last lecture we had seen how a wave propagates, how the sound wave is generated when a body moves, and we have also seen how the pressure changes due to density changes related to the velocity of summed.

(Refer Slide Time: 00:35)



In this lecture we are going to see the consequence of object moving in gas and the effect of relative velocity between the sound wave and the particle velocity or the object bluff body velocity. We are going to see the wave propagation when an object moves in space. So, if an object moves in space it is going to create a pressure change which is going to create a wave front that is moving ahead of the body and that velocity of the wave front is what we have derived to be the velocity of the sound. Now the problem what we have is, whenever there is a motion of the body there will be sound wave that is moving ahead of the it. Now there is a relative velocity between the body and the velocity of the sound. Now what is the consequence of this relative velocity is what we are going to see.

So, what I will assume now is I have a point source and I will assume that this point source is going to generate some way. So, I have a point source and this going to generate sound waves and these sound waves are going to be spherical in a nature. What I will do now is, say after 3 seconds or 3 seconds I will just look at where the waves are. Now you have infinite number of waves that is generated from the point source so we will concentrate only 3 waves which is generated at the 0th second, first second, second second and the third second, and we will take a snapshot of the view .

So, what I will do is first let me define something velocity of sound a, a meters per second velocity of the object or the bluff body or whatever is v. Our aim is find a snapshot at the third second after your t equals 3 seconds. I am taking a photograph after 3 seconds from the t equal 0 conditions. I have a point object, the first case I will assume v equals 0 which means the point source is stationary and I will assume the sound wave is uniformly at generated. So, I have here a thread there are 3-4 knots the distance between each of these knot is say a ok. So, at 1 second the light wave would have traveled a distance, at 2 second light wave would have traveled 2 seconds, and at third second liked way would have traveled 3 a.

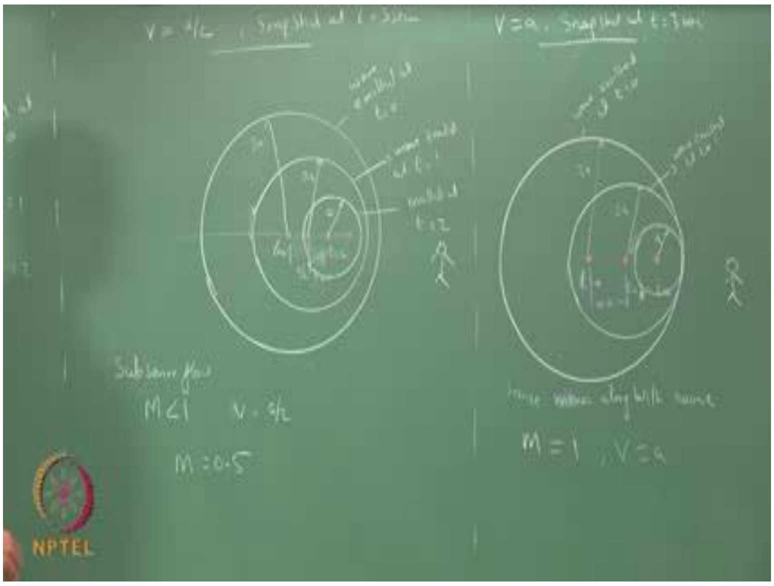
Now the snapshot at t equals 3 seconds, so the wave that is generated at the 0th second would have traveled 3 a distance. So, I take a length of 3 a and I am going to draw a circle. This is wave emitted at t equals 0 and now we are watching at the third second. So from t equals 0 to t equals 3 the wave traveled 3 a distance, so this distance is 3 a fine. Now the wave that is generated at t equals 1 would have traveled 2 a distance, so I take distance 3 a and draw a circle. This is my wave emitted at t equals 1 seen after 3 seconds.

Now wave at t equals 2, the wave at 2 equals to would have traveled only a distance because the difference is only 1 second, so in 1 second the wave traveled just a distance. So, the wave that is generated at t equals 2 would have traveled just a, so this is just a, this is just 2 a, this just 3 a. At the third second the waves have just generated but it has not traveled anywhere, so this would be the wave that is going to be the source itself.

I repeat, so this is the wave that has traveled 2 a distance from t equals 0 viewed from with the velocity a, so this distance is 3 a, so you are viewing it at a snapshot of 3 seconds. At 3 seconds this is what you would see if I have considered only these 3 waves. Remember there are infinite numbers of waves in between, but we are concentrating on just these 3 waves right. Here the source is stationary. So, source is not moving at all. The wave that is generated at the third second still stays there, the wave that is generated 1 second earlier is seen at a distance a, the wave that is generated at 2 seconds earlier would be seen at distance 2 a, the wave that is generated at 3 seconds earlier is seen at 3 a.

So, these are spherical effects of 3 d effects source and its space 3 d, these are all spheres that is concentric spheres with the sender as the source.

(Refer Slide Time: 08:16)



Now consider v is a by 2, which means the source is moving at a velocity half the velocity of sound. So, I would again snapshot at t equals 3 seconds. At t equals 0 the source is here I will mark it with a red color. So, at t equals 0 seen after 3 seconds the wave would have traveled 3 a distance, so I take 2 a in my scale and draw a circle. So, this is the wave that has generated at t equals 0 seen after 3 seconds, so this is emitted wave emitted at t equals 0. Now at t equals 1 the source would have moved at distance a by 2, so I take a by 2 and I mark that point, so at a by 2 the source has moved at t equals 1. The source has moved a by 2 distance.

The wave emitted at t equals 1 would have traveled 2 a distance if you are taking the snapshot at 3 seconds. I take 2 a and I draw a circle. This is the wave emitted at t equals 1. Now at t equals 2 the source would have moved at distance another a by 2, so this is t equals 2. At t equals 2 there is wave that is emitted that would have traveled a distance if you view it from at the third second. So, I take a distance and I draw a circle. At the third second the source would have moved another a by 2 distance, but the wave would not have moved anywhere because we are taking the snapshot at the third second, so the wave is still there at the source.

Again I repeat, so the source is moving at velocity a by 2 so at every second the source moves a by 2 distance, but the wave that is generated at the initial point which is t equals 0 would have traveled 3 a distance if your snapshot is at third second. The wave that is emitted after 1 second at t equals 1 would have traveled 2 a distance, so this is 2 a, the radius of this circle is 2 a, the radius of this circle is 3 a, radius of the circle is a. Just that the circle is moving at a different speed. We will come back to the consequence later, but this is the picture. So you have a wave that is moving, the source is moving behind the wave; the wave is always ahead of the source.

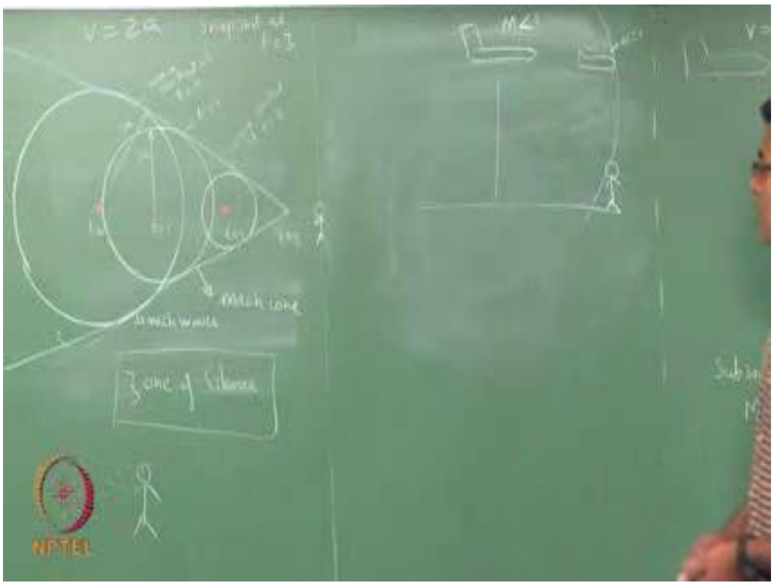
The point here would somehow know that the source is coming before the source reaches that point, because the wave is going to reach before the source this is the case of so called Subsonic Flow where m is less than 1. Here, the velocity of the source is less than the velocity of sound, so what we have drawn here is for the case of m equals 0.5. So, in Mach number 0.5 the source is moving half the velocity of the sound and this any point in the space will know about the approaching source much before the source reach the point.

Now let us look at the next v equals a. Again snapshot at t equals 3 seconds. So I have a source look at some point here. So my 3 a would be this at t equals 0, this is the wave emitted at t equals 0 taken the snapshot after 3 seconds so this distance is 3 a. The wave that is emitted at the source t equals 0 would have traveled at distance 3 a if you look at it after 3 seconds. Now, after 1 second the source would have moved a distance of a, this is at t equals 1 this distance is a, which is the velocity of the source. So, the source would have moved a distance a. And you are viewing it after 3 seconds, so it would have traveled at distance of 2 a. I take 2 a distance and draw the circle. This is 2 a, this is the wave emitted at t equals 1. Now at t equals 1. Now t equals 2 the source would have moved another distance a. This is t equals 2 and you are trying to see where the wave is after 3 seconds so that the wave that is generated at t equals 2 viewed at the snapshot of 3 seconds would have traveled at distance of a. So, in 1 second the wave would have traveled at distance of a, that is a location of the source at t equals 2 so this would have traveled a distance a.

So the source at t equals 0 traveled a distance 3 a, source at t equals 1 traveled a distance 2 a source at t equals 2 traveled a distance a and source at 3 seconds would have traveled 0 distance it is just located at the source itself at after 3 seconds. The source moves along with the velocity of sound; moves along with the sound wave. So, a point here will know about the source only when the source hit the point, because the waves are also moving along with. There is no information ahead of the source, unlike in a wave subsonic flow where the points somebody standing here will know about the approaching source much ahead of the source itself, whereas here the person standing here will know about the source only when the source reaches the point.

So, this is the case of m equals 1 where you are v is equal to you’re a; now, for the supersonic case.

(Refer Slide Time: 19:05)



If my v is 2 a, again snapshot at t equals 3 seconds. So, t equals 0 the source is somewhere here and after 3 seconds it would have traveled a distance 3 a, so it would have traveled a distance 3 a. This is wave emitted at t equals 0. Now at t equals 1 the source would have traveled a distance 2 a, so 2 a is here and at 2 a if I am viewing it at t equals 3 the wave would have traveled for 2 seconds so the distance it has traveled is 2 a. So, I take 2 a and I draw the circle. This point would be exactly on this, so this is 2 a. So, 2 a is the distance that the wave traveled in 2 seconds the wave that is emitted at t equals 1 this is t equals 0, so this is wave emitted at t equals 1.

Now after another second the source would have moved a distance 2 a. So, the 2 a is here and in this is a t equals 2, so the wave would have traveled a distance of a in 1 second which is what I would draw here. So, this is the wave source at t equals 2, this is the wave at wave emitted at t equals 2. Now t equals 3, the source would have moved a distance 2 a so the source is here at t equals 3, and the wave generated at t equals 3 would be there itself at the location of the source. So, the source is much ahead of your wave, by that time for somebody standing here there is no information about the approaching source and he will know about the source from the wave only after it has passed the location. so this is for the case M equals 2 where your V is 2 a.

So that is the consequence of what we are been discussing. In subsonic flow you always have the information of the approaching source in the form of waves much ahead of the source itself, whereas in sonic case you have the information only at the point when the source approaches the point along with the wave. Whereas, in supersonic you will know about the wave only after the object has passed the measurement point or the observation point. Now further to this you can have; so if I draw these things and if I draw the tangent of these I would get, I will take another color. With the source the vertex I can draw a tangent along this and similarly I can draw a tangent along this that touches the source.

At the third second this is where the sound waves are located. After this or the region outside this line there is no wave. So this region outside this line which would be 3 d in nature which is called a Mach cone, so outside this region is the so called Zone of Silence because you will not know about this till the wave reaches somewhere here. So, if somebody here will know about this wave only when this cone would have reach this point, which means that the source would have moved further away and the cone would have enlarged itself.

So this region is viewed zone of silence and these waves are called Mach waves. So, the Mach wave will approach this observation point only when this observation point is inside the cone. So, if I have a projectile moving ahead this will generate a Mach cone and you will know about the waves only if you are inside the Mach cone, outside if the zone of silence you will not know about the waves generated or the noise that is generated.

Now this has consequence. So, if I have an aircraft that is moving and there is an observation point here, so let us say if v is a by 2 or the velocity is the Mach number is subsonic. If the Mach number is subsonic from this diagram we know that even before the vehicle reaches this observation point there is some wave that would reach here, so even a when the vehicle is somewhere here you would know about the location of the vehicle or you will hear the vehicle, hear the aircraft. Whereas, if it is running at supersonic condition the observation point will see and here at the same time. If it is that m equals 1 you will hear and see the vehicle at the same point of time. Whereas, in supersonic is you will here at only after sometime the vehicle would have passed you before you could hear the noise.

The time difference between seeing and hearing can be used to find the velocity of the vehicle itself, velocity of the aircraft. So, we will do some examples later on. So, that is how the relation between your velocity of sound and the velocity of the object or the velocity of the gas or whatever.

So, what we are learnt today is the way in which the wave propagates if there is a relative velocity between the source and the velocity of the sound, and that has direct consequence in what we are discussing in this course which is this. And we will do the problems in a later fine of time.

Thank you.