

Turbomachinery Aerodynamics
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Lecture No. # 18
Noise Problem in Axial Compressors and Fans

We have been talking about various kinds of axial flow compressors and their designs in the last few lectures. We have done various aerodynamic issues related to the axial flow compressors and then, of course, we talked about how those aerodynamic theories and understandings can be used to create and design an axial flow compressors, blades, rotors and stators. Now, all of it together, also has another issue or a serious issue which we will talk about in the today's lecture. This is regarding the noise that is created by the axial flow compressors and the fans used in turbo fans, which need to be seriously regulated as per present regulations or traffic regulations all over the world.

Now, in the early days of jet engines, when the jet engines started powering aircraft, the main source of noise was the jet noise; the jet noise that came of the rear of the engine and that jet noise was the most noise making device or element in the jet engine. Over a period of the time, as the engines became more and more powerful, there is another component that became bigger issue in terms of noise making device. Noise related to compressors and fans in most of the turbo fan engine that are used in civil aircraft engines, have become such a big problem that, the regulatory authorities all over the world have put stinger restrictions on the noise created by various jet engine elements.

So, now, we have jet engines, that noise coming out from the rear of the engine as the jet noise; it also as noise coming out from the front of the engine, which is created by the fans and compressors. And, we shall see in today's lecture, that is one of the reasons this noise is become more and more annoying and need to be regulated, is because the aircraft compressors and fans have actually become more powerful; and, as we have discussed in the last few lectures, they have actually gone supersonic and transonic. So, when they go supersonic and transonic to create a more compressor loading and more

compression ratio in short smaller size compressors, they actually end up creating more noise; they are more noisy elements or more noisy machines.

Remember, they are aerodynamic machines, so the noise that comes out of them are essentially aerodynamic noise, and this aerodynamic noise has become such an annoying source of problem, that many regulating authorities have put stringent regulations on the noise emanating from these compressors and fans.

Many airports in the world have very stringent noise regulations and if you do not conform to those noise regulations, you cannot operate from those airports. So, the noise regulation has become such a stringent thing, it is now started impacting how the compressors and fans should be designed. And, it is one of the reasons, in fact one of the main reasons, why commercial aircrafts compressors and fans, fans being the first component in the compressor, have not gone beyond the transonic or let us say, middle transonic Mach numbers, where the tip relative Mach numbers is of the order of 1.5 or 1.6

The military engines have gone beyond that, so the technology for making high Mach number fans and compressors do exist, but they are not being used in commercial aircraft engines and one of the main reasons is noise. Because, the moment you have high inlet relative Mach numbers, the noise coming out of these engines immediately start going up. And, we shall see that the noise is very strongly related to the velocity or the Mach number with which the flow is indeed passing through the compressors.

So, some of these issues have impacted how the blades should be designed, how the blades need to be finally configured and we shall see that unless you conform to the noise regulation, your compressor is not going to be accepted commercially and your engine is not going to be certificated for operation worldwide; so, the issues are extremely important. And, we thought we should devote at least one lecture on this particular issue or in which we will discuss noise related problems related to axial flow compressors and of course, fans.

So, let us take a look at what are the fundamental issues that are involved here that is creating such a lot of annoyance to so many people all over the world. We shall stick ourselves to discussing noise problems in axial flow compressor. We will not go into the science of acoustics or science of sound making or sound measurement. We will just

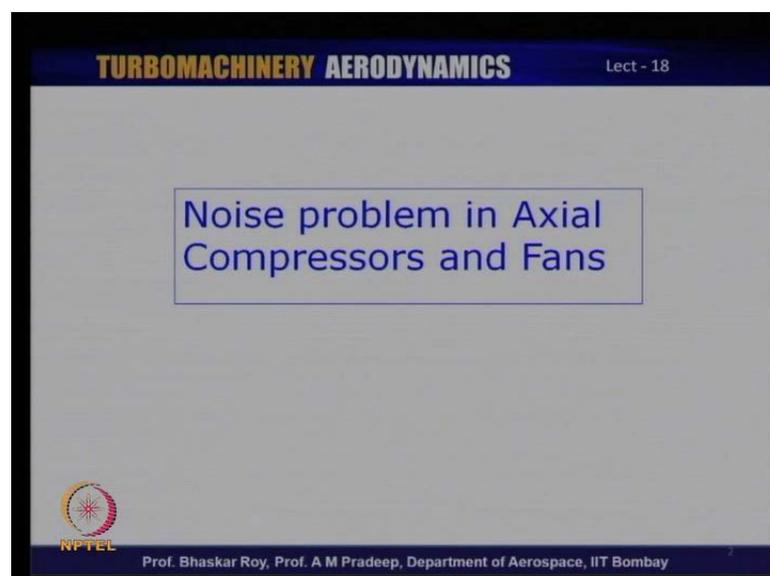
mention them in the passing, so that you become aware of the science that is involved of in this particular problem related to aircraft engines.

Because, the science of acoustics is huge; it is a science by itself. And, it involves so many things and it does involve a lot of high level mathematics. All that is really speaking beyond the scope this lecture series, so we will stick to certain fundamental issues, and I will try to bring to you certain fundamental definitions that are used in quantifying the problem that we are facing, that is the noise. And then, I will try to mention to you and show to you, how this noise is actually measured, and how it is actually related to the axial flow compressor operation, and then finally we will end up by discussing what people are doing to contain this noise.

So, noise containment, by design to begin with, and then later on by certain containment methodology is a measure technological issue with related to axial flow compressors and aircraft engine specifically. The land-based gas turbine may not have such a big issue, because most of those compressors are most likely to be subsonic compressors, which do not make such a lot of noise and not, certainly not as much as aircraft engines.

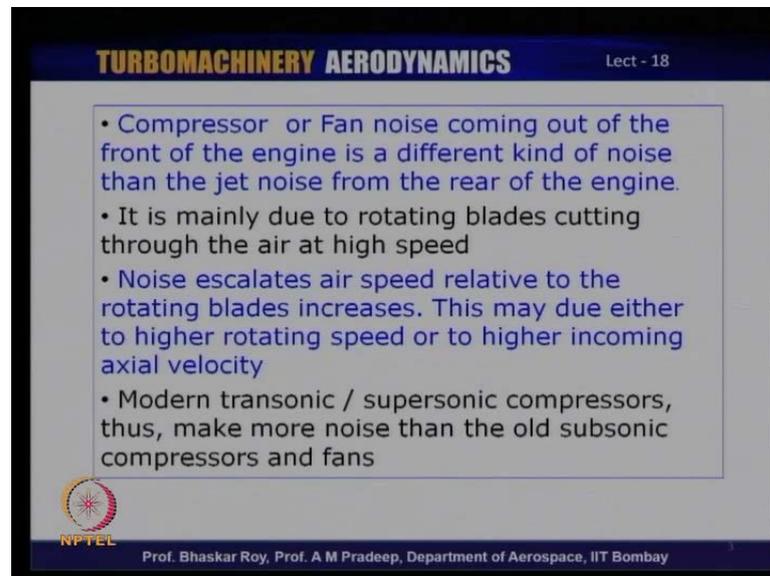
So, in land based gas turbine, that noise is not that big an issue, as it is in an aircraft engines. So, we will stick to certain issues which are relevant and really an annoying issue with relation to aircraft engines. So, first let us get into a little bit, just a little bit, a **twist** on the superficially the science of acoustics.

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We are looking at noise problems in axial flow compressors and fans.

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- Compressor or Fan noise coming out of the front of the engine is a different kind of noise than the jet noise from the rear of the engine.
- It is mainly due to rotating blades cutting through the air at high speed
- Noise escalates air speed relative to the rotating blades increases. This may be due either to higher rotating speed or to higher incoming axial velocity
- Modern transonic / supersonic compressors, thus, make more noise than the old subsonic compressors and fans

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Now, compressor or fan noise, as I mentioned, is a different kind of noise than a jet engine. So, jet engine creates a heavy noise that is due to the shearing action of the jet coming out from behind the nozzle of the engine, whereas the noise created by the compressors or fan is mainly due to the cutting of the blades, rotating blades through the air at higher at high speed.

So, as I mentioned, higher the speed of these cutting, higher is the noise that is created and this noise escalates as the speed relative to the rotating blade increases. Now, as we have seen, this relative speed or relative velocity as we use to call it or relative Mach number, may increase due to either increase of the rotating speed or due to higher incoming axial velocity coming through the intake of the engine.

So, both either of them would increase the relative velocity or relative speed related to the rotating blades. Then, of course, the modern aero-engines have gone transonic; certain of the air engines which are used in military applications have gone clearly supersonic. And, in those cases, the noise is far more than that of the old subsonic compressors and fans. So, the problem is many **fold**s today, and as I see, as we see, is directly related to the blade speed cutting through the air, and we shall see as it related to the fifth order or the sixth order of the blade speed. So, the result is, slight increase in blade speed could increase the noise tremendously, hugely and that is something which

the designers, compressors and fan designers and aero-engine designer are trying to contain by design and through containment methods.

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Fundamentals of acoustics:

- 1) All sound is due to fluctuation of pressure levels and travel of this fluctuation
- 2) Sound is measured in decibels- A,B & F scales
- 3) Sound pressure level (SPL) is defined as :
$$SPL = 20 \log_{10}(p/p_{ref}) \text{ dB}$$
where p is the RMS pressure fluctuation and p_{ref} is the reference RMS of pressure fluctuation, is taken equal to $2 \times 10^5 \text{ N/m}^2$
- 4) Acoustic power is defined as Power Watt Level
$$PWL = 20 \log_{10}(W/W_{ref}) \text{ dB}$$
where W is the acoustic power in watt, and W_{ref} is the reference acoustic power = 10^{-12} watt .

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Let us get into certain fundamental issues related to the science of acoustics. Now fundamentally, sound is due to fluctuation of pressure levels and the travel of this fluctuation. So, if they travel in waves, sound always travel in waves like light, and these waves are due to the fluctuations of pressures. If you do not have any pressure fluctuation, we are not going to have any sound. So, a silent zone means that there is no pressure fluctuation going on anywhere in that zone.

Sound is typically measured in decibels; this is been derived over a period of years. And, **it is** it is measured in number of scales, predominantly in A scale, sometimes in B scale; there are many other scale which I have mentioned and finally F scale, which is called the flat scale. And, I will, **I will** try to mention very briefly, what these scales are, just a little while later.

The sound pressure level, as I mentioned sound is actually a pressure fluctuation, so Sound Pressure Level is defined as SPL and that is $20 \log_{10} P$ by P references; and, as I mentioned, it is measured in dB or decibels. Now, dB measurement is in number of scales; we will come to those scales just little while later. Now, in this equation P , is the RMS root mean square, pressure fluctuation, and T reference is the reference RMS root mean square of pressure fluctuation, and this reference is normally 2×10^{-5} to the power

5 Newton per meter square which is the normal units for pressure. So, there is **reference**, that is been sort of universally accepted at the moment, and we, with the respected to that reference, what is the pressure that is operating at a particular instance for creation of sound.

Acoustic power is defined as the Power Watt Level or PWL in some literature, in some books and this is given as $20 \log_{10} \frac{W}{W_{ref}}$, and that is also in dB, and W is the acoustic power in watts, and W ref is the reference acoustic power in, that is normally given as 10 to power of minus 12 watts.

So, you see, the amount of power that is used by the noise is actually again coming out of the energy that is being transacted within the compressors or turbines. So, a measure of the power does tell us how much of power is literally getting fritted away in creation of noise rather than being used for purposeful use in aircraft engines. So, acoustic power gives us some idea, how the power is going away in the form of noise energy. Now, these are the fundamental definitions of some of the pressure level and acoustic power or sound power.

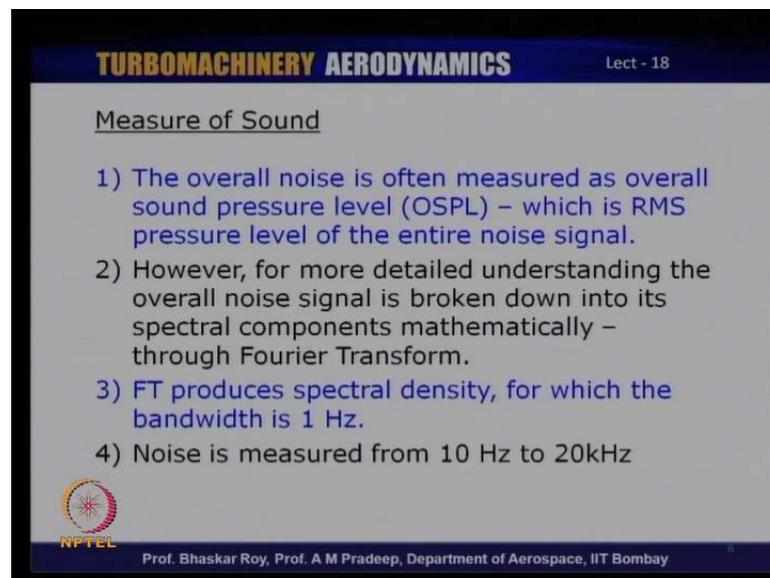
Now, fundamentals of acoustics tell us, that the pressure changes or fluctuations travel in waves with certain frequency and amplitude. Now, all waves travel with certain frequency and amplitude. And normally, higher the frequency, lower is the amplitude; and normally, these are associated with the so called high pitched noise, which are indeed also sometimes simply referred to as high frequency noise. And, these are normally producing or taken away low power. So, these are the low power noise making frequencies.

On the other hand, the high amplitude noise often has low frequencies, and these are the bass kind of sound and they often carry high power. So, this kind of sound is often associated with high amplitude. Now, when we are looking at noise, it is entirely possibly and quite often it so, that is, it carries all spectrum of noise frequencies; not just high frequency or low frequency high amplitude or low amplitude, it carries noise of all frequency many frequencies and many amplitudes. And now, this is often really the case, as a result of which, when you measure noise, it becomes a problem; because, you are measuring all kinds of frequencies that are coming out of a particular noise source, not just one particular frequency or amplitude.

And hence, you need to actually measure all of them. So, measuring them is actually very tricky job. So, the noise meters or the sound meters are essentially rather complex machines or complex measuring machines, many of them are indeed available in the market, but they have been created after a lot of, you know, scientific development, to capture all these frequencies and then show them up in a certain standard manner in a certain standardize manner in dBs; I will come to the scales in a few minutes now.

So, capturing the noise in a measuring instrument is another kind of sound, another kind of science. So, once we have the science of acoustic, which defines various kinds of noise or various kinds of sounds and tones and so on and so forth, which includes music, which is, you know, nice to our ears; but we call something noise, which is annoying to us. So, music is very pleasant thing, noise is extremely unpleasant; and, we are dealing with noise, which are indeed very, very unpleasant, and we have to ensure that those things are eliminated from or reduced as much as possible in operation of civil aircraft engines. So, we are dealing with that the science of acoustics.

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Measure of Sound

- 1) The overall noise is often measured as overall sound pressure level (OSPL) – which is RMS pressure level of the entire noise signal.
- 2) However, for more detailed understanding the overall noise signal is broken down into its spectral components mathematically – through Fourier Transform.
- 3) FT produces spectral density, for which the bandwidth is 1 Hz.
- 4) Noise is measured from 10 Hz to 20kHz

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The measurement of the sound then becomes a little more complex issue. The overall noise is often measured as Overall Sound Pressure Level or simply called OSPL, which is RMS pressure level of the entire noise signal composed of all kinds of frequencies and amplitudes. So, this is kind of an overall average noise and is often simply measured in terms of dB as the overall noise.

So, any machine that you have, the simplest possible noise meter actually gives this value, where all the noise that is picked up by the measuring sensor, is converted in to an RMS pressure level and hence it is just gives a overall noise in decibels. The more detail understanding of the overall noise signal is then broken into what is known as spectral components using certain mathematical formats, and this is of course done through Fourier Transform which is typically used in many wave measurements, various kinds of measurement of various waves and sound being ah wave form, it is also captured in Fourier Transform.

Now, Fourier Transform produces spectral density, for which the standard bandwidth is 1 Hertz. So, the frequencies of noise are indeed expressed in terms of hertz, and it is normally measured from 0 or 1 or, in most measurement machines, from something like 10 to 20 kilo hertz; that is 20000 hertz. So, that is the frequency range for which normally the measurements can be made; it is possible that the noise generated could be higher than 20 kilo hertz frequency of noise or lower than, let us say 10 kilo hertz; **it is** it is quite possible, but the point, essentially, is that those kind of noise are normally of not of interest to us.

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Measure of Sound

- Noise is measure in many scales : A, B,C, D and F scales.
- Human perception of sound is restricted between 10 Hz and 12 kHz – beyond which it is often called ultra-sonic sound
- The above scales have been artificially created for various purposes – to meet industrial noise regulatory requirements
- ‘A’ scale has been created to correspond to human hearing – very low and very high frequency noise are reduced artificially and noise from 400 Hz to 10 kHz are shown dominantly.

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Let us see what are the noises that are measured in various scales; A scale, B scale, C scale, D scale and F scale.

Now, before we talk about the scales, the human perception of sound is restricted between 10 or more likely, 100 hertz to about 12 kilo hertz. So, anything less than about 100 hertz, some very perceptive people might hear less than that; and anything above 12 kilo hertz, that is 12000 hertz, is normally not heard by a human people, human beings.

And so, anything beyond 12 hertz, which are measurable sound in normal measuring instruments, is often called ultra-ultrasonic sound. Now, this ultrasonic sound can indeed be heard by some other animals, for example, like dogs, dolphins or even whales. So, there are some other animals who seems to, or owls, who seem to be able to hear ultrasonic sounds, but human being do not hear those kinds of sound

So, as far as human beings are concerned, the sound of interest is normally between something like 10 hertz to about 12 kilo-hertz. It depends on, it varies from person to person; some people even may actually have even lower perception range than what is shown here. So, what the measurement units normally pick up, that range, to conform to the human hearing purpose. Now, the human hearing perception capability is captured in the A scale.

So, A scale that is been created, corresponds to human hearing; and lower than that and higher than 12 kilo hertz or artificially factored down to or toned down in the A scale, and as a result, the noise from 400 hertz to about 10 kilo hertz are shown dominantly; that means, they are shown on 1 is to 1 basis. Whereas, the noise is below that hertz and above 10 kilo Hertz are often factored down by in the A scale. So, that is what is calling a scale corresponding to human perception.

B, C, D scales are created for various industrial usages, where some of the scales like D are actually factoring in the noise over a period of time. Something like may be 8 hours or 10 hours or 12 hours, conforming to industrial noise regulatory requirements. So, many of these scales confirm to those regulatory requirements used in the industries. And, F scale typically confirms to flat scale, where all the noise actually that is coming out, is picked up on 1 is to 1 basis. So, the entire noise from 10 to 20 kilo hertz is picked up in the F scale.

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Measure of Sound

- A more evolved noise rating is the Perceived Noise Level (PNL)
- It is measured as perceived noise decibel (PNDB)
- A further evolved version is used to judge the annoyance created to any person at any time – which normally carried at least one strong tone. The spectrum analysis shows the presence of the dominant tone. A correction is added to account for the presence of a tone.
- This is measured as effective perceived noise decibel (EPNDB)

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So, those are the scales that are typically used in noise measurement. Typically, the noise is nowadays measured in what is known as noise level, which was acoustic, science of acoustics, but it is measured now in what is known as Perceived Noise Level, PNL, and it is measured in terms of Perceived, **Noised**, Noised Decibel or PNDB.

Over a period of time, people have tried to figure out, what is most annoying kind of noise, certain kind of noise that is most annoying. It actually can vary person to person, it can vary from one time of the day to another time of the day; sometimes, it carries certain particular tone of noise which is extremely annoying and some of these are actually, can be captured in the spectrum analysis of the noise meter. And then, a correction can be added to account for this extremely annoying tone that is present in the noise, and then this corrected noise is refer to as effective perceived noise and is measured as Effective Perceived Noise Decibel. So, EPNDB is what nowadays noise is been measured, especially which is related to aircraft engine noise.

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Pressure fluctuations are expressed as :
(derived)

$$p = \frac{\cos \alpha}{4 \cdot \pi \cdot r} \cdot \frac{f}{a} \cdot A$$

Where, A is the amplitude of the oscillating force, f is the frequency of oscillations, at a distance r from the point of observation, and a is the speed of sound.

This allows an approximate estimate of the pressure fluctuations and may provide an approximate estimate of the power associated with it. Power is proportional to sixth power of The blade speed.

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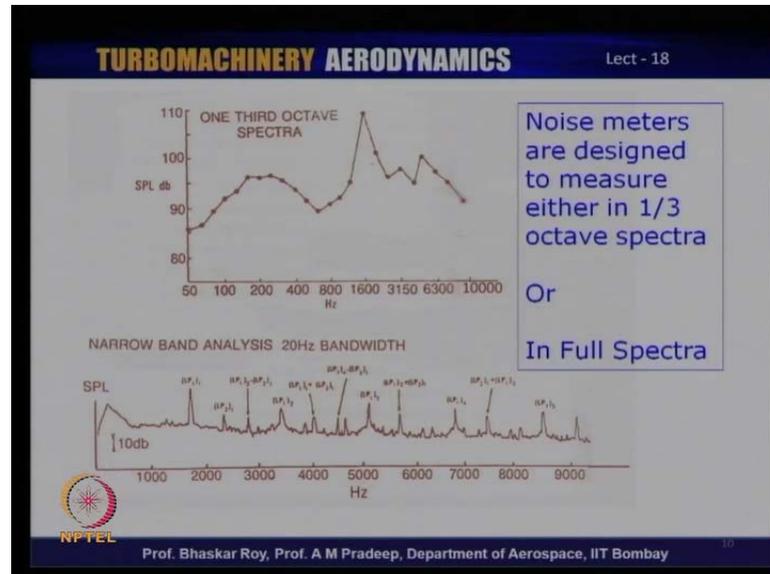
The pressure fluctuations that we were talking about, which is the source of noise, can be expressed in terms of certain parameters that are indeed used in the noise capturing or noise measurement, where P is equal to \cos of α divided by $4 \pi r$ into f by a into A .

Now, A here is the amplitude of the oscillating force, in which case, there is a pressure fluctuation; f is the frequency of the oscillation, it is being measured at a distance r from the point of observation, of the source of a noise, at a distance r from the point of measurement. So, where you measure is extremely important; noise indeed does increase as you go towards a source of the noise, and it, of course, you measure less and less as you go away from the source of the noise. So, the distance r is extremely important in the noise capturing or measurement business. And, A of course, is the speed of sound and α is the angle at which, over which the noise is being captured. Typically, you would be measuring at number of angular locations or at an angular distance and α is the measure of that.

Now, this allows for an approximate estimate of the pressure fluctuations and may provide an approximate estimate of the power associated with it. Now, as I was telling, mentioned a little earlier, the power that goes with the noise proportional to sixth power of the blade speed. So, a slight increase or decrease of the blade speed would strongly impact the noise and the power that is associated with the noise. So, we have to keep an

eye on that blade speed are the relative blade speed very stringently; if you want to keep a check on the noise that is emanating from the rotating blades.

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As I was mentioning, the spectra of the noise can be captured or show in different ways. One way is that, noise meters are designed to measure either in one-third octave spectra which is shown here at the top, which misses some of the details, but it captures one-third of octave spectra. You can see here, the band that is captured here is from something like 50 hertz to all the way to 10000 hertz, which is the normal range of human hearing, but it is captured in one-third octave spectra or it can be captured in full spectra as shown below here, and entire detail, again from lower something like 10, 50 Hertz to 10000 Hertz, has been captured. And, you can see here, all the details which were missing in the one-third octave spectra, can be captured in the full spectrum noise. The instrument that can capture full spectra, indeed is as can well expected, is a costlier instrument, whereas one-third octave spectra is a little cheaper instrument and both the instruments, of course, can give the overall noise which we mentioned a little while earlier; that is, the overall RMS of all these frequencies, average very quickly and gives in 1 single value of dB.

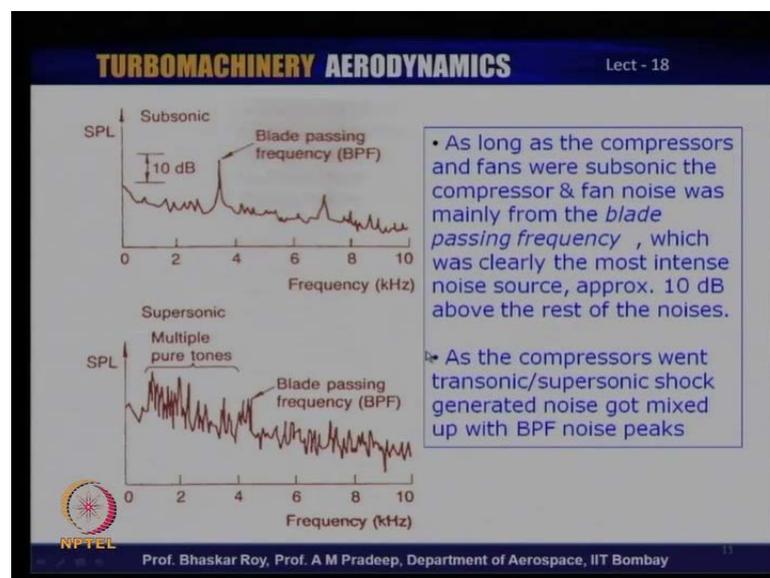
Whereas, as you can see here, at various frequencies, the dB levels or SPL levels are different; and as a result, at various frequencies, the dB levels are different. So, some frequencies the dB is lower, at some frequencies the dB is very high. And, those are the

annoying which need to be somehow cut out, and the designers and the engine designers the containment people have to work out, how to cut out those noises which are coming from particular frequencies.

Now, what happens is, with relation typically to aircraft blades, engine blades compressor blades, certain noise peaks are associated with the blade passing frequency. Now, what happens in a blade passing frequency is that, one particular blade, while rotating, passing a particular point in rotation is referred to as a blade passing frequency; it is very easy to calculate that particular blade passing frequency and that, **that** blade passing frequency or blade cutting frequency or peak is observed here.

Now, that is obvious, a most easily identifiable tone that is captured by the noise measuring instrument. And, in an old fashion subsonic compressor, that blade passing frequency was the most identifiable noise source or tone, which is easily at, at least 10 dB above the rest of the noises, as it used to be.

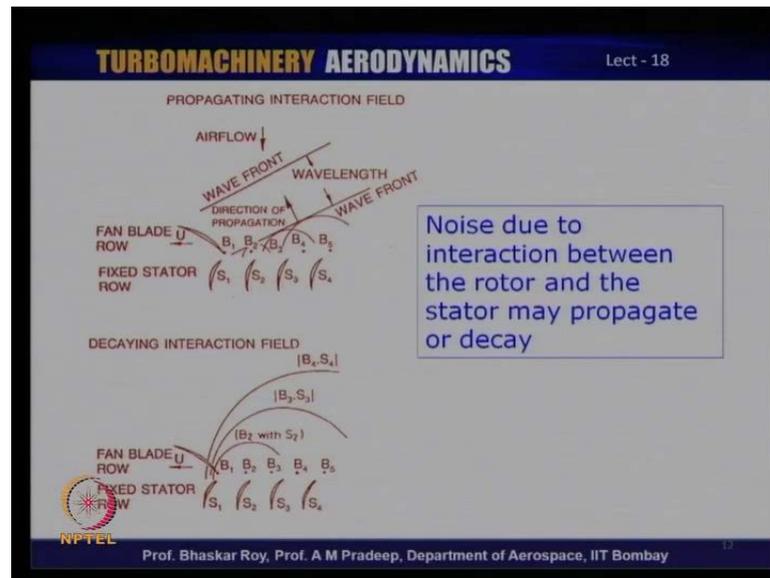
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In the recent compressors which have gone supersonic and transonic, we can see multiple pure tones; that means, there are many of them, mainly due to the shocks that are coming out of the blades, and those shock create noise, and blade passing frequency tone or that particular frequency noise is kind of mixed up or buried in all the multiple tones coming out of the supersonic compressors or fans. So, the modern engines and the 10 dB, you know, gap or safety margin that we had is gone, because there are so many

other frequencies that which I know is indeed happening; some of them are indeed higher than even the blade passing frequency. So, the noise coming out from axial flow compressors or fans, the modern ones are indeed of multiple tones and they are, of course, more difficult to contain.

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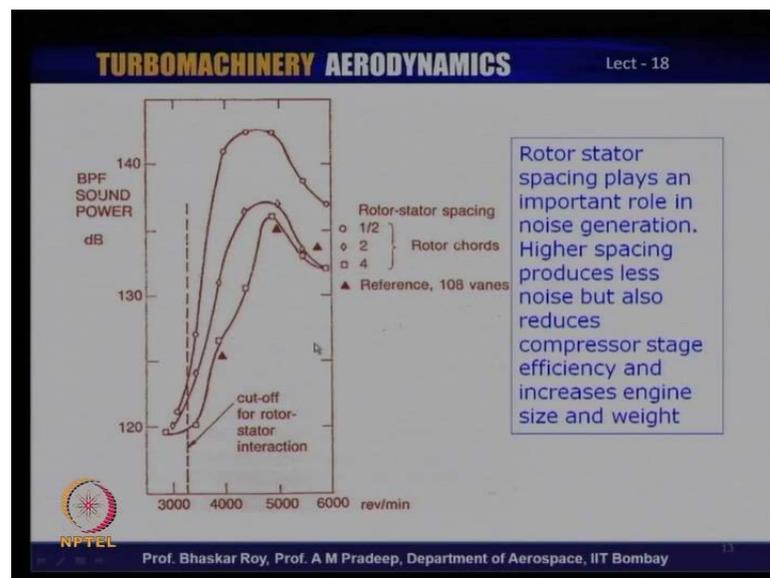


Let's look at what is happening in case where you have rotor and stator. There is an interaction of, aerodynamic interaction between the rotor and stator and this interaction also creates noise. There is a cutting of the flow that is coming out of the rotor, from the trailing edge of the rotor, and then, of course you have blade 1, blade 2, blade 3, blade 4, and then you have the stator 1, stator 2, stator 3, stator 4. Now, what happens is, there is an interaction of this trailing edge which is coming out with the stationary blades with relation to the stationary blade. Remember, the rotor is moving component, so, the way exact coming out are moving waves, and hence there is a relative velocity associated with the stator and the moving waves.

Now, so those interactions create another kind of noise and those noises can be two kinds depending on the dynamics of the situation; it can be propagating noise, as shown on top here. So, it can propagate in waves like this, it can keep on propagating or it can be somewhat decaying interaction field, where the noise, kind of, every particular noise source from B 1 S 1, B 2 S 2, kind of, sort of dies off; they do not propagate along, as shown on top here and each of those interaction are die of on their own.

So, it could be a propagating interaction field or it could be a decay interaction field. So, the interaction between the rotor and the stator; so, not only the rotor creates noise, the interaction between the rotor and the stator also creates noise. And, some of the interactions are indeed in the modern compressors, transonic or supersonic.

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Now, let us see what happens when you have the blades set apart. We know that between the rotor and stator, there is a spacing that is decided by the aerodynamics of the design and designer actually do a lot of analysis, aerodynamic analysis, before they fix that in a rotor-stator actual gap or actual spacing.

Now, as we can see here, the interaction between the two creates annoying noise and it has an impact on the noise; this spacing between the rotor and the stator has an impact on the noise. As we can see here, the lower the spacing, that is, the closer, the higher is the noise; it can be as high as 140 dB, which is extremely annoying and painful to human perception or human ear. If you increase the spacing or the distance between the rotor-stator from half chord to 2 chords, the noise comes down; and, if it is increased to as much as 4 chords, the noise comes down, even more.

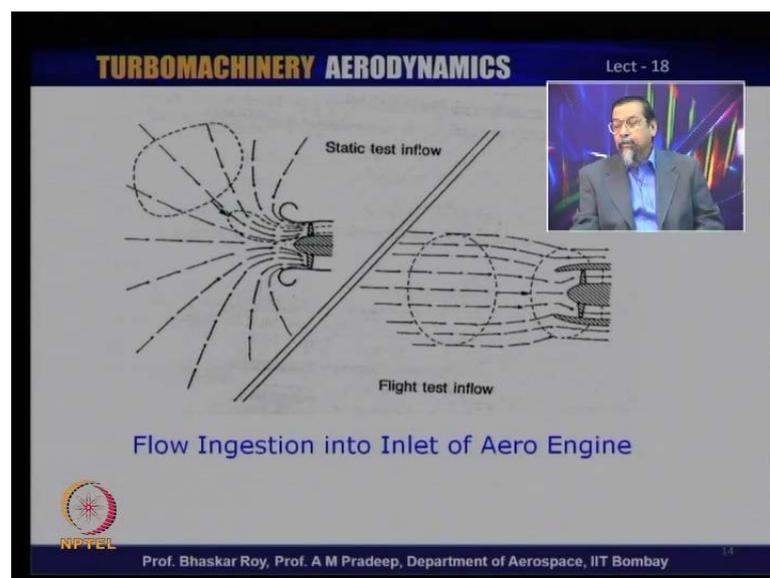
The trouble is, if you increase the distance between the rotor and the stator, it is known that the noise would go down, but it would also reduce the compressor stage efficiency; that means, the rotor and the stator would not then work as one single aerodynamic

unit of a compressor and as a result, the efficiency of the compression would actually indeed go down.

Now, when the efficiency goes down, it impacts on the overall engine, efficiency - overall engine, fuel efficiency; but even more importantly, if you separate the rotor and stator, remember, the overall compressor length is now going up. So, rotor- stator- rotor- stator, if you keep on increasing the distance between the rotor and the stator, the overall length of the compressor is going up, overall length of the engine is going up. Now, this is unacceptable; this is unacceptable to the engine designer, to the compressor designer; nobody wants a long engine anymore.

So, what is good for noise is, not likely to be accepted as an engineering solution to the engine designer. So, there has to be a certain amount of compromise between the noise that is happening and the engineering solution of a compact powerful engine which will power a flying aircraft. So, this is the compromise that has to be done a priori, at the time of design, before the engine is actually made. So, this is where most of modern aero-engine designers, the compressor designers, the fans designers are spending a lot of time, lot of analysis in trying to keep the basic source of noise-down, under operating conditions, various operating conditions of the aircraft engine.

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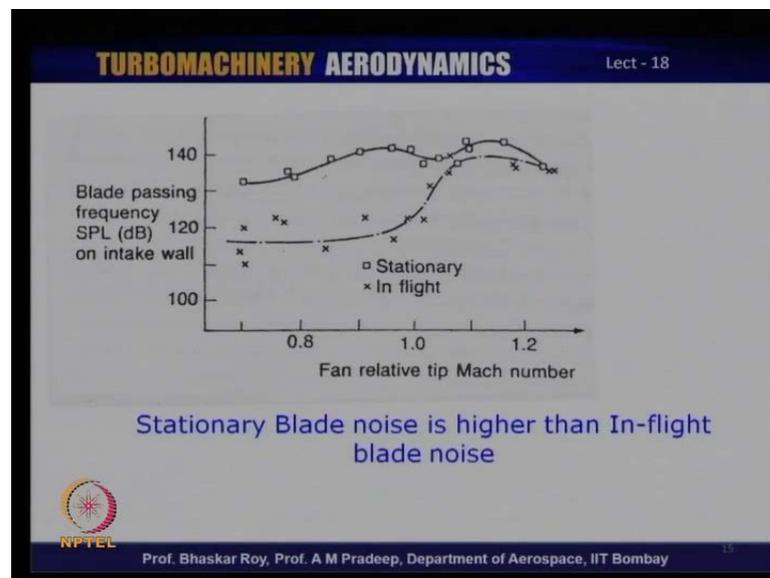


If we look at what happens to the noise, we can see that, **certain**, under certain operating conditions, the flow that is going into the engine is indeed different; for example, on the

static flow condition, when the aircraft is at the top of, let us see, a takeoff condition, takeoff run, this flow is going into the engine from hole sides. So, the noise that is coming out will also be impeded from all sides or it will be carried with this air on all sides.

So, the inflow characteristic during the static test law or during takeoff is quite different from when the aircraft is flying, when the air is going into the engine in a more uniform manner. So, the manner by which the air is ingested into the engine, also would, in a way, decide how the noise comes out of the engine and is propagated. So, as we can see here, the noise coming is out, it is in waves, so it will propagate in waves like this; whereas, in situation like this, it will propagate in waves in all directions. So, in a takeoff condition, the noise very quickly spreads in all directions; whereas, in flying conditions, it normally spreads straight in the front of the compressor or fan of an aero-engine. So, it depends on what the operation is of the engine as to how the noise actually propagates from the source of noise creation.

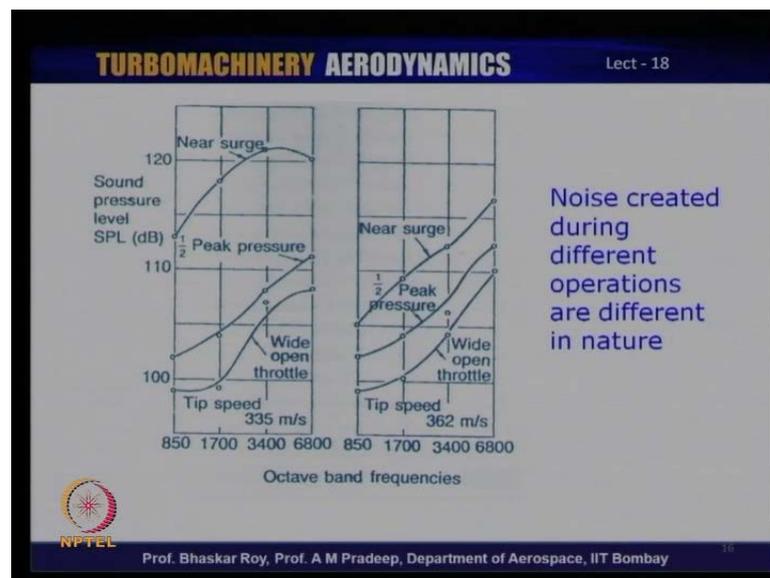
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Now, depending on that, the noise that actually can be measured shows that the blade passing frequency, if it is a stationary engine, the noise measured is often higher under takeoff conditions, is normally of a much higher order; whereas, in flight condition, the noise are of a much lower order; it depends on the fan relative tip Mach number. Typically, during the aircraft takeoff, it uses maximum thrust, and as a result of which,

the noise created is indeed is somewhere over here, which is indeed quite high, could be very high. Whereas, during cruise, at some altitude, the fan relative tip Mach number is normally somewhere down here, and as a result of which the noise, as we can see, is substantially no lower than the takeoff or ground static noise.

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So, noise does depend on the fan relative tip Mach number. We can see here, it also depends on the compressor operating condition; as we can see here, when the compressor is operating under normal open throttle operating condition in flight, the noise is normally somewhat on the lower side; tip's speed of course, impacts. On the other hand, if it is operating at peak pressure; that means, when the pressure created is high, then noise is higher. This is expected, because noise depends on the pressure; that is, the source of noise.

When the compressor has gone into surge, which is the worst situation from the stall, the noise is much higher, and in fact, an experienced compressor operator can make out that the compressor as indeed gone into stall or surge by hearing the noise coming out of it. So, the noise actually is easily identifiable when the compressor is surged. It depends on the tip speed, so, as we can see here, the noise value would depend on the operating condition and the operating speed of the compressor or fan.

So, these are the issues that are to be considered while, indeed, designing a particular aircraft compressor or a fan and together they would have to be put together in final design.

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The slide is titled "TURBOMACHINERY AERODYNAMICS" and is labeled "Lect - 18". It lists noise levels for various jet engine components and mentions regulations. The text on the slide is as follows:

Noise Levels of various jet engine components :

- Jet noise 90 to 140 dB - sub/ supersonic jet
- Fan/Compr 90 to 100 dB - subsonic fans/ compressors
100 to 140 dB - trans/supersonic fans/compr
- Noise permitted by regulations : 80 to 95 dB

This calls for noise suppressing methods

The slide also features the NPTEL logo and the names of the lecturers: Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay.

The noise levels which, as I mentioned, are of annoyance to people who are passengers and others who are around the aircraft at the time of operation. The jet noise which typically creates noise of the order of, you know, 90 to about 140 dB; 140 dB is extremely painful. The human hearing is normally good up to about 100, 110; anything more than that becomes painful. 140 is extremely painful in the sense, if you listen to it for a few minutes, it impacts your hearing capability for a long time. And, if you are subjected to that kind of noise over a certain period of time, your hearing, human hearing may be impaired for life; so, the noise is a very important issue and it can be extremely dangerous to human beings subjected to such a very high noise.

Now, fan or compressor noise of subsonic fans were of the order of 100 dB or there about; the moment it is gone transonic supersonic, the noises are now of the order 100 or more. And, as we just saw, certain tones, the noises are of the order of 140 dB. So, noise permitted by the regulations is much lower coming out, under certain conditions, measured at a certain distance, something like 50 meters, away from the engine, at certain angle, under certain operating conditions, have to be between 80 and 95 dB,

almost for all kind of aircraft engines. And, these are the noise regulations that have been put in place to safeguard the human beings that are present inside the aircraft or outside the aircraft in the airport; which means that to confirm to regulation, the engine designer have to use noise containment or noise suppressing method, because, normally, some of the noise is indeed actually much higher than that.

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TURBOMACHINERY AERODYNAMICS Lect - 18

Acoustic Treatment – attenuation of noise

- A perforated metal sheet casing surrounded by a honeycomb annular outer structure provides very large attenuation
- Depth of honeycomb structure determines the frequency most attenuated
- Porosity of the sheet metal determines the frequencies over which the attenuation takes place
- The treatment works best for high frequency noise
- High amplitude noise is most difficult to attenuate

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So, let us take a quick look at what all things can be done. The noise attenuation, as it is called or acoustic treatment as it is called in engineering terminology, is normally with the help of perforated metal sheets with certain perforation or porosity level that is prescribed by the designer, and it surrounds the compressors or the fan, so, the casing of the compressor or fan is made up of such, made with such perforated metal sheet, and around the metal sheet you have honeycomb structures which also observe a lot of noise. You remember noise carrying power or energy that has to be observed, and that results in large amount of attenuation or absorption of noise. Depth of the honeycomb structure determines the frequency which is mostly attenuated or absorbed.

So, honeycomb structure will have to be designed by specialist, to absorb noise of certain kinds, so that most of the high pitch noise is indeed absorbed. Porosity of the metal sheet also has to be **cont** in a determined in a manner, which actually attenuate certain kind of noise frequencies. Now, this treatment of using metal porous metal sheet or perforated metal sheet and honeycomb works best for high frequency noise which I mentioned

earlier, actually carries low power. The high amplitude noise which carries high power are actually more difficult to attenuate, and now we know why; because they actually carry high power.

So, most of the noise that is annoying to our ear is essentially high frequency noise and they need to be indeed attenuated or absorbed by certain mechanical means, so that, at least the minimum safety is guaranteed for the people who are around the aircraft.

So, we have seen that a number of issues are involved here. There is a lot of aerodynamics, there is a lot of mathematics which we have not done, the science of acoustics. All that needs to be factored into the understanding of the noise and then the fan or compressor designer would have to design a compressor that confirms to this noise, and only then it goes on to the aircraft. So, the modern compressor designers would have to confirm to noise regulations very stringently; otherwise, this compressor or fan is not likely to be accepted by the commercial engine designers.

So, this brings us to the end of discussion on various aspects of axial flow compressors and fans. We have discussed various things, but more predominantly, we have discussed the aerodynamics issues that are related to the axial flow compressors and fan. Now, we will move on to the turbines. And, to begin with, axial flow turbines.

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TURBOMACHINERY AERODYNAMICS Lect - 18

Next Class

Axial Turbine Introduction

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So, in the next class, we will introduce the axial flow turbines, the fundamental axial flow turbines, and we shall see that it is a different kind of machine, and that is what we will do in the next - class axial flow turbines, an introduction to axial flow turbines.