Turbomachinery Aerodynamics

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Lecture No. # 24
Multi Staging and Multi Spooling of Turbine

We have been talking about various fundamental theories of axial flow turbines. So, by now, you were aware that axial flow turbines in modern aircraft engines, typically in gas turbine engines, in aircraft usage and of course, those which are used in land based gas turbines, which are indeed much larger; the all turbines that are used axial turbine, that are used essentially, multi stage turbines; that means, there are more than one stage lined up, one after another just like multi stage compressors, to supply sufficient amount of aggregate power to the compressors. Now, in case of land based gas turbines, the entire power that is generated by the multi stage turbine is used in compressors or for taking out power for great power generation, electrical power generation.

In case of air craft engine, the multi staging is done for number of purposes; it still has to supply power to the compressor. It can also supply power to the propeller as it used to do in the earlier days of gas turbine plus propeller that is turboprops, many of which of course, are indeed still around, and then of course, it supplies power to the fan or the big fan as most of the present aero engines are which are turbo fans. So, turbines actually supply power to all of them the propellers, the fans, the compressors; and in the process of this supply of power, it is necessary that certain amount of aggregate power is indeed created by the turbine, and when that aggregate power creation requirement is more than a certain amount, you have to go for multi staging.

Now in terms of our understanding, we may say that there are certain criterian related to the gas turbine parameters that we have been talking about the pressure ratios of compressors and turbines that we have been talking about, and with reference to those parameters, we can say that certain numbers once they are exceeded, we would need to go for multi staging. Today, we will also be looking at multi spooling; now, multi staging and multi spooling are two different things; you can have a multi stage turbine, which is a single spool turbine; on the other hand, you can have multi spool turbine, which have to be necessarily multi stage, but multi spool as we have seen in case of axial compressors; they are two different groups of compressors running on two shafts at different rotational speeds or rpms. Now, that requires a different mechanical arrangement to be introduced into the overall engine configuration, so that obviously, requires for more people to agree to the business of multi spooling.

So, we will be talking a little about multi spooling also in today's class as part of multi staging, and we shall also talk a little about, how this multi spool arrangement of turbines needs to be fundamentally match to the multi spool or multi stage compressors. When you have multi spooling, each spool independently needs to be match to the corresponding compressor, and we will have a quick look at the fundamental relations or fundamental considerations that go into that matching between compressor and turbine to effect finally, multi spool arrangement. So, these are the things that we will be doing in today's class that is, multi staging and multi spooling; there are number of criterion or considerations based on which multi staging and multi spooling is normally adopted for modern axial flow turbines, which are normally part of a overall gas turbine engine, let us look at some of these fundamental considerations that go into adoption or selection of multi stage configuration for axial flow turbines.

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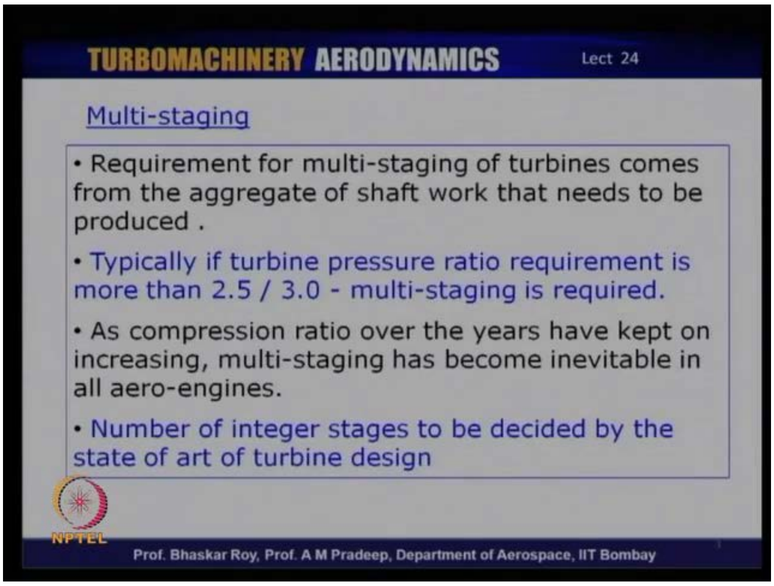

So, the considerations that normally go into multi staging and multi spooling to begin with let us look at the multi staging requirements. Normally, it comes from the aggregate amount of shaft work that needs to be produced. Now as I mentioned, this shaft work includes the work that needs to be supplied to compressor, that work that needs to be supplied to fan and or the work that is needs to be supplied to a propeller; in case of land based gas turbine engine, the shaft that needs to be supplied to compressor and work that supply needs to be supplied to the external power generation unit would have to be supplied from the turbine.

Now, so, the overall work that needs to be done by the turbine needs to be assessed and computed and on the basis of that, the multi staging arrangement needs to be decided upon. Now to begin with, if the turbine power ratio requirement is more than 2.5 and in a modern one a little more than 3, typically multi staging would be resorted to, because a single stage turbine can give you pressure ratio or pressure drop of the order of 2.5, and you can probably stretch it to 3, but anything more than that, typically he would need to in a commercial engine, he would need to resort to multi staging; on the other hand, the compression ratio over the years of gas turbine engines have kept on increasing, and as a result to supply that much of aggregate power to run a multi stage compressor, multi staging of turbine has also become inevitable, specially in the aero engines and more so in the land based gas turbine engines, which are any way much bigger than the aero engines, and they are getting bigger and bigger and bigger, and in them, multi staging is almost an inevitable result of the present configurations.

Now, the number of stages of course, would have to be a round number an integer and that is to be decided by the state of art of the turbine design, in the sense, the first stage is you know in the aero engines typically likely to be cool turbine. So, it may take you know more pressure ratio or work done in the following stages, they may not be cool, in which case they may do lesser pressure ratio or pressure drop and the work done. So, the split between the stages would have to be decided, and integer numbers of stages would have to be decided upon. So that you have 1, 2 or 3 stages, in which the total amount of work is accomplished. So, this is how multi staging is typically resorted to.

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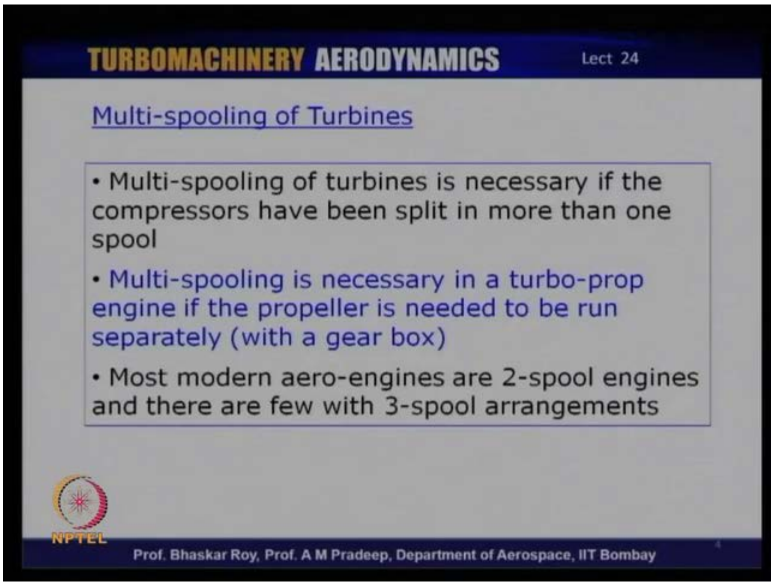

Now, let us take a look at why and how multi spooling is done? Now multi spooling is necessary, if the compressors have split in more than one spool, most of the modern engines actually are two spool engines, two shaft engines, there are of course, quite a few which are already three shaft or three spool engines. Now, the spooling is something which is decided by the engine designer or engine configuration, and as we have done before, and as we have mentioned before in case of compressors that the two spools run at two completely different rpms; for example, one of the spools may be running at 7000 rpm and another spool may be running at 10000 rpm. If it is a military engine, the one of the spools may be running at 10000 rpm, the other one may be running at 16000 rpm.

So, this is something which is decided by the engine designer, and then a certain amount of matching between the turbine and the compressor is necessary spool wise to decide upon the split of work, the split of pressure ratio and of course, the speed of the rpm at which, each of these individual spool should be running. So that is something, which is decided in a much larger manner, bringing into reckoning, the design and the features of the compressor or for that matter, if it is going out to an external generator. So, those things would have to be decided, taking into account units other than the turbines as well; now, if you you if you have a turboprop engine, which is a gas turbine plus a propeller to power an air craft; a multi spooling is often necessary or resorted to. So that the propeller has a set of turbines or at least a turbine to supply power to the propeller through normally a gear box; so when the particular shaft is hooked to a gear box, it is speed would have to be controlled through the gear box to supply it lower rpm to the propeller; now this is an arrangement which is typically, necessary for turbo prop engines, and this allows the other spools; that means, the turbine compressor combination to run at a different rpm, normally at a higher rpm and as a result as we have seen before, you can have a spool of turbine compressor and combustion chamber, which is often called the core of the engine.

So, that allows the spools to run at different speeds, and it allows a core engine to be configured or decided upon, which is a combination of compressor turbine and combustion chamber. So, some of these are decided upon not only by the turbine designer, but by the engine designer, and taking into account many factors that come into the engine design. Now, most of the modern aero engines are indeed actually, at least two spools, there are actually very few one spool engine these days, very small engines can be one spool, but moment it acquires a certain size most designers would like to go for two spool, it has a number of inherent advantages.

One of the thing that we have talked about while talking about compressors is that if you run one of the spools at a lower spool, notably the first set of compressors that is the low pressure compressor at a lower rpm, and then allow the second set of compressor that, is the hp or high pressure a spool to run at a higher speed, then the high pressure compressor can supply compression at in a study manner, and deliver it to the combustion chamber. Now, that spool of compressor would have to run by the high pressure turbine, which takes the gas straight from the combustion chamber, and then runs it at a high speed. So, the combination is that the inner turbine and the inner compressor of a gas turbine engine run at high speeds, and at a steady high speed, whereas the outer spool that is of the compressor and of the turbine, that is the front set of compressors and the rear set of turbines run at a lower speed.

Now, front set of turbines do actually have to face as we have discussed, the some of the non uniformities and some of the changes of that mass fear, from which the air is coming into the compressor. Similarly, the rear set of turbines or the Lp turbines would have to face the varying changes of the gas state as it is going through the nozzle and to the atmosphere. So, the rear set turbines are also kind of subject to certain change of state from the rear of the engine. So, from the front of the engine and from the rear of the engine, certain changes of the state of the air or gas is probably inevitable, and as a result of which the these stages, if they are on at a some at a lower speeds, and then brought to the control, through a control mechanism or control algorithm to steadier or safer speed operating conditions, then you have a better control over the engine operations to ensure that at no stage either the compressor or the turbine gets into any kind of operational problems.

So, those are the issues, based on which normally spooling is done. So, spooling is typically something which is also related to engine controls; and something which you may have done in other courses, and those controls would invariably, then come into blade in control of the spools, which are controlled independently, which need to be controlled independently. So, that is about spooling and multi spooling of the engines and multi spooling of turbines as we are talking in today's lecture; let us take a look at some of the standard engines.

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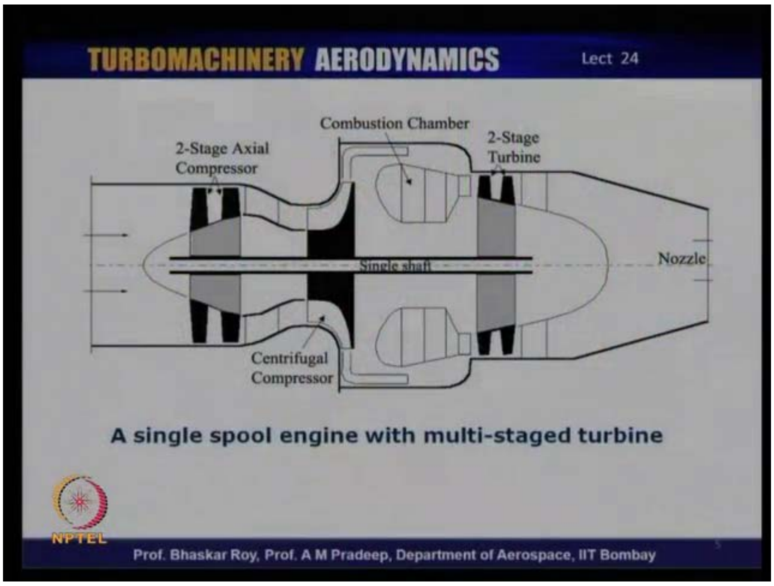

What we see here now, is a single spool engine with a multi stage turbine. So, we have one spool on which the compressors and the turbines are mounted. Now, as you can see here the compressor consists of a two stage axial compressor, then centrifugal compressor, a single stage, which delivers to combustion chambers, which delivers to the turbine and this is a two stage turbine configuration; but both are mounted on a single shaft spool. So, as a result of which, this is a first step towards multi staging of turbine, but it is still on a single spool, which is running both set of compressors here; one set is actually axial compressor and other is actually a centrifugal compressor, and this is a kind of configuration, which is very popular typically with turbo shaft engines, which are used in in helicopters, and they run of course, at very high rotational speeds or rpms of the order of a 25, 30, 40000 rpms. So, this is a kind of configuration that is used in certain kind of engines and as I mentioned, notably in the turbo shaft engines, which does have a multi stage arrangement of turbines, but they could possibly be on the single shaft.

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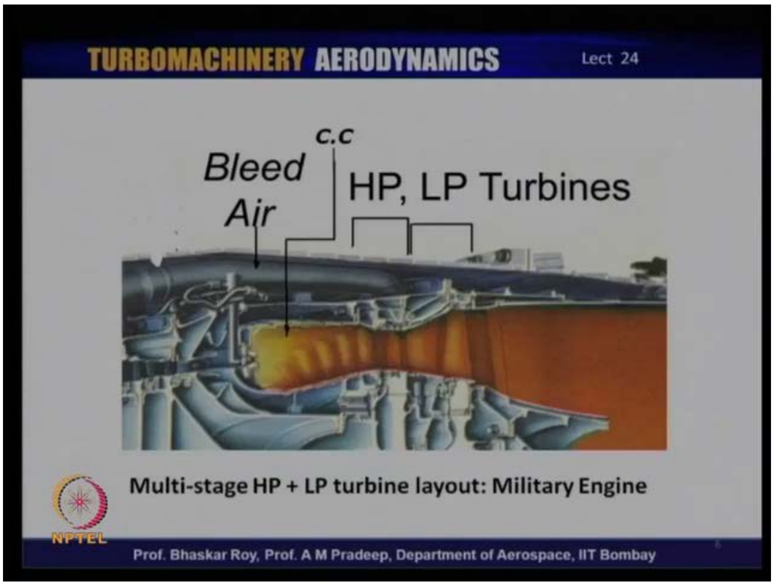

On the other hand, if you look at this configuration, in which you have two multi stage turbines two stages; one is a single stage HP and another is a single stage LP. So, you have a two stage configuration, but they are on two different spools; so one is on one rotor over here and that is on a one spool and second one is another rotor over here, which is on a different spool. So, if this is a multi stage infact indeed a two stage, but a two spool turbine layout, this is used this particular picture is from a military engine, which actually, which means that one spool or that is one stage or HP stage actually supplies power to the HP compressor set, which may be a multi stage compressor and then the LP turbine, which is again a single stage turbine supplies power the entire power to a LP stage of compressors of this particular engine.

So, and as I shown here, just as you know, aside this engine has a little bit of a bypass. So, this is the bleed air or the bypass air that is going passed to the turbine and not getting into the turbine. So, we can have a two stage turbine, which is a two spool turbine and two stage turbines, which is single spool turbine. So, those are the possibilities that engine configuration and engine designer would have to be involved with the decision making, whether it should be multi stage, multi spool or whichever way the decision needs to be taken.

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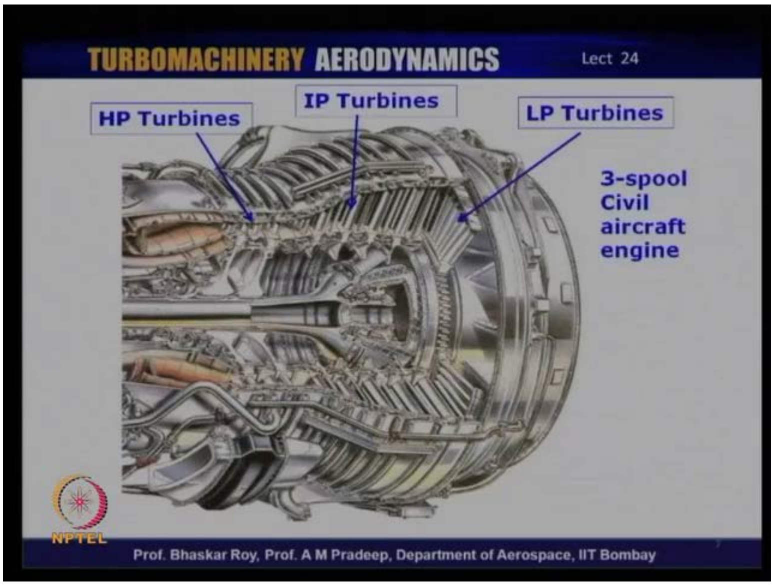

And this is a very large aero engine, which actually is a three spool civil aircraft engine and what is shown here is very large number of turbines; this is of course, a combustion chamber where the gas is created, the fuel is burned, and then this supplies into of course, the HP turbine as we know, the high pressure turbine which produces very large pressure rises, and then it goes into another set, which in this particular configuration would be called or is normally called intermediate pressure turbines or IP turbines that is a set of about three stages.

And then finally, it goes through the low pressure turbines or LP turbines. So, it has three spools; and this is one shaft, this is the second shaft and this is the third shaft. So, it is a three shaft or three spool civil aircraft engine, normally a very large civil aircraft engine used for large aircraft. So, there are quite a few of them, they are not in majority as yet. One of the problems of course, the three spools is that you need to have control over all the three spools. So, you need mechanical and good control system to effects control over all the three spools in a desired manner. So, three spools is actually a very futuristic concept, and it is probable in future, we might see more and more engines that are three spool engines.

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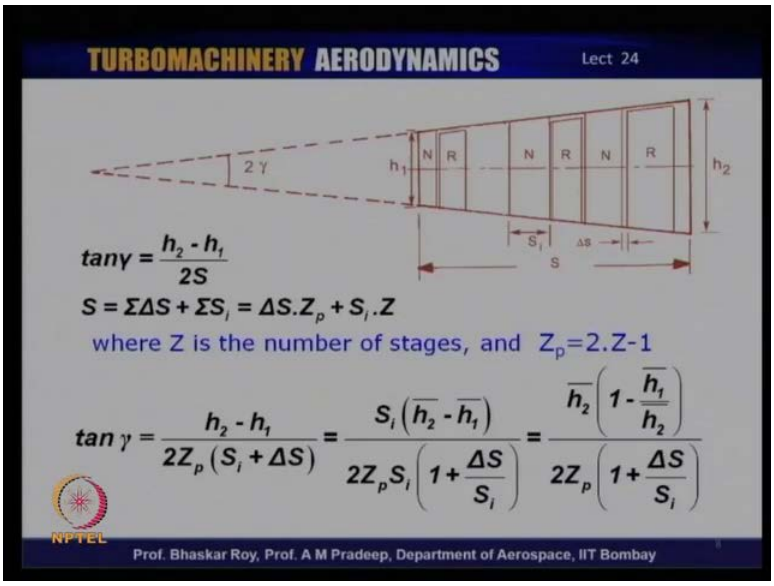

Now, if we have, we are looking at multi staging; one of the first problems that multi staging would through up is how to create the flow track of this multi stage configuration. We have just seen that you have all kinds of flow track, starting from here from the delivery of the combustion chamber and this flow track has to be designed. Now, we will be talking in a separate lecture on how the blades are designed. So, design of blades turbine would be taken up in a separate lecture, but today we will just have a quick look at how this flow track is indeed decided upon or design. Because, as you can see this flow track can be something which is which has a strong bearing on the aero dynamics of the flow through the turbines.

So, the simplest way of looking at it is it is a part of a cone, which has a subtended angle of twice gamma, and then this is decided by the change of height of the rotors and stators; rotors are called stators are also called nozzles. So, you have nozzle rotor; nozzle rotor, it is a multi stage arrangement and this is presumably HP turbine, and this is a LP turbine set, and in between there is a little bit of gap, where there is nothing and no blades. So, we have multi stage simple configuration, in which the middle or the mid height remains constant radius. So, it is a constant mean radius flow track design, which is again the simplest, and that is what people use to do in the early days of gas turbine design, is the simplest thing to actually get into your design.

Now, what it says is that if you take it as a simple part of a cone, then all you have to decide is what the cone angle should be, and this cone angle can be deduced from the various sizes and the shapes of the turbines. So, we have the shape or size of the actual length of the entire turbine multi stage arrangement, and as you can see here that is going to come into picture in deciding what this conical angle should be, and then of course, the number of stages would have to be decided, as we have done in the previous lectures, the number of stages would have to be decided by certain aero thermodynamic considerations.

And once you have decided number of stages, then you have to decide the spilt of number of stages into HP and LP, and then take some kind of decisions on what should be the gap between HP and LP and then of course, you have the actual length of each turbine row of blades. So, you have nozzle actual length, rotor axial length of each stage. So, all of it put together, and then of course, you need to decide what should be the gap between the rows of blades that is delta S. So, all of it put together gives you the total S or the length of the entire turbine, and h 1 is the first height, let us say annulus height of the entry stage, and h 2 is the exit height of the entire multi stage configuration.

So, when you put all of them together, you get a certain tan alpha, which can be deduced from this relationship some are in between we have used a Z p, which comes out of the Z, which is number of blades number of stages and it gives some value of Z p, which is 2 Z minus 1. So, when you put this simple geometric or trigonometric relationship, you get a conical angle tan gamma, which is a straight forward conical shape two in case or accommodate this multi stage configuration. So, that is a simplest way of configuring the flow track of a multi stage turbine.

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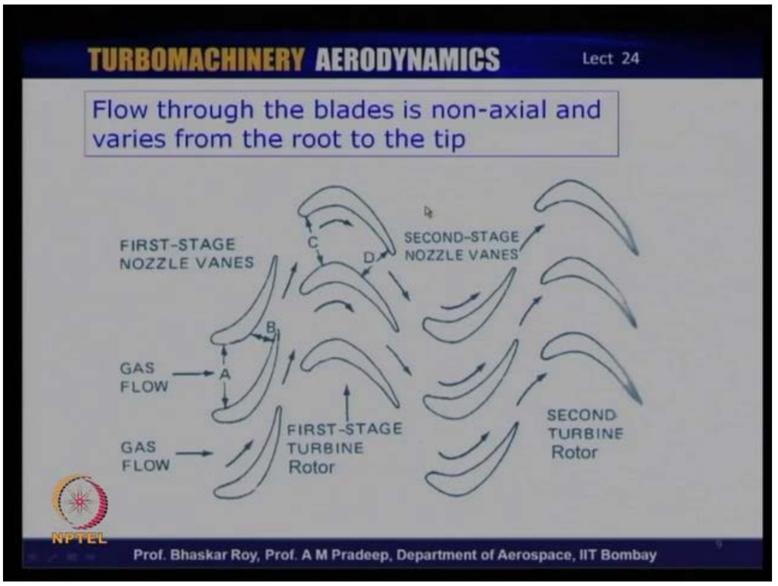

Now, the other thing that does happen is flow through the blades is non axial, and it you know, it goes something like this, it goes to the rotor like this, as you can as we have done before as a change of area from A to B there is acceleration here, then it goes out, enters the rotor and again there is a change of area from C to D, so this is nozzle, this is rotor and in a multi stage, you have another nozzle, then you have another rotor. So, more number of stages you have, more you have nozzles and rotors, nozzle and rotors, and in each of them, the flow goes through this kind of turning. So, the gas flow coming from the combustion chamber executes this turn, huge turn as we have done in the earlier lectures; then takes a another fairly large turn to the rotors, does the work or gives up a lot of energy to the rotating sharp, gets into the next row of nozzles, again takes a huge turn and a large acceleration, then gets into the next rotor, and it takes a huge turn gives up again a lot of energy and makes the rotor rotate.

So, that is how the flow proceeds through the individual rows of blades, which are nozzle rotor, nozzle rotor and more the number of stages you have, more the number of nozzle and rotors you have, and the flow would proceed along this manner through each of these rows or blades. Now, you have to remember that this happening is varying from root to tip; so the amount of turning it does in each row of blade whether nozzle or rotor would be actually varying from root to the tip of that particular blade; so the fundamental aerodynamic parameter actually is variable from root to the tip of each single row or blades. So, if you look at the earlier diagram, each of these rows or blades has varying kind of turning, and that turning is varying from root to the tip of each blade. So, this is happening inside a turbine and hence, the turbine designer needs to have very good idea about what is happening in terms of aerodynamics or simple gas dynamics, and he has to invoke all the aerodynamic and gas dynamic theories to analysis the flow and finalizes design.

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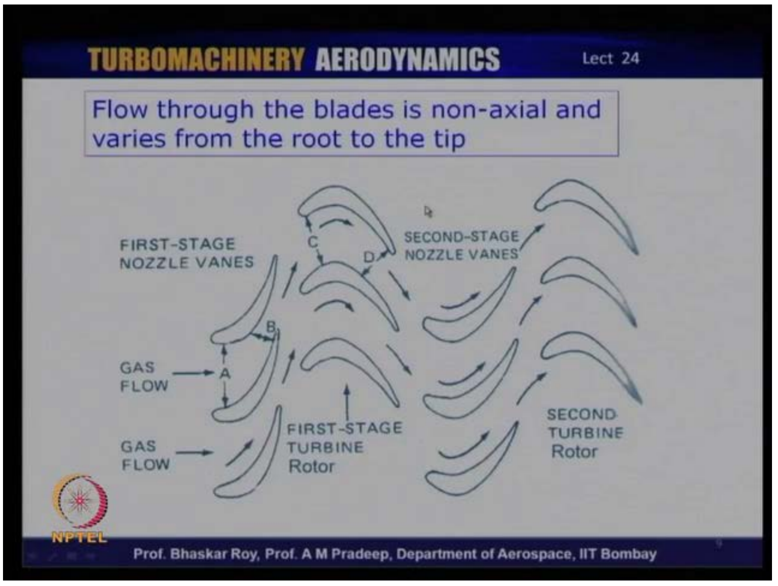

The axial flow track in a modern multi stage also goes through not the kind of simple cone that we looked at, it often goes through this kind of a curved or curvilinear passage. We of course, know from simple continuity condition that the flow has to have a expanding flow track or diverging flow track, that diverging flow track is likely to be a curved diverging flow track. So, you have stator, rotor, stator, rotor, stator, rotor etcetera, it may finally, have exiting stator or it may not have, it depends on the turbine designer, many turbine designers. Normally, may not like to have another stator over here, another exit guide vane if we can, sometimes the engine design may force him to have exit guide vane over here, as I shown here in S 4, and then of course, it goes into the passage, which finally in case of aero engine would go into the nozzle that creates thrust.

So, this curvilinear passage of flow, first through the blades like this, in comes in goes like this, and then goes like this, it is a lot of curvature it executes; at a particular radial station, if you take a cut, and then if you look at side way, it goes through a passage like this. So, the flow is executing a very complex curvilinear passage through the turbine blades, before it is exiting the turbine and going either into exhaust or into the nozzle. So, this needs to be analyzed in great detail, before you have some idea about the aerodynamics and the complexity of aerodynamics of the turbine, which you require to create turbines of reasonably competitive aerodynamic efficiency.

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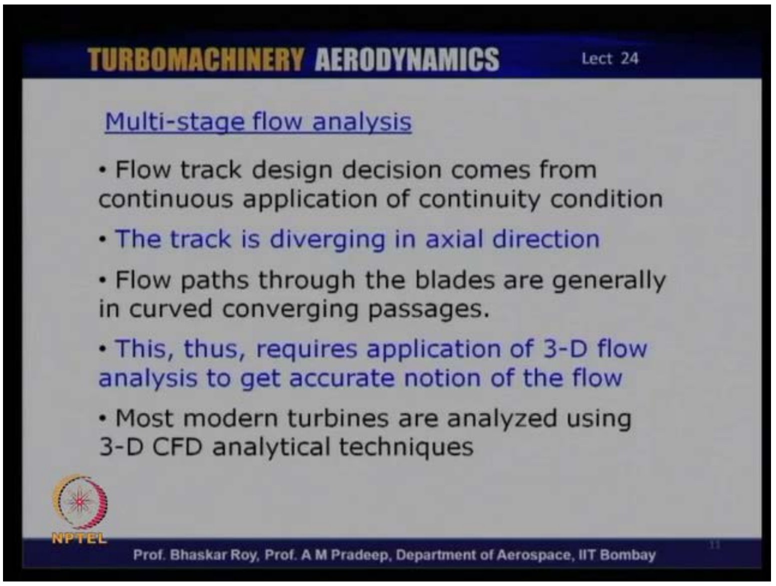

So, the multi stage flow analysis needs to be done. So, you need to do a flow track design, which comes from as I mentioned a continuous application of continuity condition which will keep giving you the values of you know, the heights or the annulus areas at each of those stations, so you can calculate the values of pressures and temperatures of each of those stations after a nozzle, after rotor, after nozzle, after rotor etcetera etcetera, and then that will allow you to calculate the density, you also need to take a call on the axial velocity, and then if you do that, you apply the continuity condition, and then each of these stations, you have your annulus area, which then knowing what the mid or median radius is or median diameter is you can then calculate the annulus height.

So, that is how you get the height of the blades from simple continuity condition application. So, first thing is you need to create the flow track by indeed applying the continuity condition, in which you have to take a call, you have to take a decision about what should be your axial velocity at each of those stages, and then of course, that will allow you to create a smooth flow track, you need to have a smooth flow track, you cannot have a flow track that is exact, we have seen that in case of compressors also.

Now, the flow tracks are modern compressor are generally you know, curved the way I showed in the last slide, and the flow through the blades is you know, curvilinear through the blades. So, this requires the application of 3-D flow analysis techniques. So, flow is indeed naturally through the turbines highly three-dimensional in nature. So, you need to apply three dimensional flow analysis techniques to you know analyze the flow, and then finalize your design of the turbines.

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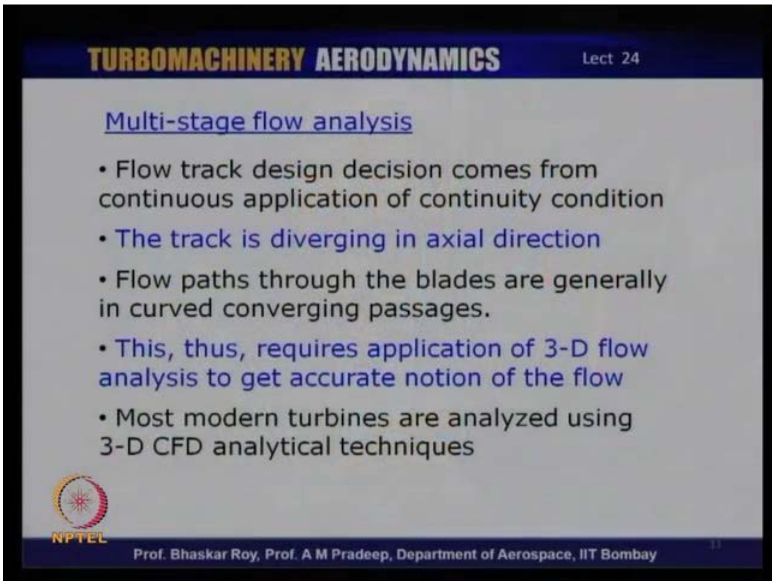

So, the modern turbines are analyze indeed through 3-D flow analysis techniques, and then you need to apply 3-D CFD techniques, analytical techniques that are available or whatever is made available to you, simple two-dimensional analysis would fall short of the requirements of modern turbine design. So, 3-D analytical techniques would need to be adopted very vigorously for modern turbine design.

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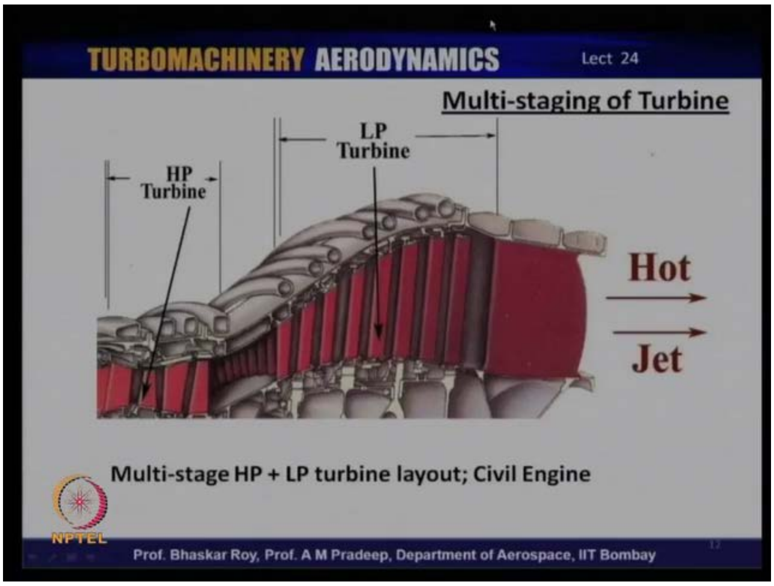

So, this is the look at the modern you know, multi stage, multi spool turbine, in which you have a HP, which itself is a multi stage affair, and then you have a LP, which again is another multi stage affair. So, and in between as you can see, there is a large inter spool duct or gap, which is created, during which as you can see the flow actually has move from median radius, which was here a lower radius, it has move to higher median radius, and it is continuously moved to a higher mid radius, which of course, tells you very quickly that this designer wanted to continuously upgrade is value of U or U mean of each turbine as you know, the rotating speed gives you the blade speed, and that blade speed if you can upgrade it to higher values. So, the blade speed here could be much higher than the blade speed here, and this holes spool is running at the same speed. So, blade the the average blade speed here is substantially here in fact, as you can see in this particular picture, the mean here is well above the tip here. So, the U mean here is substantially higher and that was indeed the intension of this particular designer.

On the other hand in HP, where the mean radius here is much lower, substantially lower than even the first stage over here; however, the HP turbines normally run at much higher rpm as we have discussed before and as a result, it is entirely possible that the blade speed of HP turbines is at least of the same order as the blade speed of LP turbine or the last LP turbine. If not actually a a little higher, as I mentioned the two spools run at substantially or significantly different rotating speeds, in which case the mean speed of the last turbine and the mean speed of the first turbine may actually be almost of the same order even though they are at a different radial setting. So, that is how the engine designer configures the entire multi stage and multi spool turbine.

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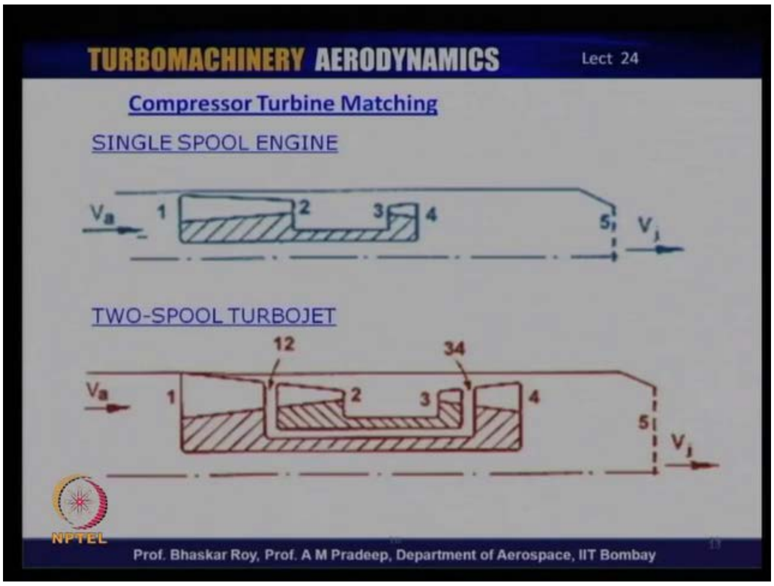

One of the thing, which I have mentioned is you need to do a compressor turbine matching and so this is just a very quick you know, block diagram matching; if you have a single spool, you have to match this compressor with this turbine; if you have two spool engine you have to match this compressor with this turbine; and then the HP compressor with HP turbine. So, this is your HP spool, this is your LP spool and this is your intermediate that is station 1, 2 between LP and HP and 3, 4 is the intermediate station between HP and LP turbine. So, this is the how the spooling is normally to be done in a overall gas turbine environment.

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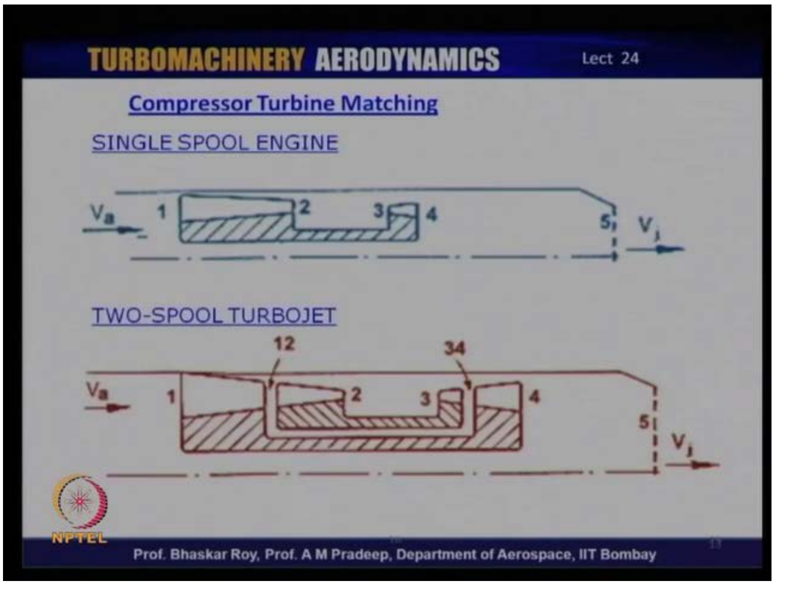

Now, if you have a two spool high bypass turbo fan, what happens is one spool that is the hp compressor, and the hp turbine spool would remain as we saw in the last one; whereas the LP turbine spool would end up running a set of LP compressors, and a very large fan, which is part of the turbo fan configuration, which produces as you know a cold thrust. So, the LP turbine has a lot of jobs to do, and as a result of which, it would actually be supplying a large amount of aggregate shaft power to the combination of this fan and compressor; one can probably make a guess that this is what this particular turbine is doing, this large turbine is a you know, it has to 1, 2, 3, 4 stages of turbines, they are essentially supplied power to a combination of compressor and a large fan in a turbo fan configuration.

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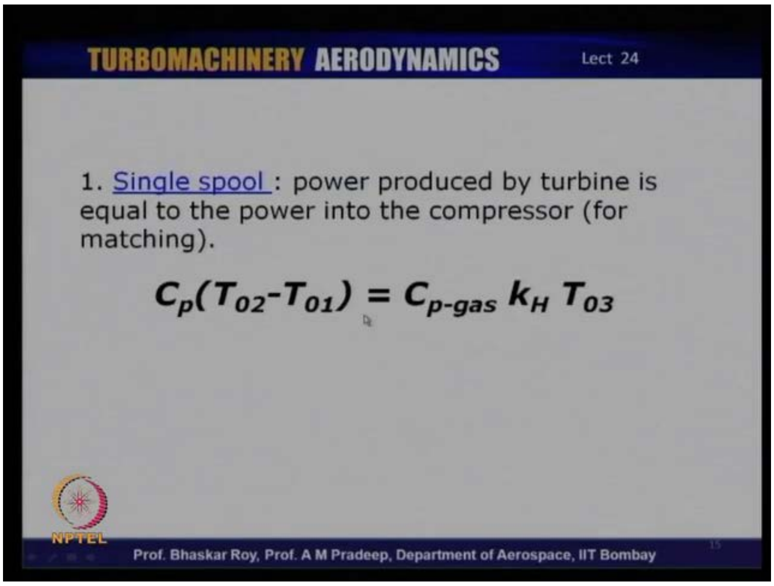

Now, the single pool spool power that is produce by the turbine has to be matched with that of the compressor; now this is the work matching between this is the left hand side is the compressor work, right hand side is the turbine work, and this is what actually gives you the finally, the matched compressor turbine configuration.

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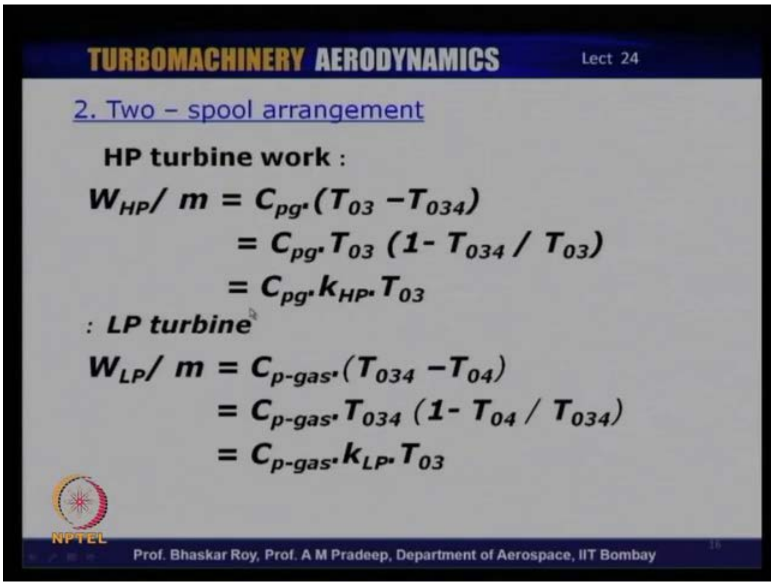

Whereas, if you have a two spool configuration, the matching has to be done spool wise; so, HP turbine compressor as to match with the hp turbine work K HP is a parameter that is been created essentially a thermodynamic parameter to stand for this pressure ratio, we saw that in the earlier one also, which is nothing but a parameter that takes care of the temperature ratio across the turbine. So, basically it is a work matching between the turbine and the compressor, which gives rise to the HP, balanced matched turbine compressor configuration then you have to do the same thing separately for LP. So, you have to match the work done by the compressor and the turbine, and you get again another matching parameter K LP as you got earlier in case of K HP.

So, this gives you, this is called an often a matching parameter, and this finally gives you the matched values of compressor and turbine work done; from this matching, you can actually then figure out what are the matched values of compressor and turbine pressure ratios at that matched design point. So, that matched point is indeed the design point; and at at that design point, you from here, you can find out what is the matched compressor ratio and what is the matched turbine expansion ratio, for which the compressor LP HP, and then turbine HP LP would have to be designed separately by the compressor designers and by the turbine designers. So, this is how the configuration is finally, arrived at before the blade design is indeed taken up. So, this matching is an essential part of compressor turbine, design and this has to be done before you actually embark on compressor or turbine design.

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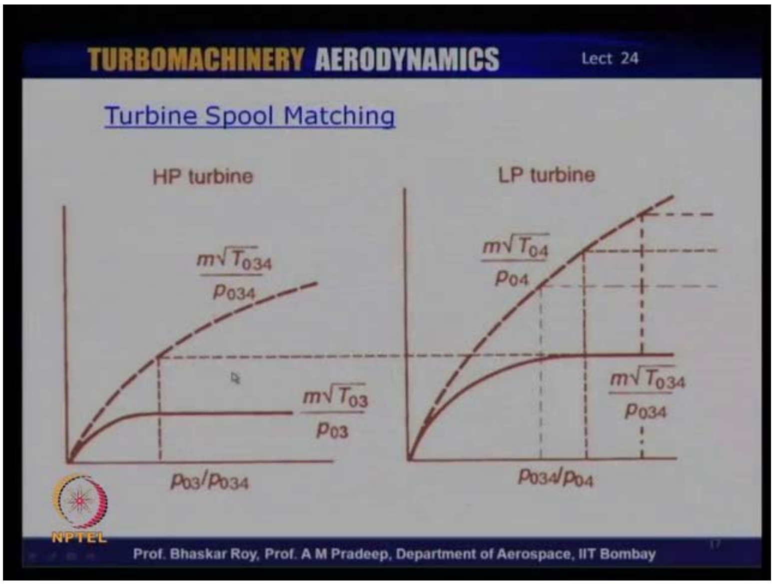

Just to take a look at the fact that if you have a multi stage turbine, you have to match those two spools. So, we were talking about compressor turbine matching, you have to match the two spools. So, you have to match hp turbine with LP turbine; now this graph gives you an idea, what happens, when you have a matched hp and LP turbine, this is post facto; that means, after they have been designed and their characteristic maps have been created. So, this is your hp turbine characteristic you know, this solid line, and then this is the exit of the characteristic this we normally, give it by the you know, entry characteristic, but you can draw an exit characteristic.

So, let us say this is an your design operating point, which you can now extend to this exit characteristic point of the hp turbine, and then from there, you can proceed from here on to the LP turbine, and this is your LP turbine characteristic on the basis of its entry conditions, and you get this characteristic point on the LP turbine, which now as you can see as a good operating point, because this flat zone over here and indeed this flat zone over there as you have discussed in the earlier lectures actually, correspond to choked flow condition that is a steady turbine operating conditions. And then of course, you can, you know extend that to the exit condition of the turbine - LP turbine, which you may like to extend later on to matching with the nozzle if it is an aero engine or if if there is another stage after this, suppose in this is IP turbine, you have to match that with the LP turbine. So, you can extend this to whatever, the component is the following, and then try to do the matching on this characteristic map. So, this is how the two spools of the turbines need to be matched, before you have set upon the detailed design of the turbine.

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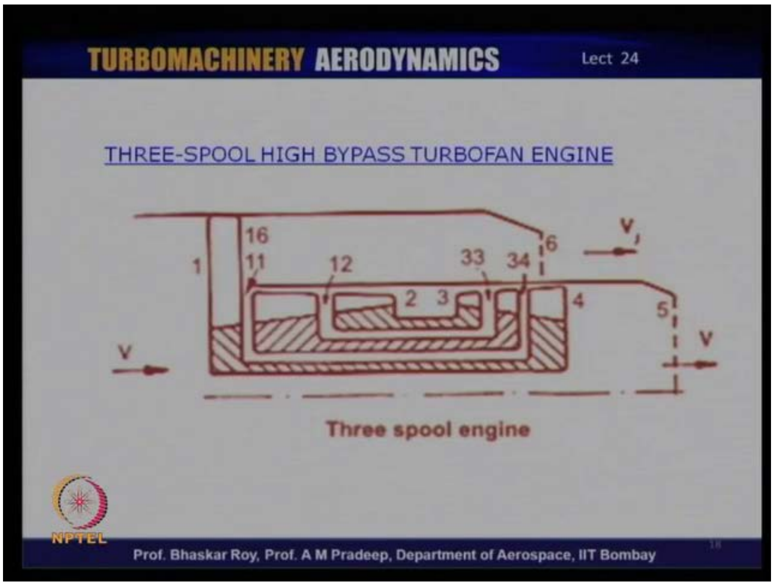

This is just a quick look at what could be possible three spool high bypass turbofan engine, as you can see here, we have three spools; this is the inner most spool of HP compressor and HP turbine in between of course, you have the combustion chamber; and then you have the intermediate spool of intermediate turbine, which runs the intermediate compressors. So, the compressors here are separated from the turbine from the big fan and the big fan is independently run by another set of turbines LP turbines, which are the outer most turbines. So, outer most turbines run the outer most compressors or big fan and the intermediate ones run themselves and the inner most compressor and turbine run each other. So, this is how the three spool configuration is typically made and we saw three spool engines a little earlier, a picture of which indeed is based on this kind of spooling.

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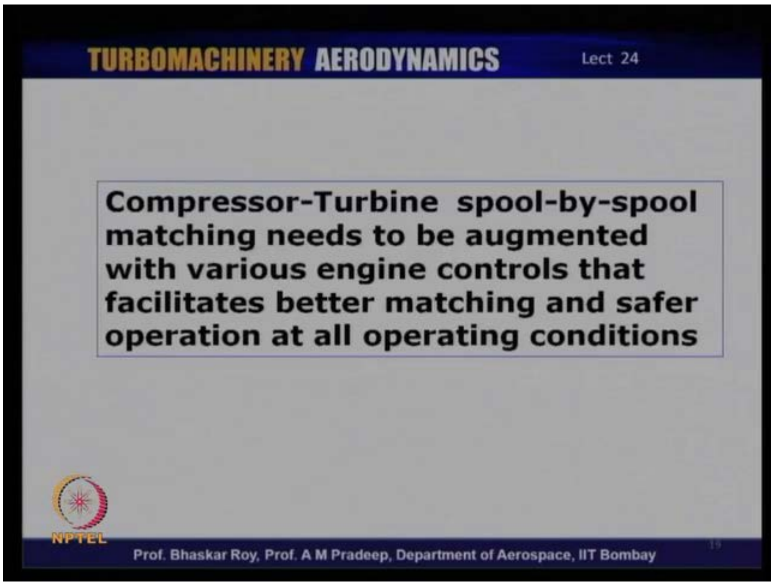

So, we can say that the compressor turbine spool by spool matching needs to be done very meticulously, and this need to be augmented in actual operation by various engine control systems. So, more spools you have, more complicated control systems you need to create. So, this is and of course, mechanically you are making a system more and more complex. So, this is something, which the engine designers would have to decide. So, there are some companies, who are comfortable going to three spool, they are comfortable with the mechanical complexity and the control system complexity, whereas some others are more comfortable with the two spool configuration, and are finding various two spool variants to kated to large engine requirements. So, it is a it is up to the particular company to decide, what they are comfortable with in terms of the state of art of technology.

So, you need to do all the things matching of compressor turbine, matching between the spools, before you have a whole multi spool multi stage arrangement of the entire engine. So, this is how multi staging and multi spooling is indeed done. In the next class, we will be talking then about 3-D flow theories for turbine blade, as we know, as we have just seen, you have to have good 3-D flow theories. So, we will be talking about the 3-D flow theories in the next lecture in relation to axial flow turbines.