Aerodynamic Design of Axial Flow Compressor & Fans
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Lecture 33
Design Strategies

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Hello, and welcome to module 6 for Different Design Strategies, lecture 33.

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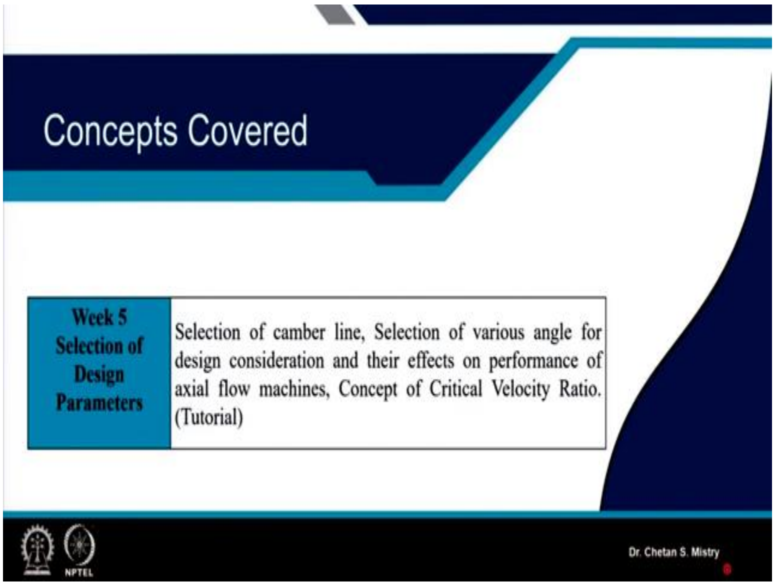

In last module, we have discussed about the selection of different design parameters. We started discussing about the parameters called solidity selection, we started discussing about aspect ratio selection, we have discussed about say number of blade selection, those all parameters are very important when we are having specific requirements. When we are talking about application to design, we are having certain constraints and in order to meet those constraints this parameter selection, that's what is very important.

We have learned so many things up till now, in last session we were discussing about how do we select the camber line, based on what flow angles we have calculated at the entry and exit. And as per our requirement, we can modify the blade to blade passage by selecting different kinds of camber lines. So, we have discussed about circular arc camber line, then we have discussed about parabolic arc camber line, we have discussed about say double circular arc camber line.

And we have realized, as per our requirement, we can modify the shape of the camber line and accordingly for specific or special thickness for using particular airfoil we are able to get the flow passage. We also started discussing about the critical velocity ratio, a critical Mach number and we tried to understand how do we use the fundamentals of this critical velocity ratio or critical Mach number for special kind of calculations.

We were discussing about two strategies for the design as say rating problem as well as on the sizing problem. So, we tried to learn how do we use our information what we learn for solving say rating kind of problem. Now, let us talk about different design strategies.

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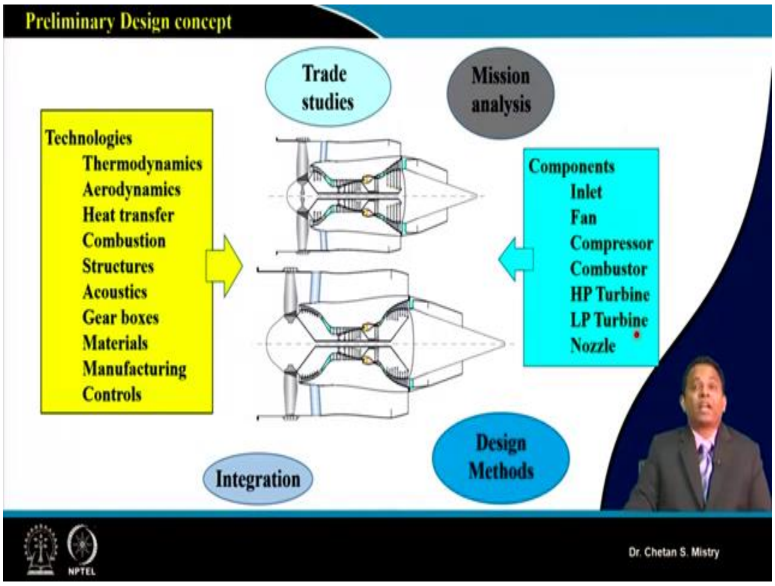

So, if we consider say, we are targeting for special kind of engine need to be made for particular aircraft. So, we are going to start thinking from very beginning, suppose say, we are looking for new engine for aircraft to be made. Now, in order to start with, we must have information about the mission.

We can say mission in the sense, we must have the information about say parameters called thrust requirement. We must have information regarding what will be my flying Mach number, how many engines we are looking for, where do we fit those engines, we are having special kind of flight envelope.

Suppose we are talking about commercial aircraft, where we are more concerned about the cruise condition, when we are talking about say fighter aircraft, our expectations and mission profile that's what will be different.

Now, in order to meet all those requirements, we need to have our fundamental understanding and we must be aware of the technologies what we all learn during our college days. No doubt all these fundamentals what we learnt, that's what we are applying straight way for a development of engine which includes, say…fundamentals of our understanding of thermodynamics, aerodynamics, heat transfer, combustion, structure, acoustics, gearbox, material, manufacturing and controls.

So, you can understand, these all are individual subjects or individual courses at the university level. Now, when we are talking about the development of our engine, group of people with different expertise they are involved for these activities. For this kind of requirement, we need to do some special kind of trade off studies somewhere we are looking for thermodynamic aspect, somewhere we are looking for heat transfer aspects maybe aerodynamics aspects, sometimes we are looking for our aero elasticity, somewhere we are looking for control aspects.

Now, based on this trade study we need to do our systematic design. So, companies, they already have long experience they are having all their old database, that's what will be helping them for initial beginning of different design strategies. After doing all this, we are looking for integration of different components.

So, the engine, we can say, it is comprising of different components that's what is say inlet, fan, compressor, combustor, HP turbine, LP turbine, nozzle, all these together that need to be integrated. So, that is where our integration part that's what is coming into the picture. There are terminologies called, you know, matching of these components; say aerodynamic matching, thermodynamic matching, mechanical matching of these components.

And that is how whole our design strategy or design or preliminary design, that's what is starting with. So, we can understand, if we are looking for the engine development it is not individual strategy or individual idea or we can say it is not that individual person will start with doing the design for the engine, it is a combined effort, it requires special kind of skills.

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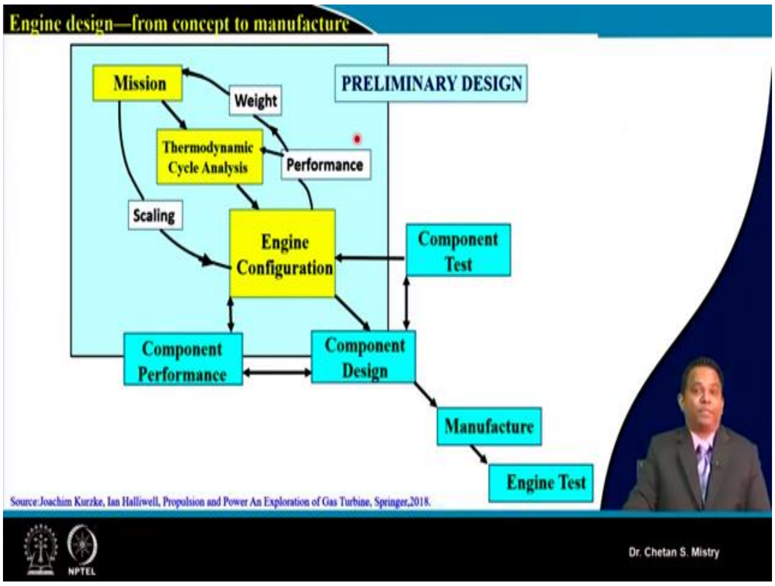

So, let us see, suppose if we consider what all we have discussed, that's what we are putting in this box, that's what is say preliminary design, okay. So, very first thing we will be starting with it is a preliminary design. What we have discussed? We have our specific mission and we can say mission we have discussed, that's what is in sense of thrust, specific fuel consumption, my flight envelope, all these data, that's what will be given from your airline companies or aircraft manufacturing companies.

Now, based on all these data, very first step, that's what is coming is doing your thermodynamic cycle analysis. Now, when I say thermodynamic cycle analysis, that is where the strategy will come in sense of selection of engine, whether we will be going with turbo jet engine, whether we will be going with say turbo fan engine. And if you recall, we are having number of options which are available with us. Even for say turbo fan, we are having big classification, that's what is available.

So, based on past experience with available engines and database, may be one of the engines or one of the configurations, that's what will be selected with. And, that's what will be giving our initial thermodynamic cycle analysis. So, when we say you are planning to do design for axial flow compressor, maybe you are working in a company, you may not be working in a company, you are a student; so, if you are looking for design of say axial flow compressor for the engine, maybe say…LP compressor or say…HP compressor or say…fan.

For that, initially, very first step, it is to do thermodynamic cycle analysis. If you are talking about say your power plants, for that also, we need to do first our thermodynamic cycle analysis. Now, what is this thermodynamic cycle analysis? That's what will be giving us idea about the variation of say pressure, temperature, speed, different say your velocity components, all those data, that's what will be available with us when we are doing our cycle analysis.

And the outcome of our cycle analysis that will be in the form of thrust calculation, in the form of specific fuel consumption calculation. Now, we can understand, that's what will be giving us some information about selection of my engine configuration, okay. So, you can say you have done your initial cycle analysis, that's what is giving some engine configuration. Now, that's what we will be checking with say the performance requirement; whether it is meeting with our performance requirement or not.

Now, when we are doing our calculation, that time it will give some information saying like my thrust requirement it is meeting with, my specific fuel consumption requirement it is not meeting with. So, what it says? Again, you need to reiterate, you need to go with cycle analysis again, you just come up with the information, again you do the configuration, so this will be a repeating cycle.

Once this is what is known or we have done in sense of calculation then we will be checking with say rough estimation of the weight of the engine. You find the weight of the engine, that's what is higher. Then, what it says? My thrust requirement by the engine need to be different. So, under that configuration, again we need to check with what is my thrust to weight ratio expected.

If it is not meeting with this requirement again I need to change with my mission statement and I will be going with this loop, okay. It may require some kind of scaling also, that's what we can do here. Now, here if you look at, I have written saying like component design; so, this component design that may or may not straightway come in sense of preliminary design aspect but we can have say initial calculation of our component.

Suppose, if I consider say for compressor, we can do our calculation for our flow track, we can do our calculation for say number of stages, we can start doing calculation in sense of say designing the individual stage. Now, when we are doing our individual stage, we need to check with say component testing, that may or may not be required.

So, suppose say, we are implementing some special kind of blading for the compressor, under that condition maybe we need to go with the component level testing and we need to check with what all we are looking for is it meeting or not. If not, then again, we need to do this as a reiteration, we will be checking with the component performance.

So, this is what all will be taking a whole lot of time, it requires lot of engagement of say manpower and based on that companies they will be coming up with some solution, that’s what is giving what they are looking for in sense of mission, okay. This calculation that may be very challenging when we are talking about the fighter aircrafts, because there the expectations and designs, that’s what is totally different, it has so many constraints there.

You can understand, for say commercial aircraft, we are having say configuration saying like take off, my cruise condition, that’s what is of main interest and landing. Now, when we are talking about say fighter aircraft, it will be having different kinds of manoeuvres to be performed and under that condition, this design will be very restricted, it will be very challenging.

Once this is what is all done in sense of component level design, it will be going for say manufacturing and after doing this manufacturing, the engine will be going for the testing. So, very first design what they are looking for it may or may not be exactly meeting with the requirement and again they need to go with different kinds of iteration, may be redesigning and finally, that’s what will be qualifying for the certification.

Once that certification has issued, then they are permitted to move with say production line. Again, for all those engines they are making, that need to be tested; it is not that single engine, that’s what has qualified by testing then they are permitted to go with say production in a bulk and there, they all engine, they need not to be tested, all engines what they are making, those all need to be tested, okay. And this testing, that’s what is rigorous testing.

There are many YouTube videos available, you can check with how the testing, that’s what has been performed for particular kind of engines. So, you can say, this is what is all we are looking for. Our target, that’s what is coming initially it is at the state of say preliminary design aspect, okay.

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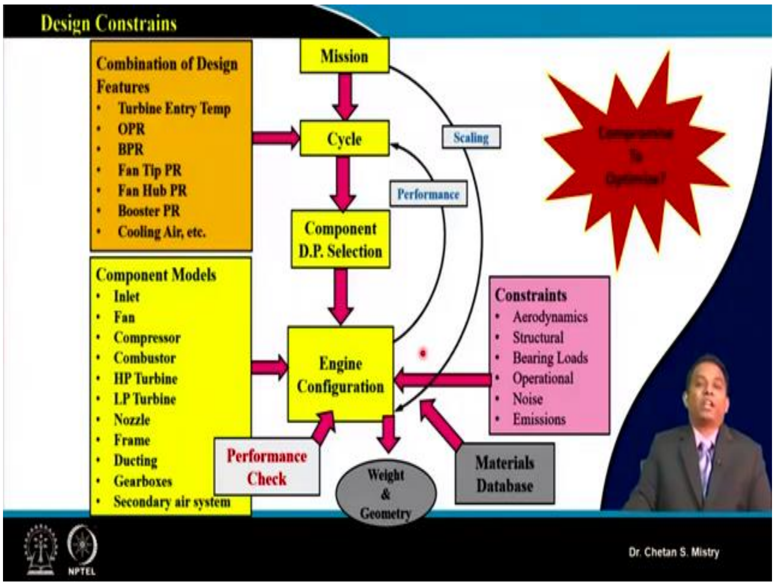

Now, in order to do this all, we can say, we are putting our design requirement or design constraints. So, if you are considering, we are defined with our mission. Now, based on that we have done our cycle analysis or we want to perform our thermodynamic cycle analysis. Now, in order to do the thermodynamic cycle analysis, we need to have the combination of different design features which includes turbine entry temperature, that’s what is a main requirement, you can understand, that’s what is deciding what will be my efficiency of the plant, okay; higher will be the turbine entry temperature, you will be having higher the efficiency.

Next parameter, that’s what is what will be my overall pressure ratio; let me have say single spool configuration, we can have two-spool configuration or even we are going with the three-spool configuration. So, overall pressure ratio, that’s what is very important. And if you recall, in last session we were discussing about say overall pressure ratio, that’s what is going to increase over the years. And, for most recent engine, this has reached almost to say number 60, okay. So, those kinds of engine we are now looking for.

Next, that’s what is my bypass ratio. So, whether we are going with high bypass ratio engine or low bypass ratio engine; you can understand, for commercial aircraft application, our major concern is a fuel economy and that’s what is promising by using high bypass ratio configuration. When we are applying these engines for say military purpose, there because of my size constraint, we will be going with say low bypass ratio engines, okay. So, bypass ratio, that is also one of the important parameter that need to be considered.

Then we need to go with say fan tip pressure ratio, fan hub pressure ratio, booster pressure ratio, cooling air requirement, all those parameters, these parameters are required at the entry when we are doing our cycle analysis. If they are not available, we need to start with some assumption, okay. So, once we are doing this cycle analysis, we will be coming with say one point, that's what is called design point selection. So, this design point, that's what is very important, okay.

For each component, we are having our design point and mostly for the design purpose of say your commercial aircraft, high bypass ratio engines, say our design point, that's what is maximum thrust condition or we can say that's what is my take off condition. This design condition may vary when we are talking about our military application because there our expectations from engines are different, okay.

So, that's what will be giving us component design point selection, okay. Based on that we will try to do our engine configuration. Now, for this engine configuration, we are looking for different components again; say, we have our intake, we have our fan, compressor, combustor, LP turbine, HP turbine, nozzle, frame, ducting, gearbox, secondary air systems, all these together, that's what will be making my engine configuration.

Now, when we are incorporating all these components, we will be checking with what will be the weight of my engine, okay. We will be checking with is it meeting with what geometrical constraints which are given by aircraft manufacturing company. Is it meeting with this requirement? If not, then again, we need to go with the reiteration, we need to check with our performance.

We are also looking for say special kind of materials to be used. Suppose, we are talking about the fan, whether we will be going with metal fans or we will be going with the composite fans. Now, if you are going with the composite fans, what all need to be the dimensions for that. So, again we will be having our constraints, those constraints are because of aerodynamics, because of structure, because of my bearing load, operational requirement, noise and emissions.

So, all this together, that's what is giving some or other way some of the restriction to our engine, okay. Now, if this is what is your case, again we need to check; we have discussed with the performance and if required, as and when required, we will be modifying our parameters and after having change of this parameter, again we will be going with the iterations. So, it is not straight way design, it is more or less iterative kind of configuration, okay.

Now, the question will come, whether we need to compromise for the optimization? So, it may happen like somewhere I am putting some constraints in sense of overall pressure ratio, that's what will be giving me some restriction in sense of size. But, at the same time, maybe it may not give what specific fuel consumption I am expecting from, what efficiency we are expecting for, what propulsive efficiency we are expecting from.

So, somewhere or some other way, we need to compromise at some point. But, that's what is based on what all understanding in a group people they are working for. Somewhere, for some point, maybe they need to check with. Suppose, if we consider expected turbine entry temperature that what has risen, now the question will come, what need to be done? How do we address this issue?

It says, you need to look for say different kind of material or maybe you are looking for some coating. So, that's what we are adopting with the new technology. Now, that new technology that need to be tested. And once we build the confidence then only we will apply that for say the development of the engine.

Same is the case for say compressor. So, we will be having expected pressure ratio to be very high. Suppose, we are expecting pressure ratio is high that means my per stage pressure ratio is very high, that's what will be giving me the reduction in sense of my length. Now, the question is in order to meet that requirement, I may need to go with special kind of airfoils.

Now, when we are applying those airfoils, we need to iterate with our design procedure, we need to check with what all we are looking for in sense of pressure rise, in sense of efficiency, in sense of my operating range, in sense of my stall margin; all those things need to be checked. And those checks, that's what is done at test-rig level and later on, that's what will be tested with say actual engine, okay.

So, this is what. So, whole this what we are looking for before say 2000 or 2005, one engine development, that's what was taking approximately 10 years or more than that. Now, with the advancement of technology, with the maturity of the technology, with computational tools and their applicability, this cycle, that's what has been reduced, okay.

But you can understand it is not that I will be fixing some parameter and I insist that need to be continue with, that is not the case. As an individual, we cannot, we need to go together in a group and we need to have some compromise somewhere for expected performance, okay.

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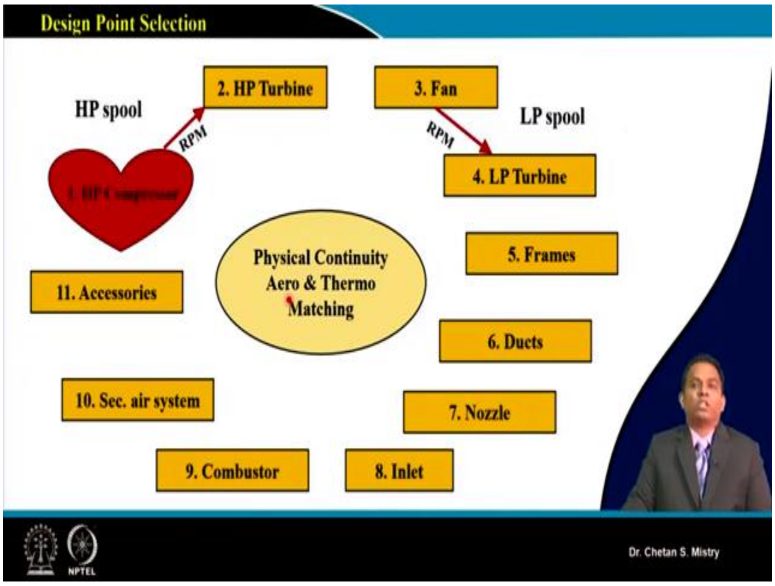

Now, here this is what is coming as our expectation what we are looking for. So, here if you look at, very challenging part or the most challenging part for say development of engine, it is the design of your HP compressor, because that's what is the heart of the engine, okay. So, the group of people those who are involved with say HP compressor design, once they will finalize with their geometry, everyone they need to appreciate that part.

Now, the thing is you are fixing with your HP compressor design from where your initial engine design part, that's what is started with. You can understand, we have discussed about this part what kind of flow track we will be selecting, is it constant mean diameter, constant tip diameter, constant hub diameter, so all those things, that's what will be coming into the picture.

Now, what need to be the pressure rise, that's what is expected from HP spool or HP compressor that is also very important. Now, how many stages we will be selecting that is also equally important. So, we can understand, when we are doing our design for HP compressor, that's what is giving us idea about what need to be my rotational speed.

You can understand, we have discussed, when we are looking for per stage pressure rise to be higher, when we are looking for lower number of stages, it may be possible we are looking for higher rotational speed. Now, the next step, that's what has come, that's what is we need to match that speed requirement with the design of HP turbine.

So, HP turbine designers, that's what, they will be taking care of having the speed range as per the requirement for say HP spool, okay. Now, the next component, that's what has come, that's what is our say fan or we can say our LP compressor or IP compressor; we can say that as a booster compressor. Again, there also, we are looking for say matching of our rotational speed, we can say for particular span we are expecting our tip Mach number to be in certain range in order to have higher efficiency, okay.

So, under that condition, my rotational speed, that's what is coming as one of the constraint. Now, based on this recommended rotational speed by fan that will be taken by LP turbine group; and, they people, they will be deciding with number of stages in order to achieve that particular speed, okay.

Suppose, if we consider, say, we are designing the engine for fighter aircraft, there we will be having lot of constraints in sense of selection of rotational speed but at the same time where I will not be having my fan speed to be very low that's what is having higher rotational speed and that can be achieved with less number of LP stages for turbine.

Suppose, we are talking about say your high bypass ratio engine, for high bypass ratio engine since we are looking for our rotational speed for fan to be lower my number of stages for LP turbine, that's what may be going to be higher, okay. So, we need to have this kind of restrictions there, so we can understand, we are looking for special kind of matching; that matching, we can say, it is in sense of RPM, okay.

Then after doing all this part, we are looking for frame or where…how you will be accommodating all these components in frame, okay. So, you can say this frame, that's what is, you know, it is a mechanical part, that's what will be given by this aero-dynamist or say this component level designers. We are looking for say ducting; so, you can understand, say for LP spool and for HP spool, that's what they are connected at different diameters where we are looking for say our frictional losses to be lower, we are looking for flow uniformity at the entry of my HP compressor, under that condition this ducting design, that's what will be coming into the picture; especially for the compressor, this is what is equally applicable for turbine also.

Suppose, if I consider say HP turbine and LP turbine, there also, we will be having say difference of this radius and that's what will be taken care of by these ducts. Then we are looking for say nozzle, this nozzle for our subsonic flights or commercial aircraft, we are not having many constraints, but when we are talking about say fighter aircraft, that's what is major governing part. It has to do number of actions, not only the thrust generation, it may be handling sometimes the vectoring part. So, all those things, that's what will be coming into the picture.

So, what kind of engine actually we are designing with, that's what will be deciding with what focus need to be done. Next, that component it is say your inlet. We can understand, at the entry of my fan or maybe at the entry of say LP compressor, we are looking for our Mach number to be in the range of 0.4 to 0.6.

Suppose, if we are considering say our flight, that's what is supersonic then maybe our intake needs to be designed in such a way that at the entry of my compressor, I will be receiving my Mach number roughly in the range of 0.4 to 0.6, okay. So, that's what will be coming into the picture. Now, for combustor, if you are looking at, the combustor, that's what dimensions at the entry and exit, basically that's what is already been decided by our HP compressor and say HP turbine design.

Now, how do we accommodate that in sense of inclination or in sense of numbers, all those things, that's what will be coming into the picture, okay. So, this combustor, that's what is not majorly in sense of mechanical design people they are looking for, but as and when required maybe certain modifications in design, it is need to be accommodated.

We will be having secondary air system that is not of priority but yes, this is what is of importance. Straight way that's what is directly impacting on in sense of my weight of the engine, okay. External accessories, we can say, we are having different kind of actuating mechanism, we are having some different kind of say mechanisms what all things we are accommodating in the engine, that's what is coming into the picture.

So, it says accessories. So, all this together, we are combining, we are doing our design, that's what will be giving us the idea about what will be the weight. Maybe sometimes you need to compromise for the weight in order to achieve what performance you are expected with, okay. So, this is what it says we are having physical continuity, aero and thermo matching, that's what is coming into the picture.

So, there is a specialized branch in engines people they are talking about aerodynamic matching and thermodynamic matching, that's what is very important what all components we have designed they all need to be both aerodynamically and thermodynamically need to be matched. If they are not matching, then it is of no use, okay.

So, this is what is giving us idea about how do we think in sense of development of our engine. Now, this course, that's what is dedicated for the aerodynamic design of compressors and fans, we will be moving ahead with say different design strategies for design of say fan, we will be discussing about the strategy for the design of compressors in more detail in next lectures. Thank you, thank you very much for your kind attention. See you in the next lecture, thank you!