Fundamentals of Aerospace Propulsion
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Lecture - 27

We have discussed about various performance parameters like efficiencies, propulsive efficiency and thermal efficiency and overall efficiency, but question arises where we will evaluate those efficiencies of an engine. Can anybody tell me just to facilitate to answer, I will tell you in the two places, one can for example, I talk about propulsive efficiency if the my vehicle in the ground. I can evaluate when the vehicle is moving, I will have to evaluate if you look at the definition of propulsive efficiency as expression for propulsive efficiency. You will find there is a flight velocity particularly for air breathing engines and also for non air breathing engines.

If the flight velocity is 0, what will happen to propulsive efficiency, can you look at you know notes, what you are getting, it will be having no meaning. So, therefore, it has to be evaluated, all the efficiencies depending on what you are doing at two conditions, one is tactic condition and another in the level flight at the particular altitude and particular flight mac number. It is being designed and of course other places one can, but these are the two which are being used routed. Now, we will be talking about another, you know parameter which is quite important that is known as static thrust.

Static thrust means like on the ground condition, it is static, it is not dynamic, and it is not moving. The vehicle is not moving that means my flight velocity will be 0, if I look at the thrust expression, what we have derived, it is having two components. One is the momentum thrust, other is pressure thrust and we can assume for the simplicity, the nozzle is fully expanded. So, if it is nozzle is fully expanded, then pressure thrust will be 0, p e is equal to p a.

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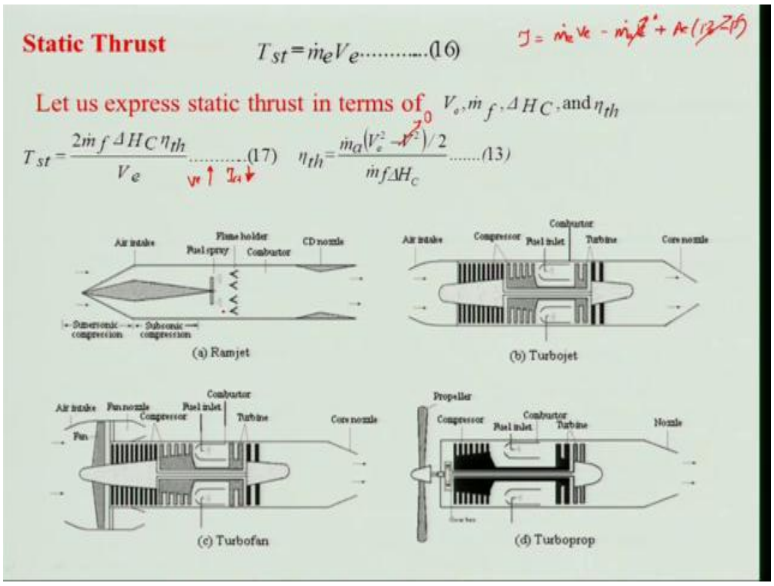

So, therefore it will be 0 and then if the flight velocity is 0, then we will get static thrust is equal to m dot e V e. So, if you look at basically thrust definition is m dot e V e minus m dot a V a or V is simply I am using plus a e p e minus. So, this will be 0 and this is 0, so we will get static thrust is basically the m dot e V e. That means what is indicating, it is indicating that static thrust will be higher or will go on increasing when the exit velocity or the jet velocity from an engine will go on increasing for a particular air mass flow rate.

Air mass flow rate will be depended on what for an air breathing engine, it will be dependent on the flight velocity yes or no and also the cross sectional area of the engine. Now, when you talk about this whether the static thrust, you need to have higher or lower what you need that depends upon your what requirement. So, because you know if something is there in the stationary, you need to make it to move, what you will have to do, initial thrust will be higher or the force you will have to apply more static thrust will be higher if the payload is higher. Then, naturally I need to have a higher static thrust and if i look at this, static thrust will be dependent on what exit velocity or the jet velocity from the engine.

Jet velocity will be dependent on what you know like I am putting some fuel, it will be depended on how much fuel is getting consumed because I am adding energy, it will depend upon type of fuel I am using. That means calorific values, it will be dependent on also the efficiencies, what is that efficiencies, thermal efficient, how good it is the energy is converted because we are using thermal energy. Therefore, that means how much kinetic energy or the energy you know being obtained by burning the fuel.

So, we need to look at the static thrust can be expressed in terms of V e exit velocity m dot f that is the mass flow rate of fuel and the heat of combustion of course which will be dependent on kind of fuel you are using. For example, nowadays people are thinking of using hydrogen as a fuel in air crafting, although aviation turbine fuel is being used and now people are talking about using bio fuel, bio diesel. You know bio diesel, rather bio aviation fuel, they are designing it because the fossil fuel would not be there.

So, the calorie value will be changed and it will be dependent on the thermal efficient because you may burn certain amount of fuel how good it is in converting to the change in kinetic that will be looking at. So, let us look at the expression for thermal efficient which we have already derived and keep in mind this efficient thermal efficient. We have derived assuming that nozzle is fully expanded, therefore you know p e minus p term is not there and whenever we are talking about static thrust the flight velocity will be you know 0. So, then what I will get, I will get basically static thrust as m dot V e that is by definition is equal to 2 m dot f delta H c and thermal efficiency divided by V e.

If I assume that certain amount of fuel I am burning for a particular fuel flow rate and particular kind of fuel, let us say for aviation turbine fuel in case of air crafting and the efficient is remaining constant. I mean of course may not be then the thrust efficient is inversely proportional static, sorry static thrust inversely proportional to the jet velocity or what I call exit velocity from the engine, what is indicates?

It indicates that whenever exit velocity will be go on increasing, what will happen to the static thrust static thrust will be go on decreasing because V e is in this case is increasing the static thrust. What will happen decreasing and when the other way around, if V exit velocity, jet velocity is lowering like down. Keep in mind whenever we are showing, we are showing that for a particular mass flow rate of fuel for particular thermal efficient and particular kind of fuel, then it is valid keep this in mind.

You should not get confused with that, I will then talk, so therefore it will be other way around. Suppose, I want to have a higher static thrust, I will have to decrease the jet velocity keeping of course, the same mass flow rate and same kind of efficient thermal efficient and same kind of fuel based on this. The gas turbine engine can be divided into three categories as I told you earlier the based propulsive efficiency people have also defined divided the gas turbine engine.

They have you know innovated three kinds of engine to meet their requirement for example, I want take some load like you know let us say there is Kargil war, I want to take some ammunition from the land to the war sight from interior to the land war sight. I will have to carry lot of ammunition which is heavy, so that means I need to have a static higher static thrust, what I will have to do, then and also propulsive efficient should be high.

So, I will have to go for a turboprop engine although the exit velocity turboprop engine the exit velocity from this engine will be much lower as compared to the turbojet engine. Here, what will happen static thrust will be low that means I cannot really lift or I cannot have you know carry the heavy kinds of things, but however I can get a higher thrust. If I get a higher thrust, I can with a faster speed because flight velocity will be higher, so it is a compromise you are doing.

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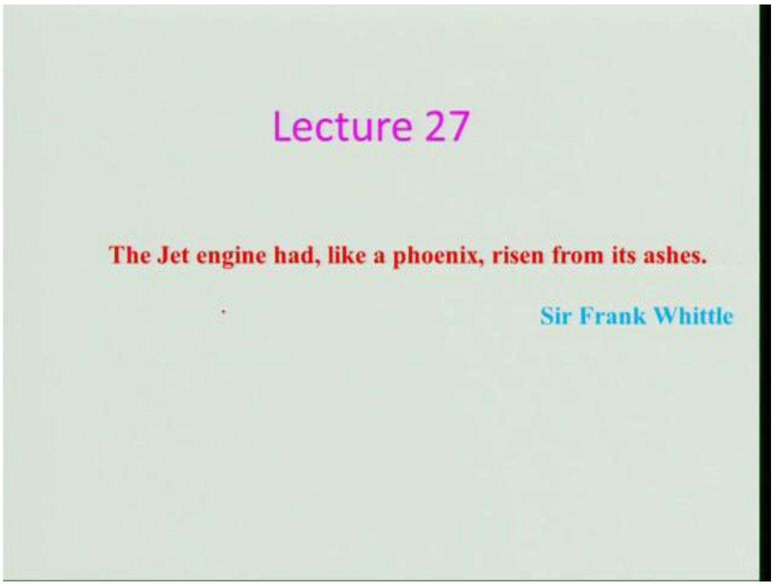

So, similar way we can get a in a middle value that is the in between which is being used for the turbofan engines and ramjet engine. You will get you know the static thrust can you get you cannot really get the static thrust, it is impossible, why is it. So, we will answer that question when we will talking about ramjet, what I would, I would urge you people to look at this picture because second time I am showing this figure and you will find that it is quite you know interesting to look at.

So, we will start this lecture with a thought process from a legendary Sir Frank Whittle who says the jet engine had like a phoenix risen from its ashes. The concept was almost dead and then he and also with the Von Ohain who is another inventor of this engine. They caught it and now we are enjoying you know their ideas and implementation at the engine.

So, if you look at in our culture, it is been talked about to became these that means second birth, you should be like a phoenix, you should be all your things and became a person of you know excellence. So, the objective of education is to achieve the excellence in yourself which is lying hidden in you. So, coming back to this like as I told like we have really talked about in the last lecture about what you call thrust expression. Then, we move to the various efficiencies like propulsive efficiency, thermal efficiency overall efficiency. Then, we talked about static thrust, now we will be looking at another performance parameter which is known as aircraft range.

Why we are interested to look at range that means or what is the meaning of aircraft range for a particular amount of fuel. How much distance it can travel or how this the distance travelled by an aircraft, you know can be altered or can be enounced because you know from the fuel economy point of view.

Also, from these suppose I can have a higher flight, I can use higher thrust to go at a at a faster rate, but what penalty I will have to pay for that is it optimal or not so for that. We need to look at the aircraft range, keep in mind where aircraft is going, there will be ascending stage. That means it will take off and go in level flight, particularly the passenger aircrafts you know, long range passenger aircraft, it will be moving at a level flight at a particular height. Of course there might be change, but for us we can assume it to be and then it will be land.

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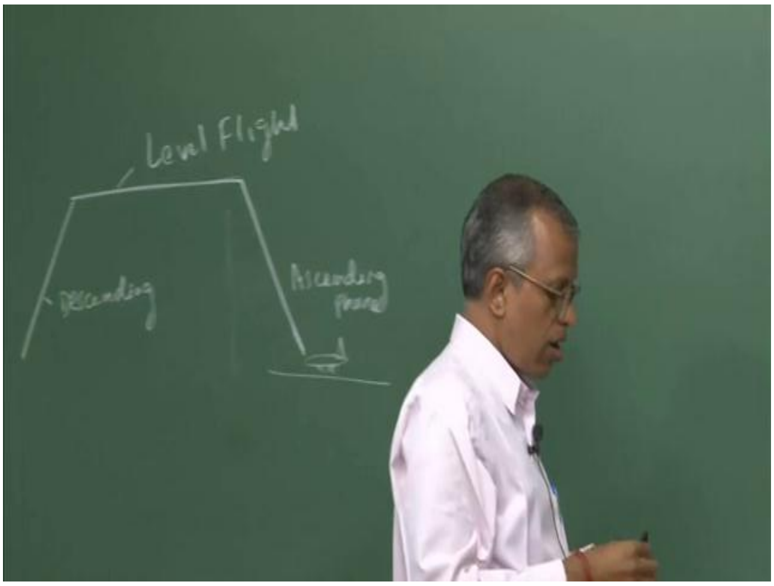

So, if you look at the aircraft will be taking off from the ground, you know let us say this is the ground kind of things this is your aircraft which is flying kind of thing like and it will be moving you know like it is ascending. This will be level flight and this will be descending that means this is known as level flight. Keep in mind that this portion is a very small time and this is for this portion, this is descending you know this is ascending phase or take off kind if things. Therefore, this leveled zone is a highest or the larger amount of time you spend on level flight particularly for long range passenger aircraft.

Therefore, those portions are not very important we are not considering however in the complete thing one has to, but what assumptions in this level flight, what is really happening when the aircraft is flying level like at one high altitude. You know what is happening there, you do not have much acceleration, here it will be accelerating and there it is decelerating in the descending phase and then I see that case the drag is equal to the thrust and the lift is equal to the weight of the vehicle.

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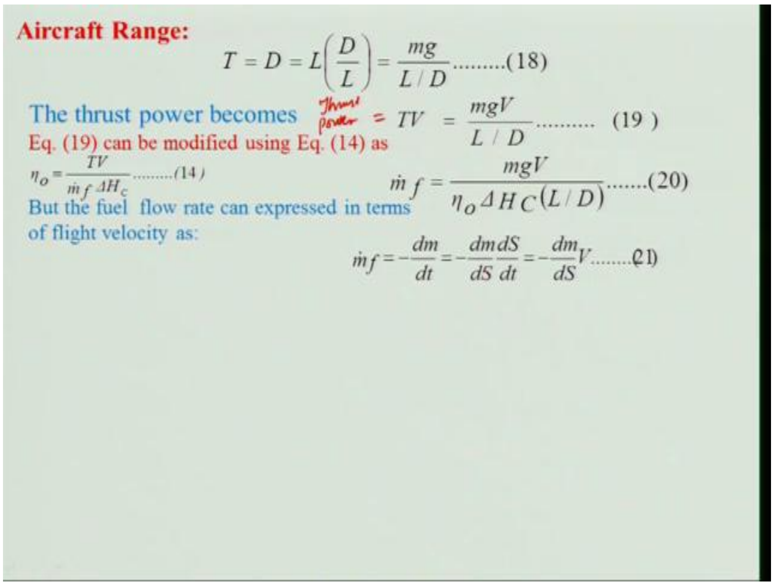

So, this is the condition what is being we will be looking at that means the thrust is equal to the drag in the level flight. We can write on l is equal to d by l, I can basically this is d by l on in other words it is L by D lift and drag ration and what is a lift in the level flight is basically what m g m is the mass of the aircraft g is the gravity which is acting. So, what we will be doing now is that we will have to basically find out thrust power, how much power is required to do that and by definition thrust power is equal to thrust into the flight velocity.

That means t into V that is your thrust power, this is your thrust power is equal to t into V or into m g, L by D. So, what we will have to do, we will have to look at this equation this 19 can be modified using what using your overall efficiency because if you look at overall efficiency is nothing but thrust power ratio of thrust power. The amount of fuel or the amount of heat released due to combustion due to burning of the ATF aviation turbine fuel in case of aircraft, but in rocket engine there might be several kinds of fuel.

So, what we will be using, we will be basically looking, I mean putting this clubbing this together, what I will be get in place t V, I can down eta overall into m into f delta h c. Then, I can on m dot f is equal to m g V and eta delta H c L by D, so in place of basically t V, I am writing. So, it will come out of this, so what is saying, it saying that mass flow rate of fuel or mass consumption of the fuel will be dependent on the mass of the vehicle flight velocity and inversely proportional to the overall efficiency and heat of combustion. Of course the lift and drag ratio if the lift and drag ratio is higher, what will happen the mass flow rate of fuel or the mass consumption of the fuel will be reduced which is always of course keeping other things same.

So, then it is desirable to have, but the mass fuel flow rate can be expressed in terms of flight velocity, how we will do that because if you look at a long range passenger aircraft is there. Once it is on the flight level flight condition, what will be change in that mass of the aircraft will be changing or not, it would not be changing because the fuel is getting consumed and it is consumed as a very little faster rate. You know let us say it is Boeing which is carrying, it is a bigger one you know 500 people or 700 people can carry 800 people.

So, that means so much of you know fuel has to consumed, it is a very big aircraft, so if it is coming in this case that consumption of the fuel will be very high. It will be reducing because you are getting consumed and leaving to the atmosphere freely, you know and polluting it also. Then, that mass of the aircraft will be decreasing and so that means mass of the due to the consumption of the fuel the mass of the aircraft will be decreasing because there is no way anybody can go out in the level fight.

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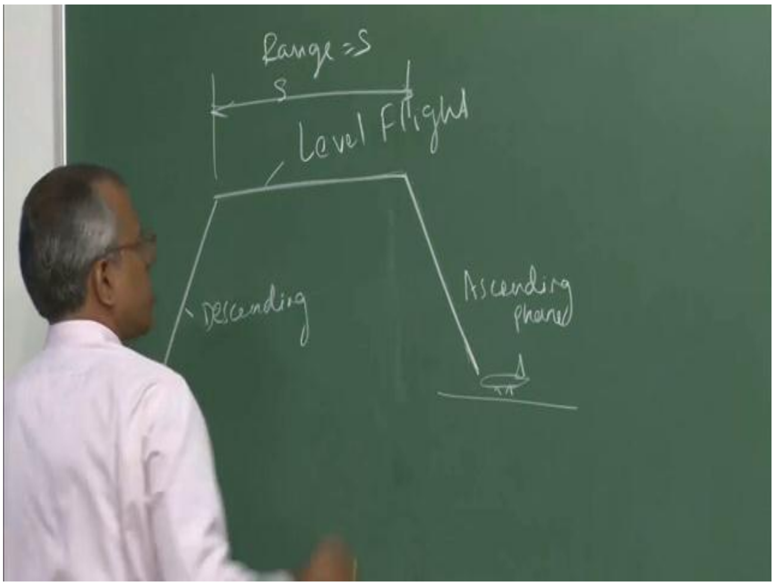

So, I can write on m dot f is equal to minus d m by d t that means the mass of the vehicle will be containing passenger’s fuel and of course crew member and other things. Aircraft itself mass, those are not changing when it is in level flight, so I can write on d m by d t is equal to d m by d s that is you are the range that means this distance.

What I am calling it as a s the range this distance, I am calling it as range equal to s, therefore I can write down minus d m by d s and that d s, d t is what nothing but your velocity.

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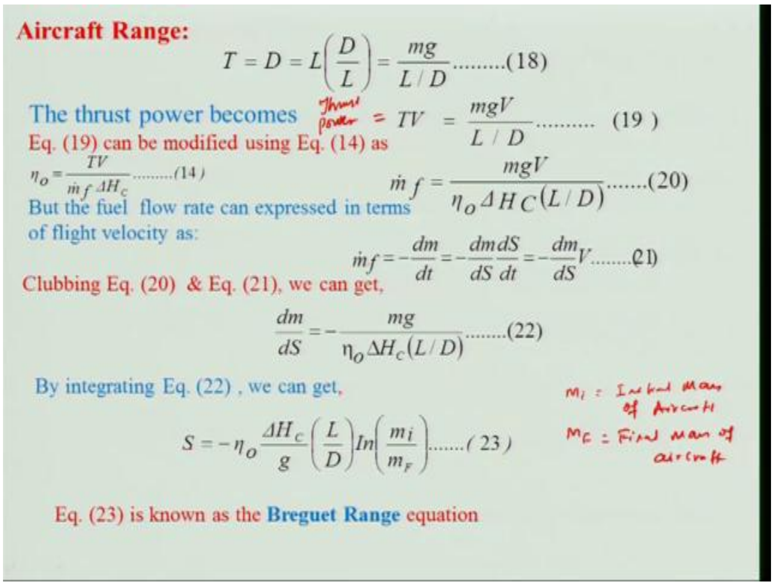

The flight velocity and keep in mind that there is no acceleration, therefore flight velocity remains same. Now, what I will do we will put this here this club this equation 20 and 21 and we will get d m by d s is nothing but minus m g divided by eta not delta H c L by D. What we will do, we will now take this out m d m by you know m and then other terms remaining constant because overall efficiency you can assume to me constant L by D is constant. Everything constant including g because g is at one particular altitude whatever it will be.

So, you can take that and only then if we integrate this expression, we will get s is equal to minus eta not delta H c g multiplied by L by D l n m i by m f what is this m i, m i the initial mass of vehicle of aircraft. I can say vehicle means aircraft and f is the final mass of aircraft and change in the mass will tell you that you know range that is the range. So, if you look at this range, you know equation is known as the brogue range equation which you some of you might be aware and keep in mind this range will be dependent on the overall efficiency. It will be dependent on the heat of combustion and it will be dependent L by D.

Now, what we will looking at we will be looking at basically what kind of this range you know, we can maximize this range and how we can maximize that we can look at how my overall efficiency is varying with the flight velocity. For example, you might be riding a motorbike of course a layered diesel there is a green zone, you know where in your speedometer, there will be green zone. If you travel in that range you will be get the least fuel consumption, but if you go beyond that which of course you can fly at a higher or you can ride at a higher velocity, but you will have to pay penalty and that is true for the life.

Each individual is having their own pace of doing the things and if you try to catch somebody, then you will get a stress and that is the problem with the modern life and the same with the aircraft. If you look at it, it is all natural things, therefore one has to look at let us look at how we can maximize the range or minimize the fuel consumption for a particular initial fuel and final fuel ratio, we will be looking at that.

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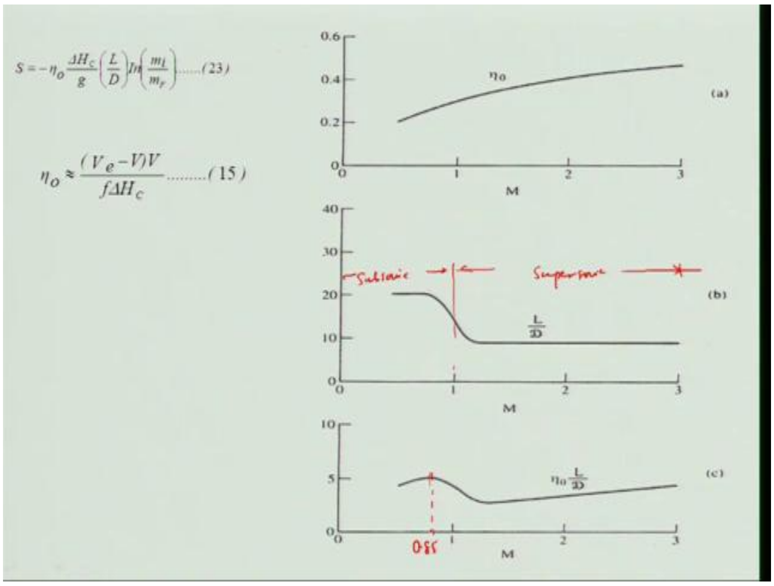

As I told you that overall efficiency will be dependent on flight velocity or not and similarly L by D will be dependent on flight velocity. So, the overall efficiency will be you know depending on flight velocity, whether it will be increasing or decreasing, can you look at your formula or expression. So, if we will see, it will be goes on increasing because if you look at overall efficiency s equal to V e minus V into V and of course you can say particular exit velocity, you know kind of things and delta H c remaining constant.

You know for a particular kind of fuel and f is you can assume it to be constant, so then you will find out overall efficiency is goes on increasing, but whereas, L by D is you know maybe little bit change is occurring. It is remaining constant in the range of flight mac number, but after that it decreases and it becomes you know slowly decreases in case of a supersonic flight. You can note that in supersonic flight which is greater than 1, you will find L by D is very low as compared to the subsonic, this reason is the subsonic and this is supersonic. From now, if you club this together that eta L by D, you will find you know if I just use multiplied this and plot repot it, I will see I am getting that this thing is goes on increasing and reaching a value.

Over here, you know if you look at and then it is decreasing and again of course it goes on increasing because this is increasing and this is decreasing. So, finally, it will be increasing, what is indicating that the range maximum range can be obtained whenever you are flying at a subsonic speed of 0.85, do not go by that exactly 0.85, but around that. If you will fly then we will get the maximum range for same the kind of fuel or same amount of fuel. So, that is a reason why all the long range passenger aircraft will be in subsonic not in supersonic and when for example, war or something, you will have to fly at supersonic.

You will have to pay penalty for that, so that is very important as I told you for the life, whenever emergency is there that is a different thing, but you cannot make your life as emergency situation and what we are doing. So, we will have to careful about that, now we will be looking at another parameter what we call it as a specific thrust, what is the meaning. Thrust per unit mass flow rate of air, what it indicates, why we should at this parameter specific thrust, it will tell me the size of my aircraft because the mass flow rate of air is there, specific thrust is small, what it indicates?

It indicates for a particular thrust the mass flow rate of air is higher if my mass flow rate is higher, what will happen, I can get a higher mass flow rate of air which is entering into engine at a higher speed pressure. If I go for a higher pressure, then what will happen the all this, you know things material, you know I will have to exerting materials or I will have to use whatever material available at this moment with a more thickness.

That means weight will increase or I will increase my area, if I will increase my area, cross sectional area of the inlet, then the drag will be more. Therefore, you know it is a problem, so size of engine will be higher, you know lot of problem will be coming. Again, the material cost will go up and several other things will happen, therefore it is very important to have a specific thrust as a parameter.

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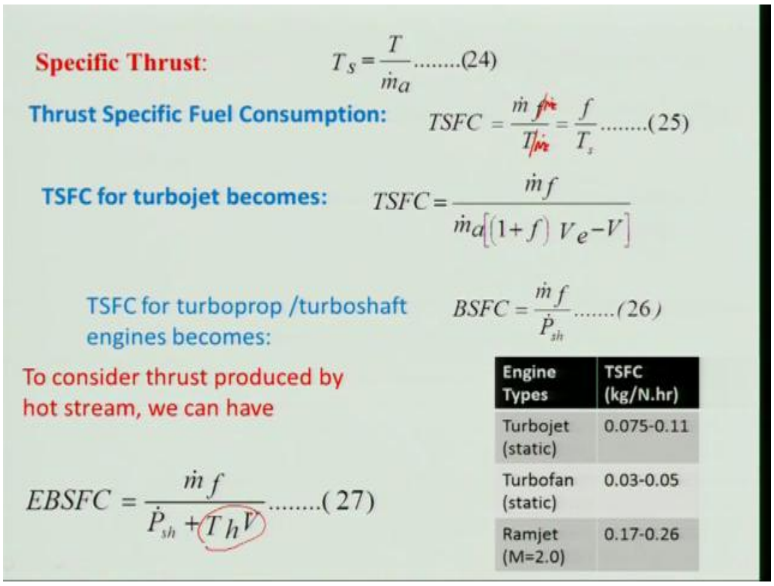

So, generally we should have what you call the higher specific thrust so that it will be compact engine and then you know you will get higher thrust. That is another very important parameter which we will have to look at that thrust specific fuel consumption. As the name indicates, what it says the amount thrust produced per unit mass flow rate of fuel consumption. If I multiply, if I divide this by m dot a and then m dot a divide by m dot a, you will be f that is fuel air ratio and other one is a specific thrust.

They are very different than what we use in our life for your particularly auto mobile engines, we use that for example, mileage and of course nowadays we are talking about kilometer age. That means how many kilometers you should go every, I mean like in particularly car or for you people bike will be going per unit per liter of fuel because the fuel price is going up.

That is more important you know and there is another parameter which is not being considered, particularly aircraft engine of course not buyer of the automobiles that is the emission, how badly how badly you are polluting the atmosphere where you are living. So, that is not being considered by user which is very important aspect and as you people are educated, you must be worry about that because uneducated people are the business people, they would not be worried about it.

They are ignorant, so that is very important point, so the thrust specific fuel consumption indicates the quality of an engine for and aircraft because the cost as I call it you know money as vitamin m is more important. Therefore, it is also a very important parameter, so let us look at how this thrust specific fuel consumption for a turbo engine becomes that is m dot f divided by the thrust. We know that m dot a 1 plus f V e minus V keep in mind that here what you call thrust due to the pressure is being neglected, pressure thrust.

Basically, what you could see here that V is a flight velocity comes into picture. That means this thrust specific fuel consumption will be not only dependent on the jet velocity, but also it will be dependent on the flight velocity and that is also true for your automobile. As I told you that earlier that there was a range of the speed in which you will get the optimum fuel consumption or the minimum fuel consumption, but after that whether you go at a lower speed, you will have to you know supply more amount of fuel. If you go at the higher speed you will have to also pay penalty of you know consuming more fuel.

Similarly, in this case it will be and questions arises where we will evaluate this TSFC and can I use this TSFC for a, you know turbo shaft engine, can I use this because there we are not producing any thrust, we are producing power. Therefore, we cannot really use that because here by definition, it is mass flow rate of mass consumption of you know fuel divided by the thrust and where we can evaluate this. So, I can compare and see that whether it is good or bad for various kinds of engines, even in the same kind of let us say turbojet there might be various manufacture.

I need to look at it, you know where I should evaluate this, should I like evaluate at the static condition or should I evaluate at the flight condition where there are two conditions or it can be there various places. Generally, it is customary to look at the turbo jet and turbo fan particularly at the static condition and another also is there some people evaluate at what you call the design condition, design flight condition, altitude and flight and whatever.

So, if you look at some number typical number I have taken TSFC that is 0.075 to 0.11 kg per newton hour, for hour you will be consuming this many kg of fuel for a particular newton thrust, whereas turbofan is very fan is very low value. If you look at that as compared to the turbojet, of course you get for turboprop engine.

It will be much lower and that is the reason why turbofan being used in the long range, you know passenger aircraft instead of turbojet engine, whereas the ramjet you cannot really evaluate at static. So, you will have to evaluate at certain designing mac numbers and altitude, if you look at, if I take this number some range, it is much higher as compared to any gas turbine engines turbojet turboprop turbofan anyone of them. So, you should keep this in mind and for as I told you earlier the TSFC for turboprop and turbo shaft engines becomes basically what you call brake specific fuel consumption.

We call it and that is m dot f by the shat power and this brake specific fuel consumption is being used reputedly for automobile engine as well and, but however in case of a turboprop engine particularly there will be certain amount of thrust. This is being produced by the expansion of gas in the jet, so how to take care of that because this is not good enough for the turboprop engine the BSFC for the turbo shaft where the shaft power is being obtained it can be, but for turboprop engine.

It is not because some of the thrust can be obtained by expanding the gas in the nozzle, nozzle means exhaust nozzle from the engine. Therefore, how will take care of it i need to take care of how much thrust power is being produced by the expansion of the gas in a nozzle. For that, I will have to use another one which is known as effective brake specific fuel consumption. If you look, it is same as that m dot f divided by p s h, whereas this thrust you know is being added that is the hot jet thrust. The T h stands for hot thrust and V because the propeller will be producing some thrust is taken care by p s h, whereas this will be producing some these thing, so that will be different, so this is being used.

Now, we have looked at various what you call the performance parameters that means these are the performance parameters. We need to use for evaluating how good engine is, how it is performing and under what condition, but now we have to look at air breathing engines and understand what is happening. If you look here, we are not worried about what it contains whether compressor is there turbine is there or nozzle is there. We are not bothered if we take a propulsive doc and look at it.

Overall, what is happening as a engine, now we will be looking at air breathing engine, now air breathing means which breathes air not like rocket engine, which will be carrying the oxidizer with itself. Now, air breathing engine can be divided into two categories, one is based on the gas turbine engine power.

That is known as gas turbine jet engines and there is another class which is called as a ramjet engine and scramjet engines where it be divided on gas turbine power plan gas turbine means compressor. You know turbine that is basically gas turbine, I mean which you will be of course compressor turbine will be there for your steam as well water as well no water as well, but there we are not considering, we are considering about gas.

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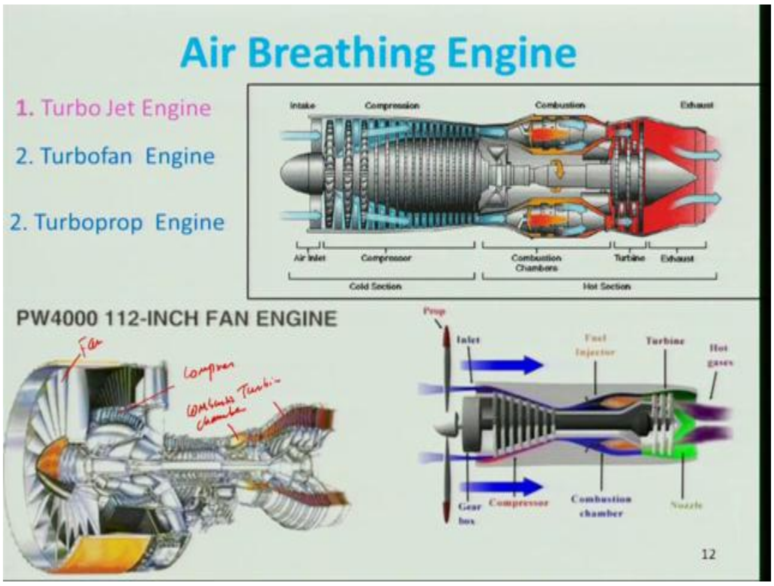

So, let us look at turbojet engine and we is really happening here, turbojet engine is having various components, one portion is a air intake this is the compressor of course this the axial compressor there is also centrifugal compressors and nut. Nowadays, people are using preferring the axial compressor, but some engines are there particularly turboprop kind of engines which will be using centrifugal and this is the combustion chamber, where you will be burning the fuel.

Generally, people try for it and then this high, you know high temperature and high pressure gas is expanded in the turbine and which is again expanded further in the exhaust nozzle to get the thrust. So, if you look at whatever you know work being derived from this hot high temperature and high pressure gas by the turbine is meant just to run the compressor.

So, if you look at what is a function of turbine, turbine is just to supply the power to the compressor and the all the thrust of this turbojet engine is being used or is being is harness by expanding the gas in a nozzle. Similarly, the turbofan engine which is little different and if you look at this compressor combustion and turbine is known as the gas generator. It will be generating the gas and the gas generator is there in this case. Apart from that, there is a fan here and of course the compressor is there, this is your compressor and this is your what you call compressor is also in this place is there is quiet big and then there will be some turbine and combustion chamber.

So, what I am saying this is basically different from that, but what is happening to the fluid which is entering in this engine because as it the air enters into this compressor the pressure its pressure will be increasing. Then, when in combustion, its temperature will be again increasing there will be also increase in the temperature when it is passing through air or not through the compressor or not that will be even when the air intake is not shown properly here. In this case, there will be also increase in pressure, so the temperature which pressure is it total or static, what about total actually in air intake, if you look, this will be the total temperature.

You know we assume to be remaining constant because we say that heat losses will be negligibly small, therefore the total temperature, also the total pressure. It will decrease because of some losses in fluid dynamic from aerodynamic point of view, but however there will be increase in total pressure in the compressor. So, total pressure will be almost you know remain constant, but however it will be little bit lower because the objective is to decrease the change in total pressure in the compressor and the turbine, of course the total pressure, what will happen.

It will be lowering down because you will be extract the work out of it, so if you look at what I know, discussion objective discussion to make you aware that properties are changing. You know in a very drastic ways how to take care of this, how to you know carry out an analysis is very important and it is quite complex. Not only the properties of temperature and pressure also the composition of the air is getting changed particularly whenever the combustion is passing through the combustors. So, that has to be taken care and if you look at the turboprop engine, the turboprop engine is basically you know the air will be passing through this propeller and then air intake and the compressor and combustion chamber turbine and expanded in nozzle.

You keep in mind that this whatever being harnessed by this turbine will be not only the running the compressor, but also it will be running the propeller through a gear box because the compressor is being run at a very high rpm. The propeller cannot really run at that rpm because of several problems, therefore we need to use a gear box, gear box will reduce the speed and you know of this couple and like you know from the compressor to the this thing or the shaft.

So, in this case most of the thrust is being produced by propellers, some of thrust will be used by you know when being produced in the nozzle you know that is a residual thrust what we call or it will be very small quantity as compared to the propeller. So, if you look at this kind this three kinds of engine, we will be discussing and we will be discussing also the ramjet.

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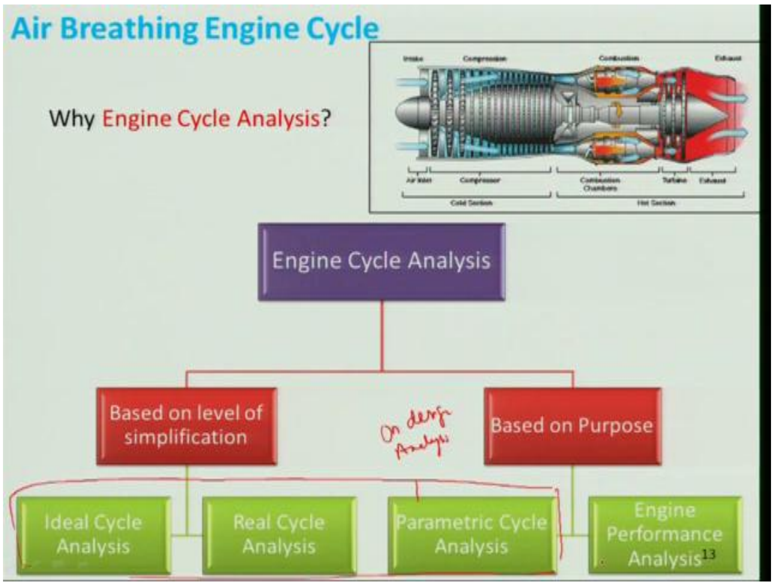

Let us look at we need to basically look at this air breathing engine cycle analysis why you will really want to do carry out this engine cycle analysis. You know basically what we are looking at we are looking at thermodynamic cycle analysis, what we you might have studied in your B. Tech and also you might have in your even thermodynamics and that is the Brayton cycle and what we will be doing.

We will be also looking at better cycle why we will you know maybe around seven to eight lectures, we will be talking about it. What really we will get, we are not going to get anything, as a matter of fact I am wrong, the Brayton cycle is same cycle, you know like the compressor. Then, combustors and then turbine what we will be looking at there are several questions comes in picture, how to enhance our thrust is there, any way we can enhance the thrust is there. Anyway, we can enhance the thrust or is there anyway we can reduce the TSFC is there, anyway we can enhance the propulsive efficiency and overall efficiency.

What are the parameters that will be governing as an engineer, we need to know that, but is it that cycle analysis which is being carried out in your thermodynamic course help you or can give you directly. It will definitely help you because that is the basis of all what we will be doing, now generally it is not being considered there except looking at thermal efficiency. What are the parameters that governs, you know is very important that we need to look at what kind of turbine material will be judging. What is the effect of you know like altitude, what will be the effect of flight velocity, all those things we need to look at it.

So, I told you that it is quite complex as I told you just now, I mean like that the whenever the fluid is passing through this compressor combustion chamber turbine it is undergoing lot of changes. Now, how to handle that, when the composition of air is changing, the temperature is changing, pressure is changing. You know it is quite difficult to handle, so we will have to first carry out making some assumptions. That means we can divide this engine cycle analysis based on the level of simplification because we need to simply that what we will be doing.

We will be making assumption, we will assume the processes or ideas that means as if air is moving nothing is there like no combustion, and no change of properties and then processes are isentropic in nature. You know lot of places like combustion expansion, there is no pressure drop in combustion. All those things we will be using and that is a simplification and other one is based on purpose. What is our objective, why we will do this analysis that also based on that we can divide the engine cycle analysis. So, what we will be looking at is ideal cycle analysis where we will do all our those assumptions, just now I told that we will be using the air as if passing through that.

You are adding some heat, there is nothing no you know really combustion is taking place, but you are adding heat that which you are done a layer for what you call ideal cycle in your thermodynamic force. Then, we will adding those you know like a processes which is actual and then we call it as a real cycle analysis, how we will do that real cycle analysis is very important one. Then, we will be looking at parametric cycle analysis because we need to understand vary those parameters which will be governing you know thrust and then TSFC and then other efficiencies, other parameters and play around it.

We will see what is happening, we may not have an engine, but we can play around and see that imaginary engine and look at it like you know like in your antitragi people are doing imaginary things imaginary stories or fantasy. So, it is similarly, you will be thinking my engine will be like that, these are the parameter what I need to do. Then, once you design the engine, we need to find out that what these are, how this parameters will be affecting my thrust and other parameters variables, how these variables which will be affecting my thrust and other performance parameters.

That is known as off design analysis like what we call it engine performance analysis, we call it as an off design analysis and this parametric cycle analysis is known as the on design analysis because we have not design, but for designing we look at it. So, in this course, what we will be looking at, we will be basically looking at this three analysis, you know which is I mean together because ideal cycle you know, but I will be looking at ideal and parametric cycle together. Then, I will be looking at aerial cycle, also you might have studied, we will be doing that and adding this parametric variation, you know and look at it, however engine performance cycle is not a part of this course, if some of you are interested, you can look at it in some other class.

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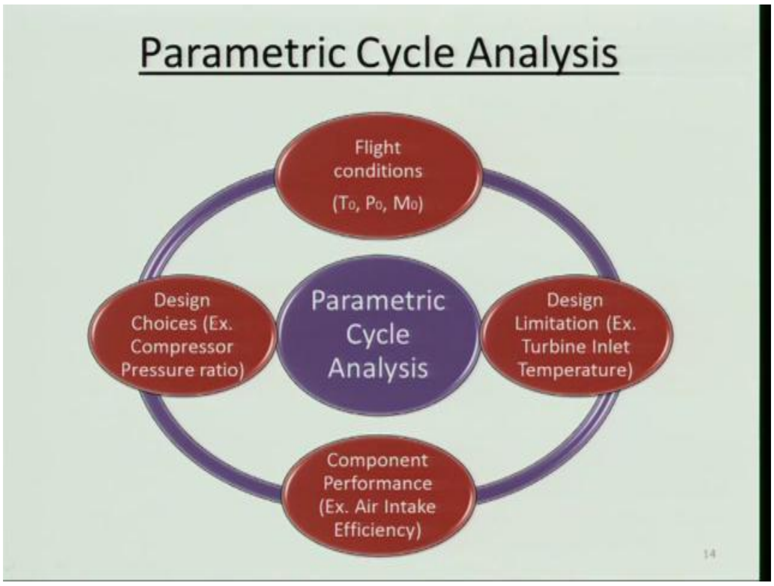

So, let us look at how we can carry out this parametric cycle analysis that means what we will be doing we will looking at parametric cycle analysis, first we will be considering ideal cycle, then we will be considering the real cycle. So, as I told you, parametric cycle analysis is very important because here the flight conditions like altitude flight velocities, when I talk about altitude, it is basically the temperature and pressure at a particular altitude which will be varying.

So, the flight velocity how it is varying how it is changing the thrust and your other performance parameters that we will be looking at it and then we will be look at what design limitation, what are the design limitations? We are having you turbine inlet temperature, you do not have material of course. If you can develop better material, you can go for higher temperature in the turbine because the most critical part of turbine material you know is the in the engine is the turbine material and also the combustor liners.

So, that is a limitation, how we will live with limitation, how we will you know do that and what is the way to, how it will be varying this performance parameters we need to look at. Similarly, the component performances like you know for example, air take in efficiencies, compressor efficiencies, turbine efficiencies, nozzle efficiencies.

How it will be affecting your result that is the way we need to because we all the time will be trying to improve the efficiency of this component so that overall efficiency of the engine will be increasing, but how to do that. What is effect we will be looking at and this is the very important one that is the design choices like compressor pressure ratio turbine expansion ratio and other parameters.

So, what I am saying, we are looking the same cycle analysis thermodynamically from a different perspective how to design. When we design, we need to know the whole envelop of where it will we will be operating which is the best and how to choose that and develop a judgment is very important, not only for the what you call design or the cycle analysis for also the life and what we are lacking.

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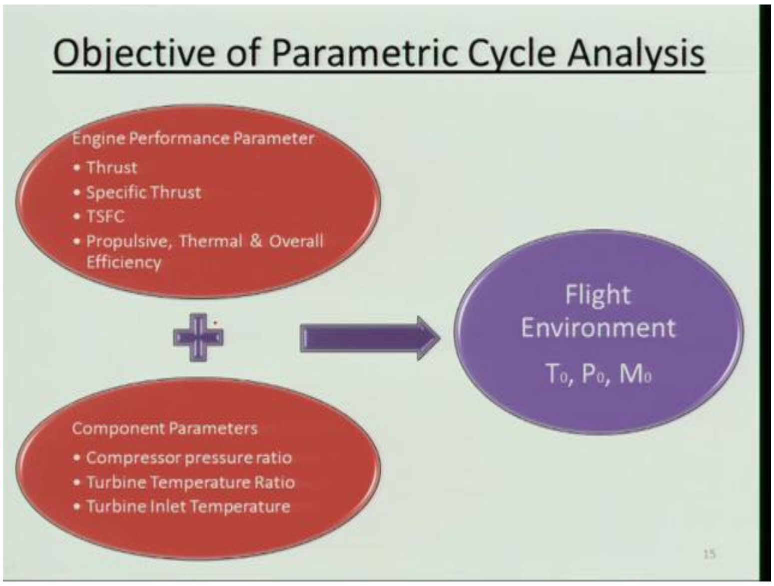

Today is the proper judgment in life, therefore both are in intending and let us look at how to go about it and objective of parametric cycle analysis. As I told you, it is engine performance parameter thrust specific thrust and thrust specific fuel consumption. We will be looking at propulsive thermal and overall efficiency, these are the parameters just two and we will be looking at component parameters like pressure ratio, turbine temperature ratio, turbine inlet temperature. You can look at turbine expansion ratio, they can be linked and we will be looking at how this flight environment.

I call it flight envelope, you know will be affecting the performance of the engine, so if you look at pole gamete of this thing, we will be looking at in this parametric cycle analysis. I believe or I assume that you must not have this way of looking at this because this is a whole things which will be can be used as a very important tool for a designer of aircraft engine.

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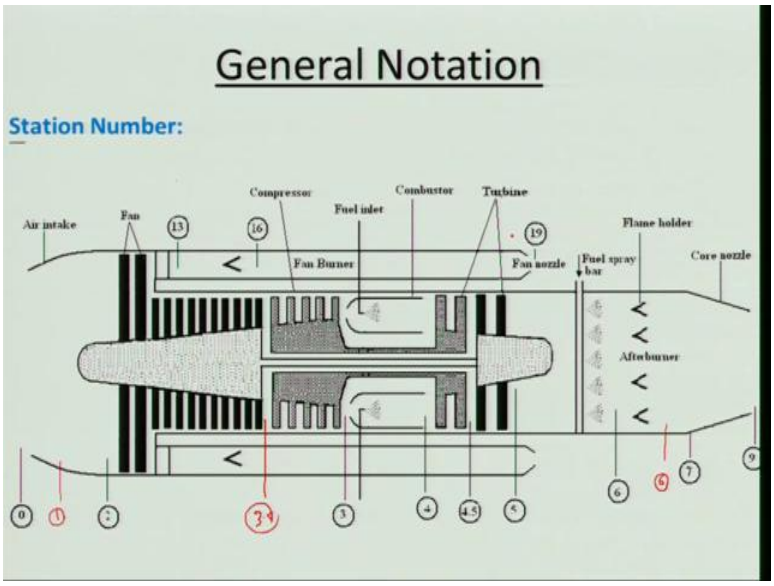

So, we will be looking at that for that let us look at general notation like what we will be using for our analysis this is very complex one I have taken. It is basically turbofan engines with afterburner, if you look at from 0 to 9, I used the station number for the core engine. This is known as core engine, this is a 0 to 1, because one will be somewhere here, you might be thinking why 0 is and there is no one. If you look at supersonic air intake if you look at the supersonic air intake will be 0 to 1 and 1 to 2 will be sub sonic air intake which is particularly for fighter air craft.

All those things is required, similarly 2 to 3 and sometimes some people use here 3.5 because this is your high pressure, what you call low pressure compressor and this is high pressure compressor, this one. Similarly, 3 to 4 is your combustors and 4 to 5 is your turbine, but 4 to 4.5 is your high pressure turbine and 4.5 to 5 is your low pressure turbine and 5 to 6.

Basically, you can say kind of a what you call the basically 6 could have been here, like it is at afterburner and there is a pipe jet pipe will be there for mixing and other thing and 7 to 9 is basically nozzle. You might be thinking why where the 8 is, 8 is there whenever is use the conversion diversion nozzle the throat region is known as the 8. Similarly, for the other engine that is 13 to 9 and this is a standard which is known as aerospace recommended, you know kind of things standards being used internationally that is why we are using that, so another thing we need to look the location.

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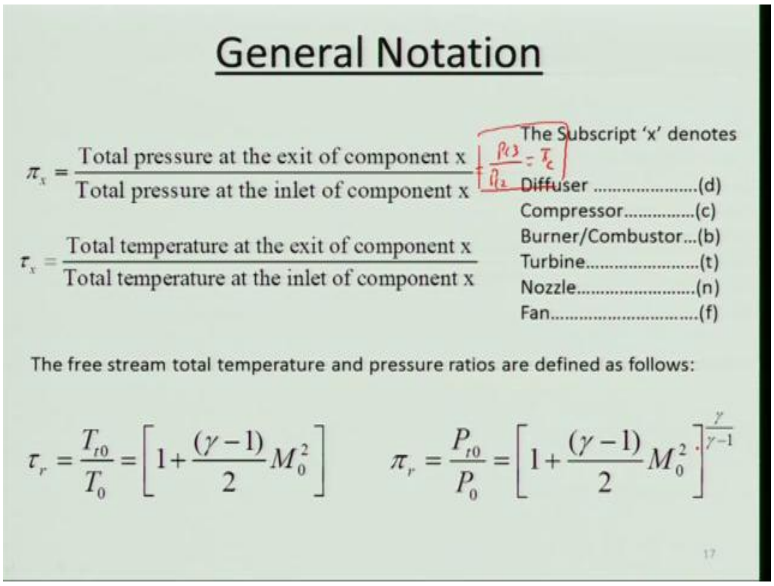

We will be using that, we will be using pressure ratio and when you talk about pressure ratio of a component x that is nothing but ratio of total pressure ratio at the exit of component x divide by total pressure at the inlet of component x. That means basically if I look at a compressor, it will be basically at the exit in this case, it will be basically P t 3 by P t 2. Similarly, total temperature if I look at for a compressor, if I say this is pi c, then only P t 3 by P t 2 that means this will be the thing.

So, total temperature ratio will be basically for x component will be total temperature ratio at the exit of component x divided by total temperature ratio of component x. So, if you look at that, we will be using this symbols in place of x for diffuser d that is basically air intake compressor c and burner and combustors.

We will be using b pi b for turbine, we will be using pi t nozzle, we will be using pi n and fan we will be using small f. So, these are the notation which we will be using and free steam total temperature and pressure ratio can be defined as tau r that is t t not divide by t. You know for this isentropic relationship is equal to 1 plus gamma minus a divide by 2 m not square and pi r is equal to P t not divided by p not. The same thing 1 plus gamma minus 1 divided 2 m not square r minus 1, basically isentropic relationship I have written in terms of flight mac number.

So, we will stop over here and maybe some of the assumption I will be talking about in the next class that is ideal cycle analysis and then we will be talking about ramjet engine to start with.