Introduction to Airbreathing Propulsion
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Lecture - 11
Introduction to Gas Turbine Engines

So we will come back. Let us, what we have done the initial part of the discussion that like introductions which to give you an idea about this aircraft or the propulsion and the different aircrafts, their status and state-of-the-art situation and that was followed by some of the basic discussion on fluid mechanics and just to review the thing. That is not a detailed lecture on fluid mechanics or thermodynamics.

So that just to let you know that these are the things, which are going to be repeatedly used, so you can refresh your memory or go back and look at the basic thermodynamics and fluid mechanics books to refresh those information and then finally we did some discussion on compressible flow, where we started with one-dimensional compressible flow and then moved to normal shock relations, where we derived normal shock relations.

And obviously when you have normal shock relations, one can always also use the normal shock from the table but these are and then finally we did discussion on compressible flows and pressure and temperature variation in the atmosphere and with that kind of background we are all set to move further actually the detail discussion on our air breathing engine. So what we are going to look at now, we are going to look at the aero-thermodynamics of the air breathing engine.

And where we start with some of the performance parameters and once we look at the performance parameters and then go in detailed discussion of each of the individual, different kind of engines that we have planned for.

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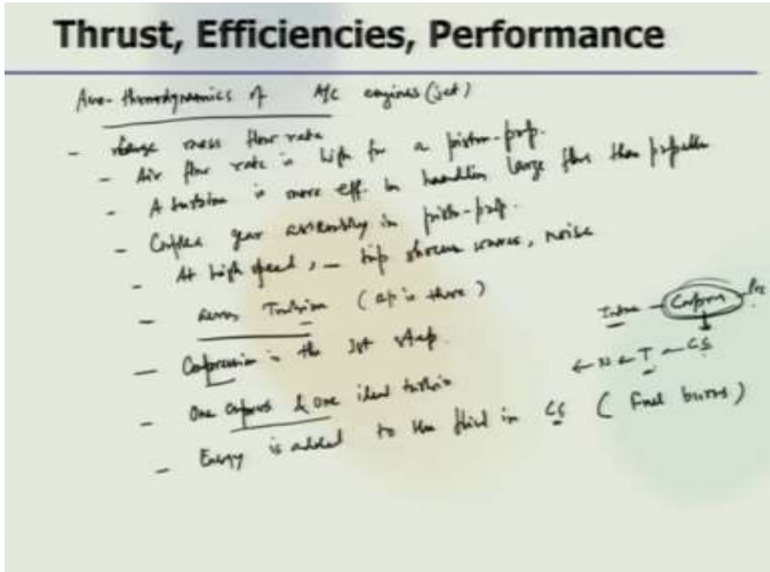

So let us start with the thing that what we want to do. So as I said we are going to talk about the aero-thermodynamics of aircraft engines or aircraft jet engines rather. Now here when it passed through these big airlines which are quite height, so the mass flow rate it deals with this aircraft engines or the jet engines is large mass flow rate, that is very, very important. Now air flow rate is also high for a piston propeller engine.

Now a turbine is more efficient in handling large flows than a propeller. So in piston propeller, there is a complex gear assembly in piston propeller engine. Now when you have that kind of propeller at high speed, there are tip shocks or tip shock waves generated. There would be noise. Now turbojet and turbofan can operate quite reasonably at high subsonic speeds. Turbojet can be supersonic. Piston propellers are more efficient for low speed and small aircraft.

Jet engines also can do VTOL and thrust vectoring. This already we have seen some of the example while doing the introduction. Turbine is very efficient machine to convert flow energy to other form of energy that is electricity and all these. So when the gas flow through the turbine, it turns the turbine and the rotating motion of the turbine can be used to generate the power and the gaseous expands across the turbine.

Now to have gas flow across the turbine, there must be a pressure drop. So across turbine, there must be pressure drop delta P is there. So hence the pressure ratio across the engine must be provided, therefore the first necessary step in a gas turbine cycle is the compression of the working fluid. So just to get that, so one can see compression is the first step and that is what happens when you look at the total sequence of process.

It comes to intake and then to compressor, then compressor to combustion chamber, then turbine, then nozzle and then finally goes out. So this compressor is very, very important and to get this compression, compressor is used and mostly in the gas turbine, these are axial flow compressor and also used in multiple stages because when you use the multiple stage compressor, we can get desired pressure rise or high-pressure rise.

Now if the compressed gases are expanded directly in the turbine and there are no losses in any of them, the power developed by the turbine would be the power absorbed by the compressor. So in ideal situation, you need one compressor and one ideal turbine, that means no loss are coupled together and then the combination can just turn itself and you will get but no useful work. Now when the turbine develops the power or the power developed by turbine can be increased by adding energy to the working fluid.

So that is done, the energy is added to the fluid in combustion chamber. So this is where the fuel burns. So you can see first the large amount of air, which is kind of drawn into the system and then there is a compressor, which does the compression process, then when it goes to the so this increases the pressure and also slows down the flow field or the velocity, then it goes to combustion chamber where due to the burning of the fuel the extra energy is added.

And this added energy when it passes through the turbine, where the expansion takes place. The turbine produces power and it passes through the nozzle, so due to this high due to this added energy or the hot gases which are expanded in turbine it produces the power and that provides the useful output.

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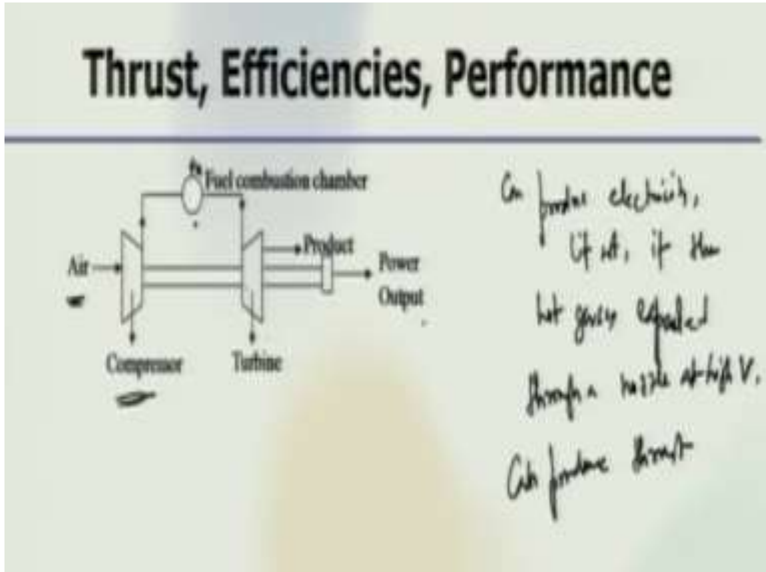

Now if we look at a schematic of the basic gas generator, so that is very basic of a gas generator which you can see. You have air coming in, then this is the unit of compressor, then after compression this air goes to the combustion chamber where the fuel burns and extra energy which is added and then finally it comes to turbine and then the product pass through to get the output and the turbine and compressor sitting on the same mechanical component like a shaft. So this can produce electricity. It can lift weight and if the hot gases expanded through a nozzle at high velocity can produce thrust. So that is what it happens.

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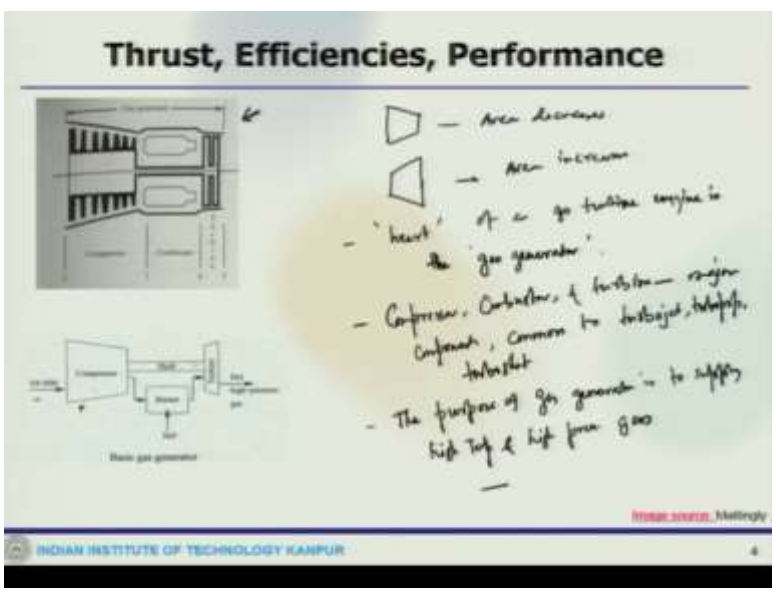

Now when you look at this basic gas generator, so you have air comes in, pass through the compressor, then the combustion takes place, hot gas goes to this turbine, then this turbine is connected with the shaft to the compressor and if you look at the cut section here, this will give you an very nice picture of that engine. So this component from the compressor-combustor turbine this is what we call it the basic gas generator.

Here it passes through and you can see in compressor very interestingly why we use this kind of a typical symbol for compressor because the area actually decreases and these are axial stage compressor and turbine this actually increases, so area increases. So one can say the heart of a gas turbine engine is the gas generator, which has compressor, combustor and turbine, which are major components and very common to turbojet, turboprop, turbo shaft.

So the purpose of gas generator is to supply high-temperature and high-pressure gas. So that is the basic gas generator, for which this is it. Now when we have a basic gas generator and you can see how this development or the proceeding added component can make things complicated and enhances that capability.

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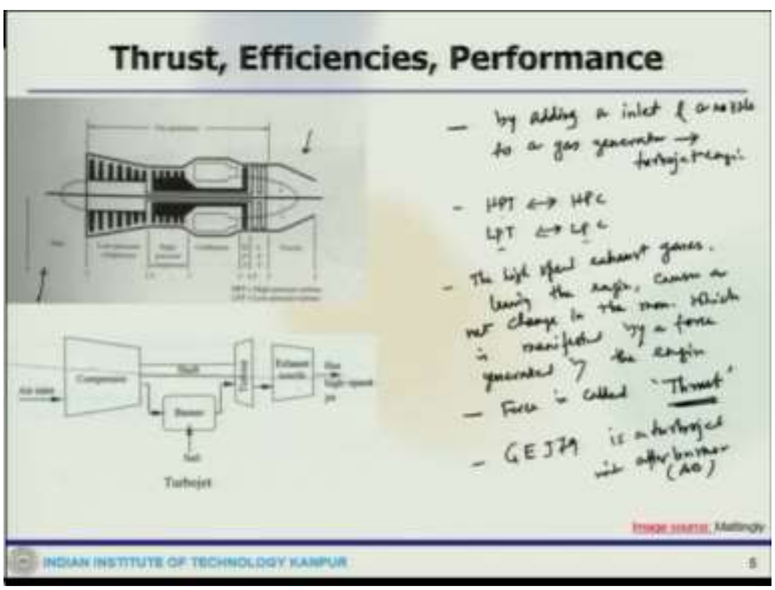

Now with this basic gas generator, so let us say by adding an inlet and a nozzle to a gas generator. What it gets? You get a turbojet engine. So again if you look at, this is the basic component of the gas generator compressor turbine and then now we have added an exhaust and inlet. So this is the portion which is there. Now previously we had and then this is the portion which is added.

Now here immediately this schematic will give you another picture which is also quite informative that you have two different stages of compressor, so that means they are not also put on. Now, one is the low pressure compressor where area ratio is quite drastic or area change is quite drastic and then the high pressure compressor. After this, the flow pass through the combustor, then obviously when these are there you have high pressure turbine and low pressure turbine.

One important thing is that high pressure turbine is connected with high pressure compressor and low pressure turbine is connected with low pressure compressor and you can see from that picture which is sitting on which mechanical component like the shaft, because the power produced by HPT partly goes to run the HPC; power produced by LPT partly goes to run LPC. These are very, very important and very fundamental information for any gas turbine engine or the jet engine.

Now here the high speed exhaust gasses leaving the engine causes a net change in the momentum, which is manifested by a force generated by the engine and this force is called thrust. So we have seen a lot of turbojet example. One of the quick just to GEJ79 is a turbojet engine with afterburner or AB; that means after turbine before passed through the nozzle, there would be secondary fuel inlet where the burning takes place. So from the basic gas generator, when you add this inlet section and the nozzle section, we get the turbojet engine. Now with this turbojet engine if we add some fan and some component.

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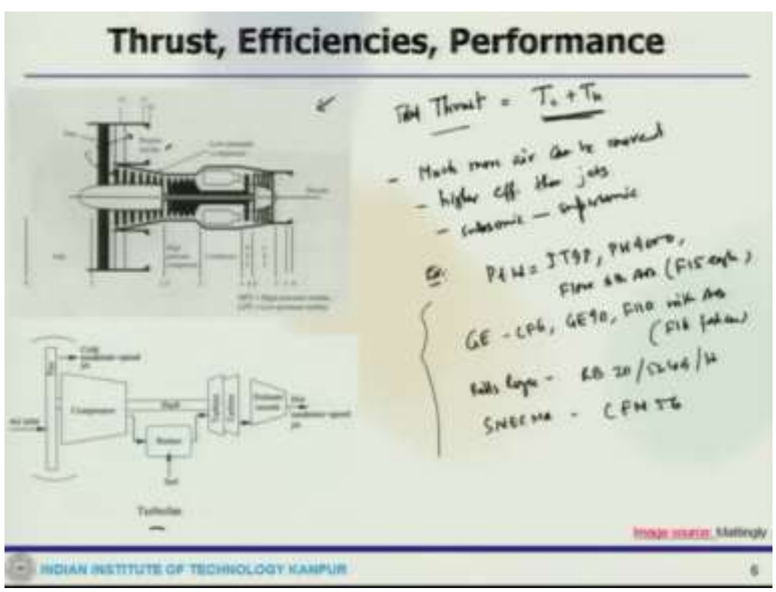

Now except this fan if you look at the rest of the portion was there in this turbojet engine. Now when we add that component of the fan, this mix in turbofan engine. So apart from the compressor, we have added fan sitting there. So there are some advantages using this kind of system, but let us look at this schematic here. So you see the fan is sitting there. You have already the inlet, then from fan, after fan the air gets split into 2 component.

One goes through this bypass; this is called the bypass nozzle or the bypass section; one pass through this core of the engine. So the one which pass through the core of the engine that passes through the rest of the component of the gas generator which is compressor, I mean low pressure high pressure combustor HPT, LPT and the nozzle and the rest. So this bypass nozzle also, so the total thrust here has two components one is the thrust due to cold or the bypass and the thrust due to hot.

We have two components which also that means this bypass contributes to the thrust generation of the production and what it allows that much compared to turbojet much more air can be moved efficiency is higher than turbojets and it can go from subsonic to supersonic application. So there are that means the flow component will have that pass through the fan, then splitting. Some of this example we have seen in a detailed introduction.

There are different kinds of turbofan engines in application today, not only in the civilian applications they are both in military application also and that the increase of turbofan engineering is more and more because of this. For example, like one can say Pratt & Whitney JT9D, PW4000, F100 with AB this is used in F15 Eagle, then GE-CF6, GE90, F110 with AB, which is also using F16 Falcon, then you have Rolls-Royce which is RB211/524GH.

You have SNECMA-CFM56. So these are some of the examples but the exhaustive list is already kind of discussed during introduction. Now so that is how things get more and more once you add one after another component, things get more complicated. Now another is the turboprop, where we added in propeller there and ahead of the compressor, so just to have this propeller or to run this propeller one has to have the gearbox, which is necessary.

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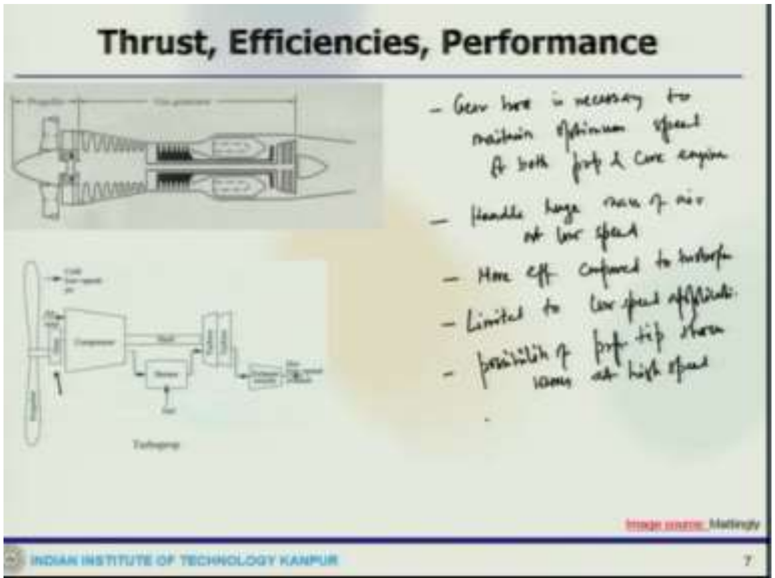

Why? To maintain optimum speed for both propeller and core of the engine. So you have a gearbox sitting here. Now the schematic if you see, there is a gearbox sitting there and this is the section which is propeller and this is the basic gas generator portion which has compressor, I mean LPC HPC combustor HPT LPT and then pass through the nozzle and all this, but this propeller kind of configuration obviously there are certain advantages and certain disadvantages.

One of the big advantage with this configuration is that, it can handle huge mass of air at low speed; that is one of the advantage. So at the low speed application, this is more efficient compared to turbofan, but as I said this is limited to low speed application, because when you go to high speed there would be possibility of propeller tip shock waves at high speed. So that restricts the application at high speed.

And also another advantage for the propeller engine because of this gearbox and the huge propeller the engine become bit bulky and heavier, but obviously nothing is kind of perfect. So whenever we use something, it will come with some added advantage and come with some added disadvantage. So these are the basic gas generator with some component like turbojet, turboprop or turbofan engines. Now we can look at the calculation of thrust.

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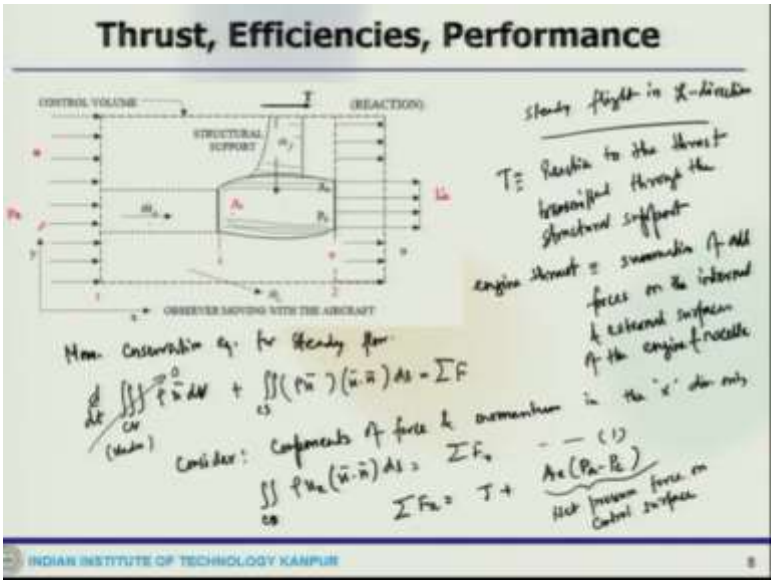

Now let us take a system like this where the inlet area is Ai. This is the structural support just to keep this. This is a free body diagram and this control volume that we have taken. This is the inlet mass flow rate and we have inlet exit station 1, 2 and then upstream velocity temperature and this is the reaction force. So you can say that let us say steady flight in x direction and T is the reaction to the thrust transmitted through the structural support.

What would be engine thrust? Engine thrust is the summation of all forces on the internal and external surfaces of the engine and nacelle. Now what we can write, let us say the momentum conservation equation, equation for steady flow. So this is our control volume plus control surface rho u, u dot n ds summation of F. So this goes to 0, because steady assumption. Now what we can do considering the components of force and momentum in the x direction only.

So consider the components of force and momentum in the x direction only, then what we could write

$$\iint_{CS} \rho u_x (u \cdot \bar{n}) ds = \sum F_x$$

$$\sum F_x = T + A_e (P_a - P_e)$$

which is net pressure force on control surface.

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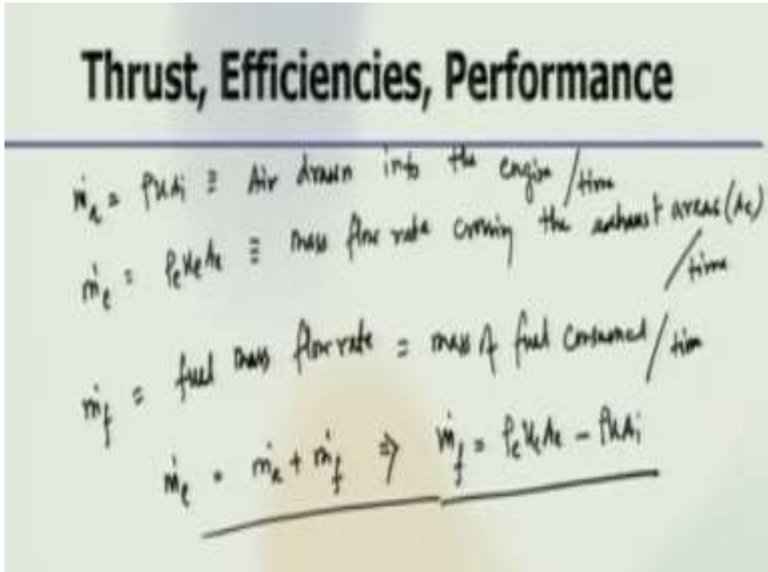

So let us say

$$\dot{m}_a = \rho u A_i$$

which is your drawn into the engine per unit time, then

$$\dot{m}_e = \rho u_e A_e$$

which is the mass flow rate or mass flow rate crossing the exhaust areas that is Ae per unit time m dot f is the fuel mass flow rate, which is mass of fuel consumed per unit time and what we can write is that

$$\dot{m}_e = \dot{m}_a + \dot{m}_f$$

So now we can write the continuity equation or rather the total mass conservation.

So m dot exist, if you look at the diagram this is where the mass is drawn into the system, fuel is added and this is where $\dot{m}_e = \dot{m}_a + \dot{m}_f$ which one can write that

$$\dot{m}_e = \rho u_e A_e - \rho u_i A_i$$

So this is a very, very important information that you get the total mass balance. So the mass which comes in, that is the air comes in.

Typically, the subscript that we use, this will follow whether it is air or fuel or exhaust so that it makes it bit easy or consistent to understand the things. So this is what you get in the mass balance. We will stop it here and find out the thrust and all this expression in the next session discussion.