Turbulent Combustion: Theory and Modelling
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Lecture - 22
Laminar Non-Premixed Flames (cont…)

Okay, welcome back and we are almost towards the end of the discussion of the laminar diffusion flame or laminar non-premixed flame and one of the issues that occurs in the laminar diffusion flame is the soot formation when you burn hydrocarbon fuel and that is what we are discussing.

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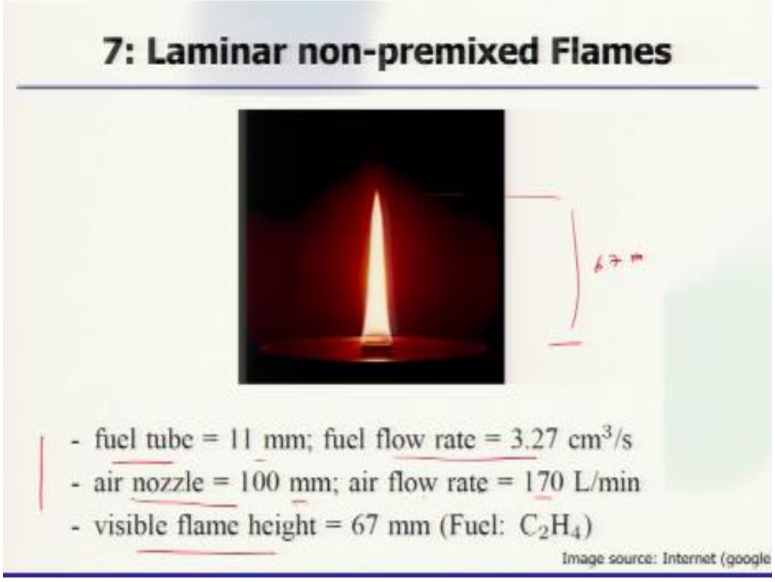

So, this is where we stopped and we will continue from here. So, we looked at this particular example of a simple burner these are the dimensions of that particular burner, tube diameter, fuel flow rate, nozzle and this is a visible flame height now and the fuel is C_2H_4.

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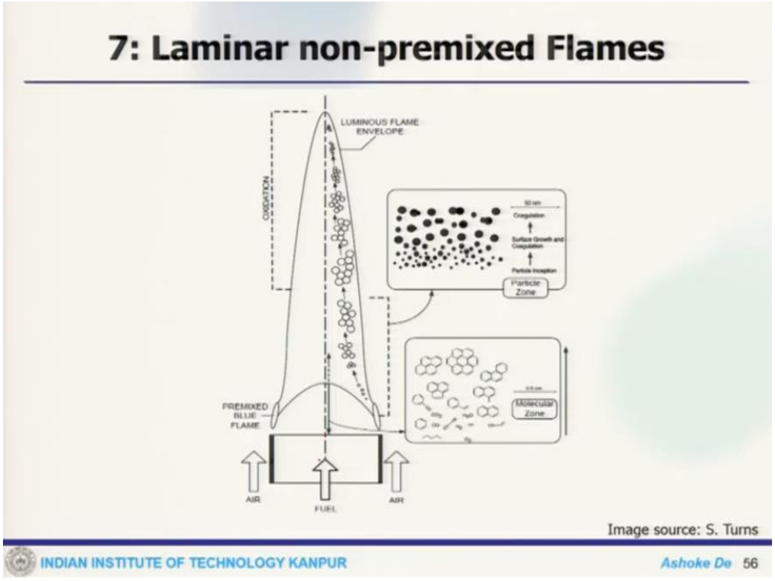

And this is a fuel which is coming through this nozzle or the tube and this is where air comes in. So, this will try to go like this it will be here which will try to entertain and the reaction will take place along the stoichiometric situation. Now, then, this area where you see this aromatic structure formation or reformation so, this is happening at the where the this hydrocarbon fuels the C_2H_4 gets into the higher order hydrocarbons and form this sheet like structure or ring like structure.

Then at this position of the flame the other process which actually takes place that means, from here to here within this visible flame height from this sheet like structure, there is a phase change takes place. So, you start getting the small size particle and the small cells particles when they grow there is a surface growth and coagulation. So, this is the situation where and the rest of the height which is a sort of your total flame height or flame envelop they are the oxygen takes place.

If the oxidation is quite complete, when you don’t get to see these particles at the end of your process, otherwise you get to see these particles.

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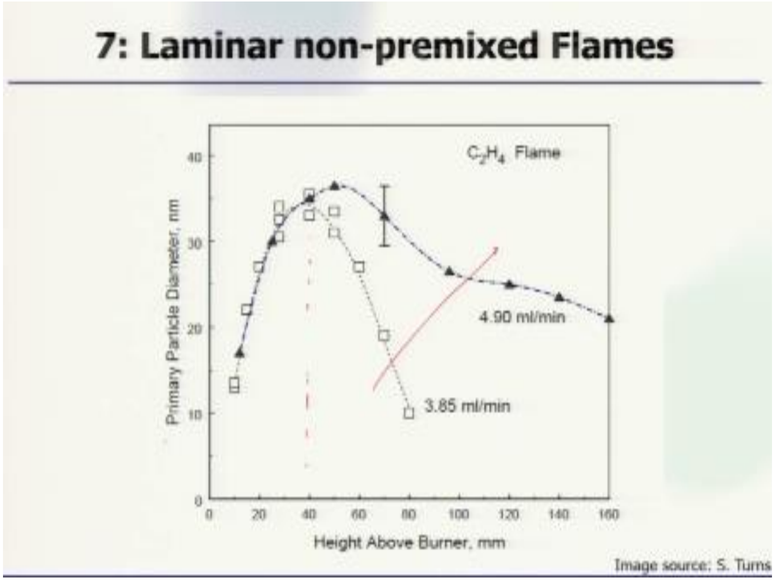

Now, this is where there are some images these are the primary diameter particle, this is height of the burner and there is a variation of the fuel flow rate and you can see how it varies. So, be up to certain height there is not much change which is visible with the change in the flow rate and that because up to that this is the process which takes place or rather this process then beyond that, there is the oxidation process which is quite different from different flow rate and so that is why that happens.

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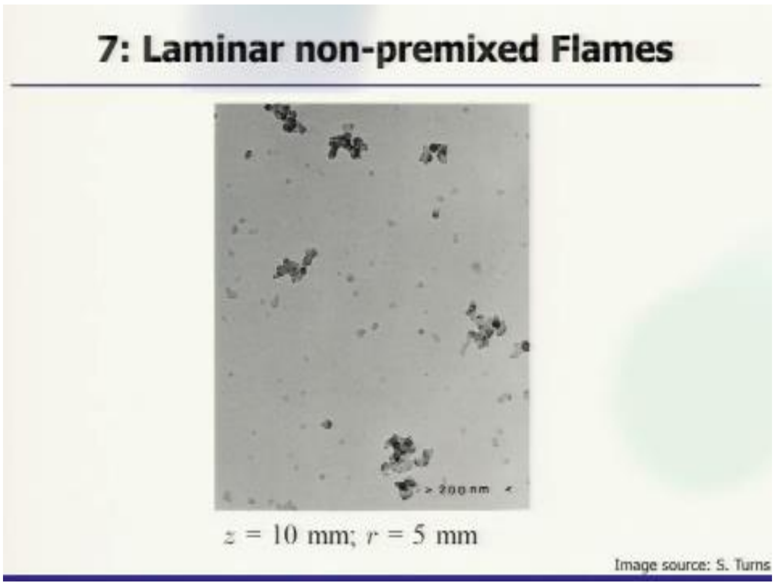

So, these are the typical images of the soot what one can see under microscopes, this is what visibility one can see this.

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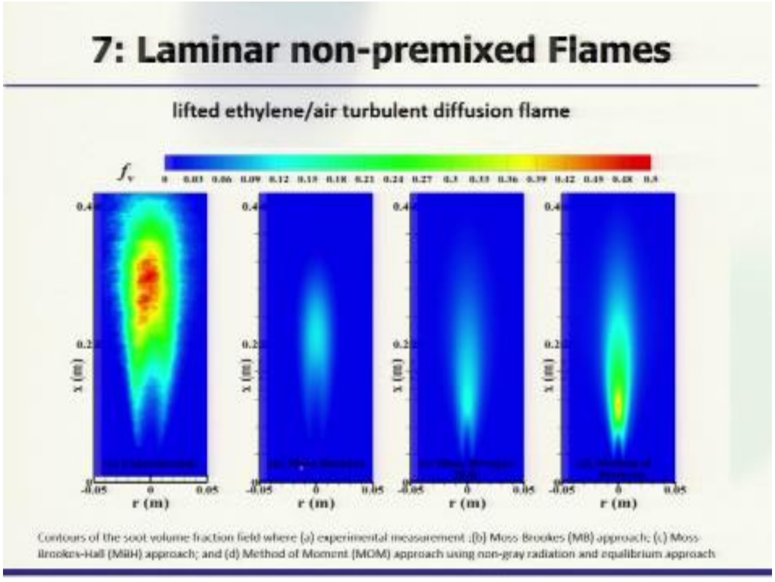

So, there are just to give you an idea even there are a lot of competition effort has gone into prediction of soot and all these things. There are different models the lifted ethylene flame and this is experimentally observed soot volume fraction and this is how one can computationally obtained. And so, this is another area which requires a lot of attention especially under turbulent condition where you get soot and all these things.

How accurately one can model? Because most of the natural processes I mean reacting system they are sort of directly or indirectly bonding hydrocarbon fuels and once you bond hydrocarbon fuels under non-premixed mode these are bound to happen. So, an accurate prediction of the soot is an important aspect and quite challenging. There are algebraic models available, there are advanced particle based model available, but none of them are accurate enough to give you these things.

Now, that is pretty much concludes the discussion on the laminar non-pre-mixed flame. Now, we will discuss some other topics and before moving at with the turbulence or turbulence flow discussion. So, one of this things that we would like to discuss is this.

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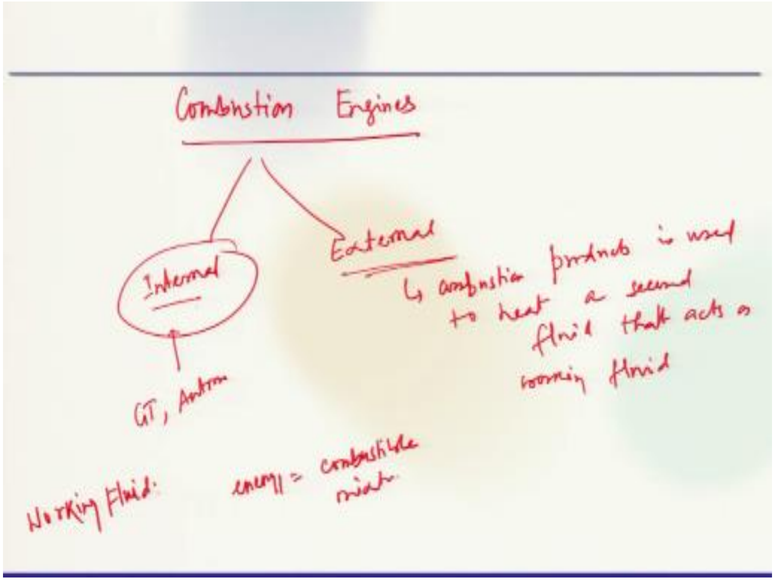

This combustion engine because one must have some idea about this combustion engines. So, the practical systems pretty much what you look at it the practical systems there are 2 types of combustion engines one could be internal and other could be external. Now, most of the system practically that we see their internal combustion engines, which is primarily used or dominant used for propulsion system.

Whether you think about application of the gas turbine or whether you think about the application of the automobile engine and external combustion engines also will look at it and the working principle of internal and external are quite different especially there is a difference in the nature of the working fluid. So, that makes sense quite different from these things. Now, if we think about the working fluid for internal combustion system.

So, here internals engines produce work by pushing a piston or turbine blade that in turn rotates the shaft. So, any internal combustion unit that produces that work by pushing a piston or doing that. Now it works at high momentum fluid that is used directly to the propulsive force and especially in the internal combustion system the energy source is the combustible mixture. So, the energy source is the combustible mixture and the combustion products is essentially the working fluid.

Rather in an external system or external combustion engine, the combustion products is used to heat a second fluid that acts as working fluid. So, that is the basic difference. Now, the most common internal combustion engine is the gas turbine engine.

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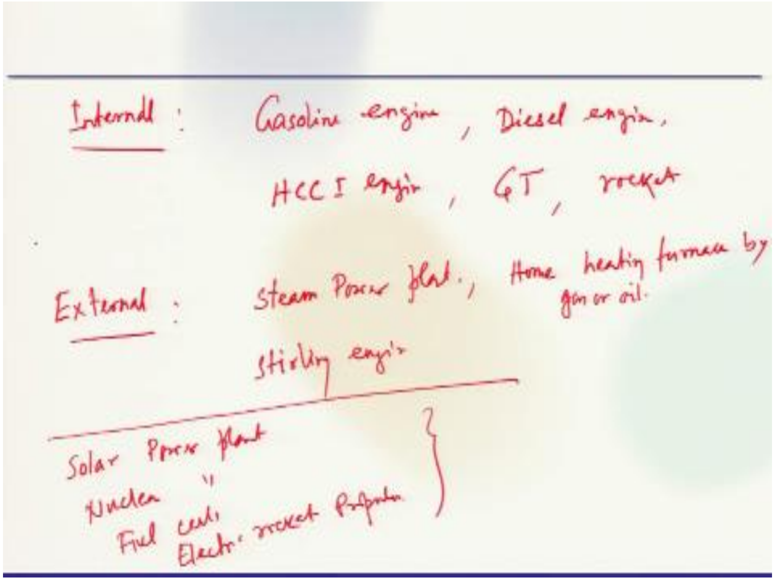

Then you have one can ride this internal combustion system which are gasoline which is you can spark ignition engines homogeneous stratified start diesel engine which is used in your heavy road vehicles, then HCCI engine which are homogeneous charge compression ignition this is obviously under development stage, and optimize gas turbine engine whether it is used for aircraft propulsion or stationary power plant then rockets engine or chemical rockets, so these are what they use internal.

Now, the external combustion engine you can think about steam power plant, then home heating furnace, home heating furnace by gas or oil, Stirling engine. Now, there are some more engines which we don’t categorize them either internal or external for example, solar power plant then nuclear power plant, fuel cell, electric rocket propulsion. So, this we do not specifically categorize or put them in either of these baskets like internal combustion or external combustion engines, Okay?

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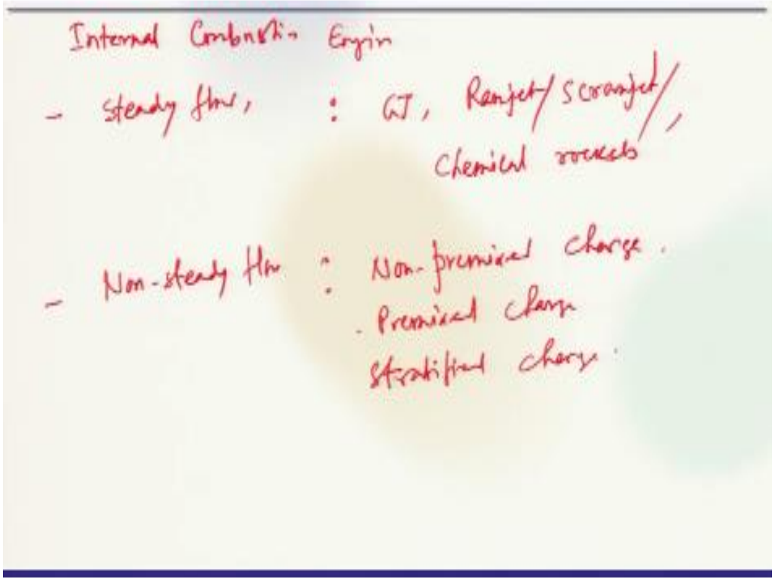

Now, one can also now, for the internal combustion engine you can have one category could be steady flow engine which brings gas turbine engine, ram jet or scram jet engine, chemical rockets or another category could be non steady flow. So, here you can have non-premixed charge, premixed charge, stratified charge.

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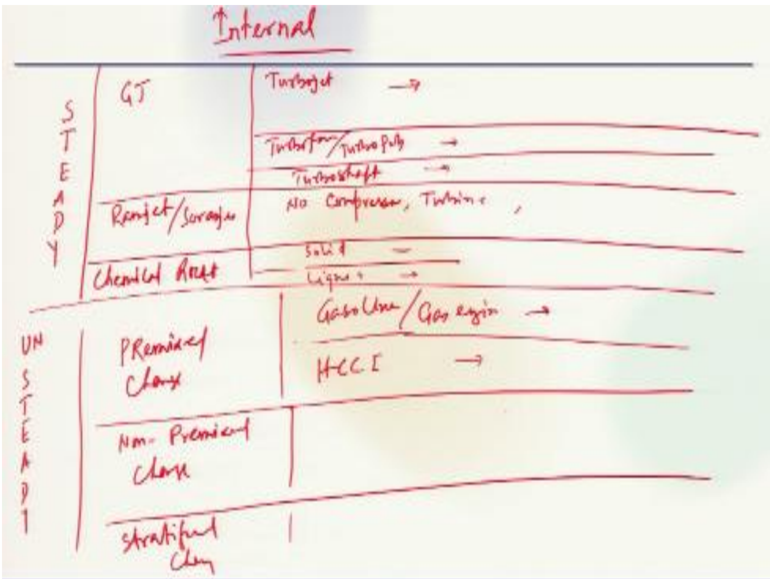

So, if you draw a nice picture of this so, one is that all is your internal system. So, either one can have steady. So, that could be one category under steady you have gas turbine then you have ramjet or scramjet or you could have chemical rockets. Now here also you can have turbojet you can have turbofan or turboprop you can have turboshaft. So, here turbojet what it does that all jet except for work needed to drive compressor.

Now, in turbofan or turboprop part jet, part shaft work to drive a fan propeller, turbo shaft all shaft to drive the propeller generator or rotor. Here there is no compressor or turbine it uses high Mach number ram effect for competition. Chemical rockets that could be again 2 types one is solid and other could be liquid fuel. Solid fuel, fuel and oxidizer are premixed and placed in chamber; whether in the liquid case, fuel an oxidizer are pumped separately to mix in the chamber.

Now, in unsteady case, you have a premixed charge. So, under premixed charge you could have 2 type either gasoline or gas engine or HCCI. Now gasoline it is a homogeneous charge spark ignition engine and this is homogeneous charge, compression ignition engine. So, there is a difference small difference then non-premixed charged and stratified charge. So, in this case non-premixed charge only air is compressed.

Fuel is injected into the cylinder compression ignition system like a diesel engine and this case studies partially predicts charged equivalent ratio changes especially. So, there is a nice differences among all these different engines.

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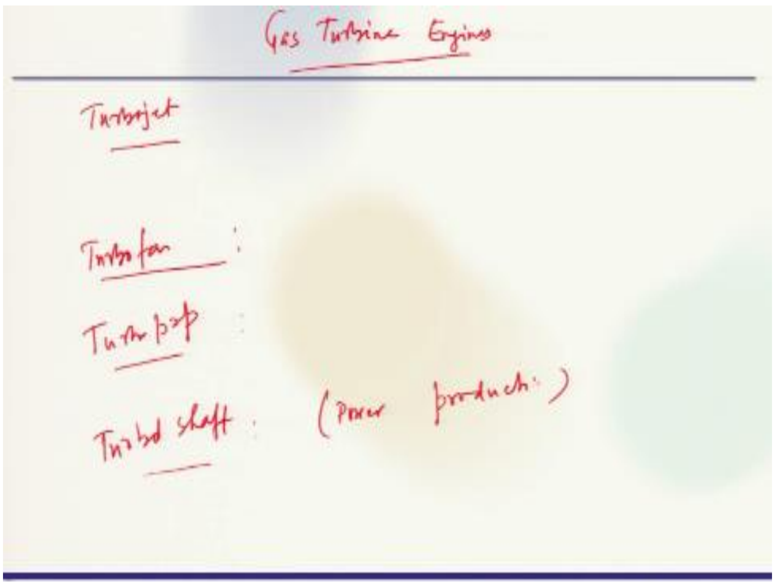

Now, look at the gas turbine engine. So, there you have turbojet, then you have turbofan, then you have turboprop, then turboshaft. So, here in the turbo jet, what it does is that all jet except for work needed for the turbine that drives the compressor so is a turbojet. Now the turbofan is partly jet and parts have to work to drive the fan obviously, in addition to the compressor and that fan provides 5 to 6 times more air passing around the engine core.

Then you have turboprop where it is pretty much similar to turbofan engine, but the rate of air flow through the propeller may be 25 to 30 times air flow through the core engine so, that produces primarily the force and the turboshaft this is an industrial stationary engine used for power production. So, this is used in power production to drive a pump sometimes it is also used in helicopter to drive a rotor or drive ship's propeller. Now, all these different engine they have one thing which is common is the gas generator.

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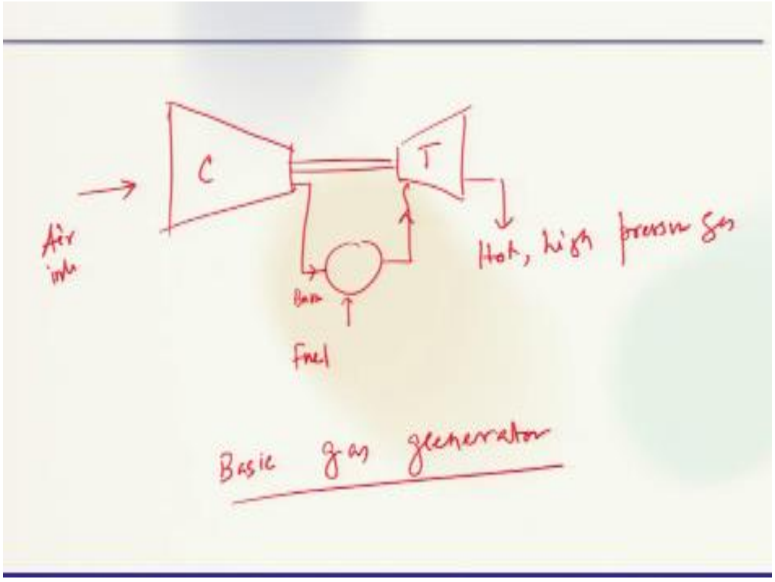

So, there is a basic gas generator one can think about this is a compressor then there is a shaft connected with turbine then this is what it comes and goes out this is your sort of burner you have fuel inlet closing this is hot high pressure gas, this is your air inlet. This is a simple schematic of a basic gas generator.

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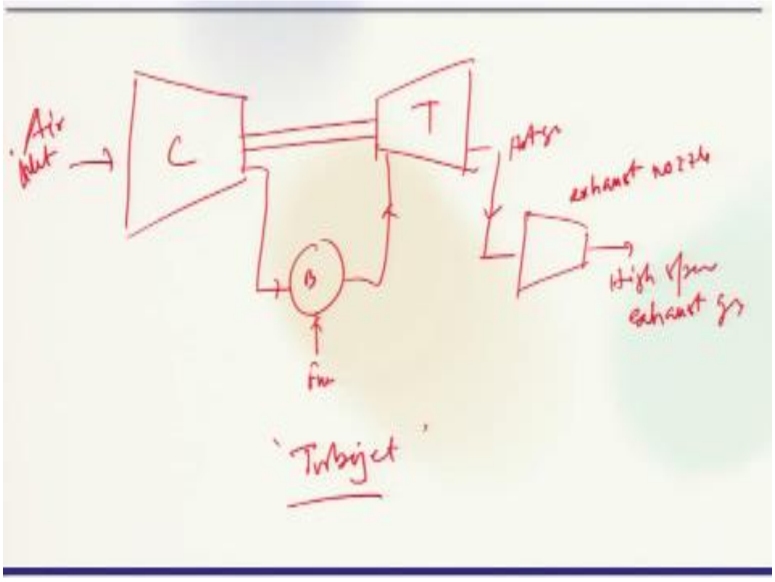

Now, top of that one can actually build up the turbojet system where we have compressor which is connected with the turbine. Now, this is connected with the burner or fuel goes in, this is your burner and this guy comes in and goes through some exhaust nozzle. This is the hot gas so then finally we get high speed exhaust gas. This is a schematic of a turbojet system so similarly, you can see the turbo shaft engine or turboprop engine or turbofan engine.

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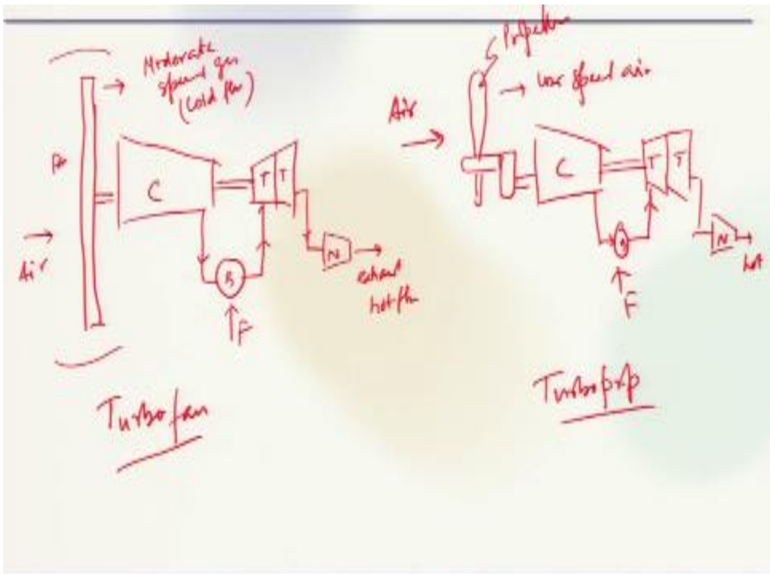

So, one can draw that schematic there is a fan sitting there which is connected with a compressor, which is connected with the shaft turbine. This is your burner, fuel comes in this is air so, this also fan, this is moderate speed gas, this is cool flow then finally passed through a nozzle and you get the exhaust so this is hot flow. So, this is your schematic of turbofan and at the same time turboprop will look slightly different.

There is a gear which is connected to the compressor, shaft connected to the turbine and in between you have the gas generator which has fuel burner. This is propeller, this is low speed air, here is the air inlet and finally it pass through the nozzle to hot air so that is your turbo prop. Already we have seen some images of turbofan engine while in the introduction lecture and typically that scene used in your aircraft engine there is a big engine.

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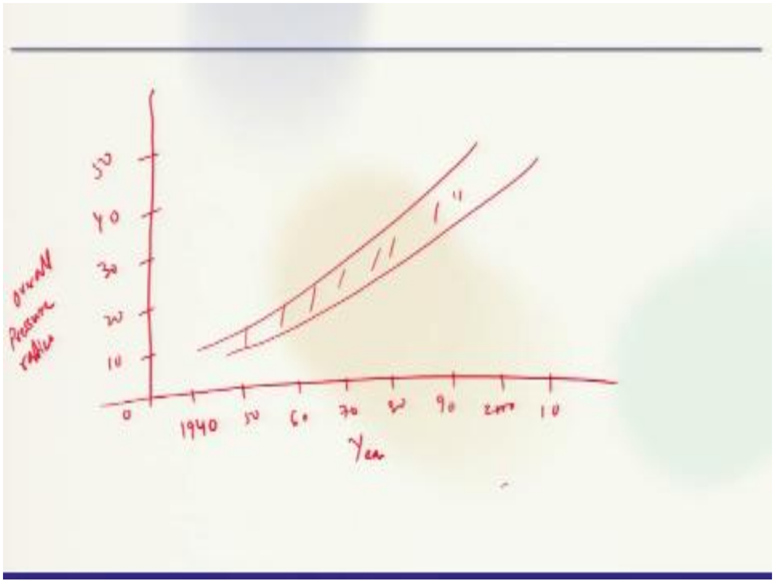

Now, there is also and trained up pressure ratio if you plot they started with somewhere 1940 then 50, 60, 70, 80, 90, 2000, 10 and this way if it is goes 10, 20, 30, 40 ,50. So, there is a trend increasing trend of increasing pressure ratio this is where all pressure ratio and this is air. So, our all these engines are civilian aircraft and fighter aircraft they use sort of a turbofan engine, but the different category there is a one thing that like in your turbofan, there is a portion of the air which goes out of the core.

This portion of the air comes through the core of the engine, there is a call this ratio if this is the cold flow and this is the hot air the ratio is the bypass ratio that the percentage of the cold flow of the total. Now typically in the civilian aircraft the turbofan engines are high bypass ratio engine. So, they are the major component of the thrust generated from this cold flow. Whereas, if you look at the fighter aircraft, they are the low bypass ratio in the primary air goes through the core of the engine. So, most of the thrust is generated in the core of the engine.

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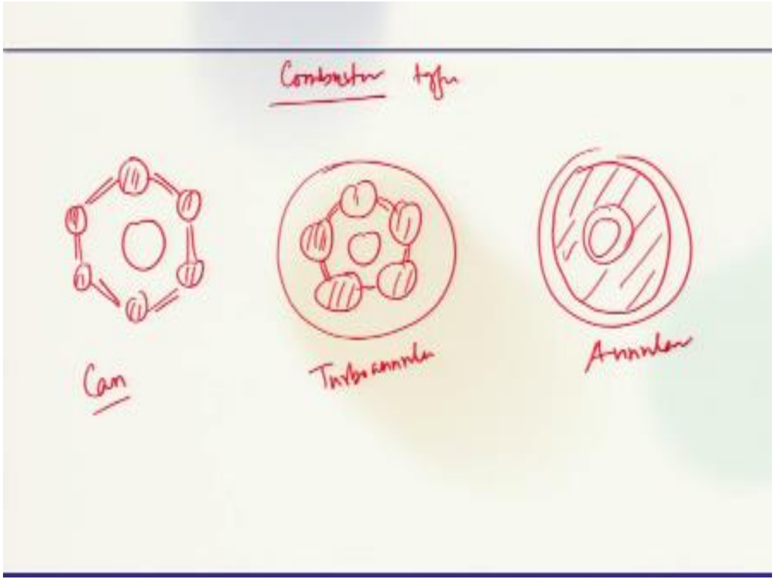

Now, we are talking about the combustor. Now, this combustor is also of different natures, there could be like this kind of situation where this is connected. So, this is called on some schematic of can combustor or you can have something like which is called turbo annular or on can have some simple, this is an annular combustor. So, the development has been made, they try to mix this can annular kind of combustor and that has some advantages some disadvantage.

But this is what has been tried by the different people to see and if you go to internet and try to search for these different kinds of combustor and there is also one can use multi can combustor, can annular combustor. So, these things you can find out in the google and one can look at the book of the gas turbine engine. Specifically different kinds of combustor and what do you use for the aviation purpose or in the aircraft engine and what do you use for the gas turbine in the land based power plant production.

They are different but one can have a look and see what kind of combustor that they are using and what not. So, we will stop the discussion today and continue from here in the next lecture.