Combustion in Air Breathing Aero Engines
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Lecture - 49
Aero Gas Turbine Combustors II

So, next we will see; what are the different types of combustors that are being used or have been used in gas turbine engines. So, this is about the types of combustors that we encounter. So, there are essentially 3 types of combustor first is this can type of combustor where we will see the combustor essentially looks like a can and these are these cans are essentially circumferentially arranged around the central shaft of course, you see that the.

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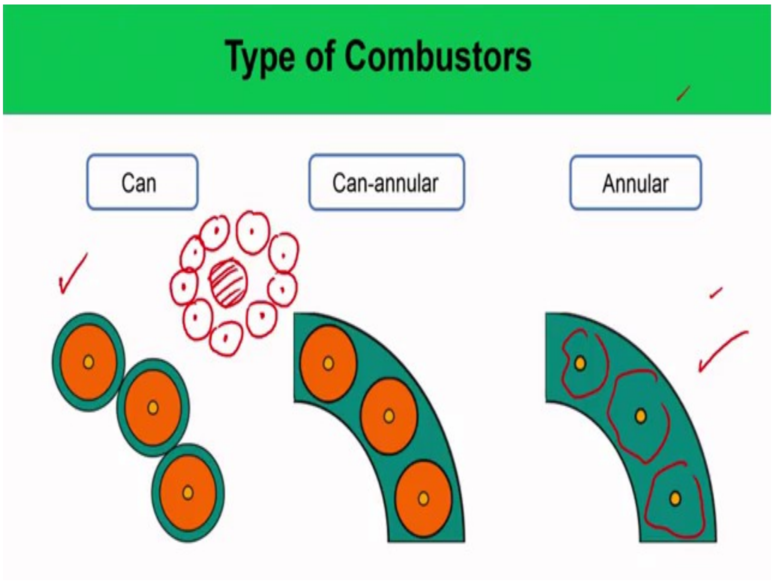

If you look into the basic architecture of the gas turbine engine; so, this is the cut section. So, you see the combustor has to occupy this annular space which is surrounding the central shaft.

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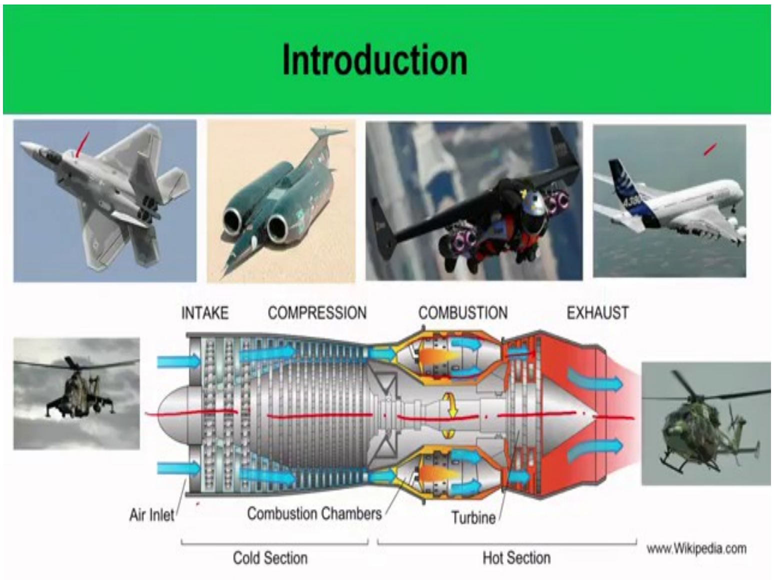

So, the overall architecture of the combustor has to be in a annular form now these.

This essentially; this is you are; here you are just showing this 3. Here we are just showing only 3 this cans, but actually it will looks something like this; that this is arranged in this form of beads around the central shaft and this is how can type combustor looks like. So, these are the central injectors that are being shown, but here each of the combustors are essentially separate the central part contains the shaft. So, these combustors arrange in this manner in the can annular manner. So, it is similar to the can combustor, but there is also this shroud surrounding. This can and there some air flow that can happen across these different can annular combustors.

In the annular combustor, you see that there is these injectors are just placed in this annular space and there is absolute interaction between all the combustors. All the essential individual burners which are at the flam is essentially similar like this and there is nothing that separates or physically separates this flam from each other and the flame and flow can interact and what is most modern engine, essentially this type of combustor where as this is the most primitive type of combustors. This is the most; this combustor are used in the most primitive engines of the first engines which was said by the frank whittle, etcetera, but modern engines like the Rolls Royce engines G E engines are all essentially use this annular type combustors.

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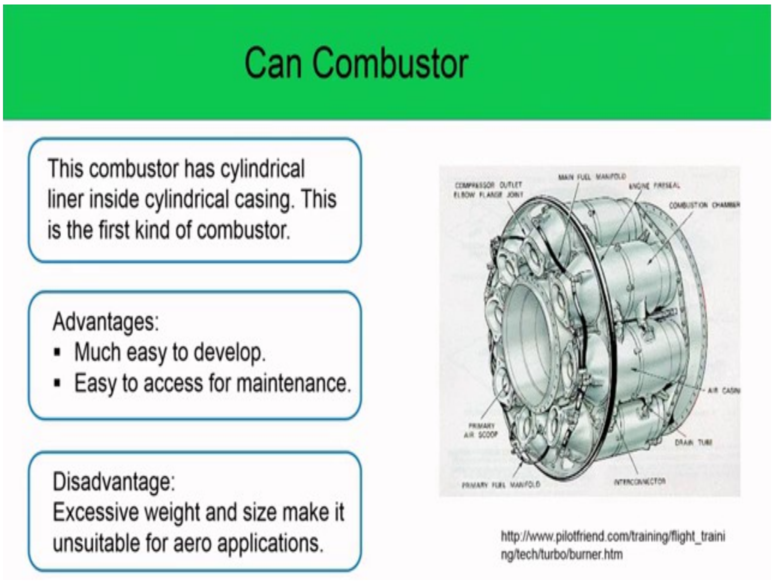

So, what is the can combustor? This is the example of a can combustor. So, you see that all this combustors are essentially put into different cans and this combustor has a cylindrical liner inside this has a cylindrical liner. Inside the cylindrical casing, this was the first end of combustor. Now the advantage is that this was very easy to develop because you just need to develop one can combustor and then you can replicate that combustors and arrange then in a circumferential manner.

So, and it is easy for maintenance also you can just take out one combustor and then repair whatever has been done and. So, that is how this thing is can be done, but of course, as you see that the metal that goes into the individual cans that adds a excessive weight and size at the makes it unsuitable for aero applications in aero engine; anything related to aero space applications weight is a very important factor. So, you want to have minimal weight for the engine.

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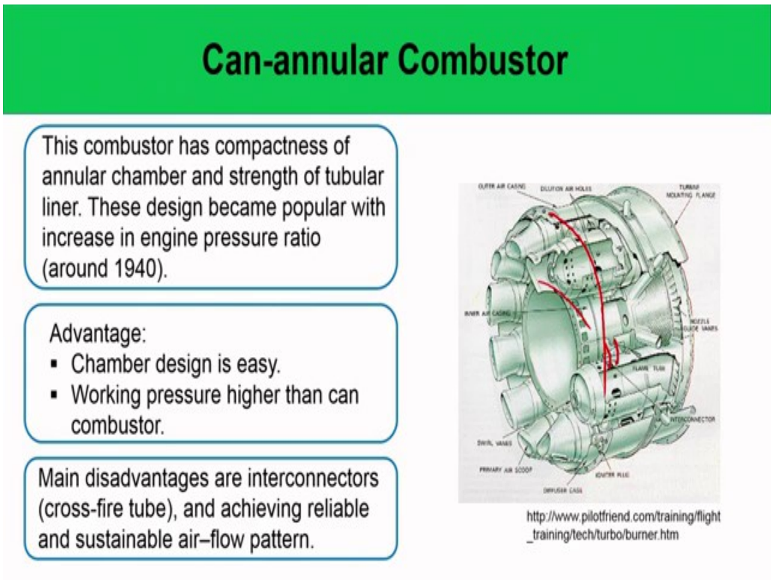

Now the second term; this is the can annular combustor. So, here you see that this; in addition; there is outer casing which is provided and also this; in this; these are provided in this annular space and this can combustors usually sitting in the annular space and then there is this flame tube where essentially the flame can pass from one combustor to the other combustor and you can have only essentially one igniter.

The idea is that you can have one igniter and then the flame can basically interact from one combustor to the other combustor. So, ignition if it is ignited a kernel that is ignited in one combustor can develop into a full flame and then that full flame can propagate can send out the hot gas. So, this flame tubes and those can ignite the other neighbouring combustor and so on and so forth. The whole all the combustor in the engine gets ignited.

So, this was also a little bit used in old engines and then once again the chamber design is not difficult and working pressure can be higher than the can combustor because here we have 2 layers of protection. The main disadvantage is that at this cross fire tubes are very difficult to not only it is to develop and achieving reliable and air sustainable flow pattern is also very difficult to achieve. So, that is very difficult thing that to ensure this flow to this narrow tubes into an in and out of these different combustors are not; this are not really simple to achieve and that led to this abandoning of this kind of designs.

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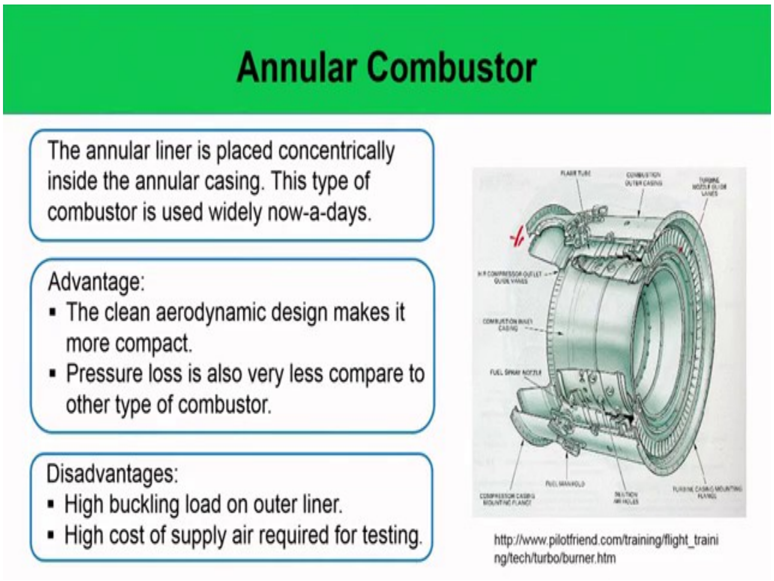

So, the most modern engines use this annular combustor. This is this round engine; this; what you see here and Rolls Royce combustor that you see here. So, the annular liner is here; the thing is that individually there are these are these are the injectors. So, the combustor is essentially occupying this space. This is the space of the combustor and then this essentially has goes a full along this; this occupies this full annulas between the compressor blades and this star wind blades. So, the compressor blades are here and the turbine blades are here. So, in between this annulas and this shaft hole for the shaft; so the shaft will be something like this. So, in between these; this combustor occupies this space and it is a full annulus design and where individual injectors are not physically separated.

There is absolutely no; nothing that separates them and it is just an annular liner is placed consequent concentrically inside the annular casing. So, this is the popular combustor that is present in most alter modern engines and the advantage is that the clean aerodynamic design makes it more compact. So, because there is no separation such and there is no walls intermediate then; this there is it can this combustor can allow can have much less can occupy much less space and it also has much less weight because it has totally done away with the cans.

Now also the spatial loss is also very small because you do not have much interaction with this kind of this walls and we can aerodynamically more important we can design this flow path in a much better way the disadvantage is that that because there is less metal of course, there is less material to take the buckling load. So, the buckling this outer liner takes huge amount of a buckling load and this high cost of air supply air required for testing. So, it is very difficult to I mean though people do it is like this combustors has to develop in a systematically from one injector to the multiple injectors to the full annular testing. So, development is more difficult and more challenging than a of course, single can type combustor.

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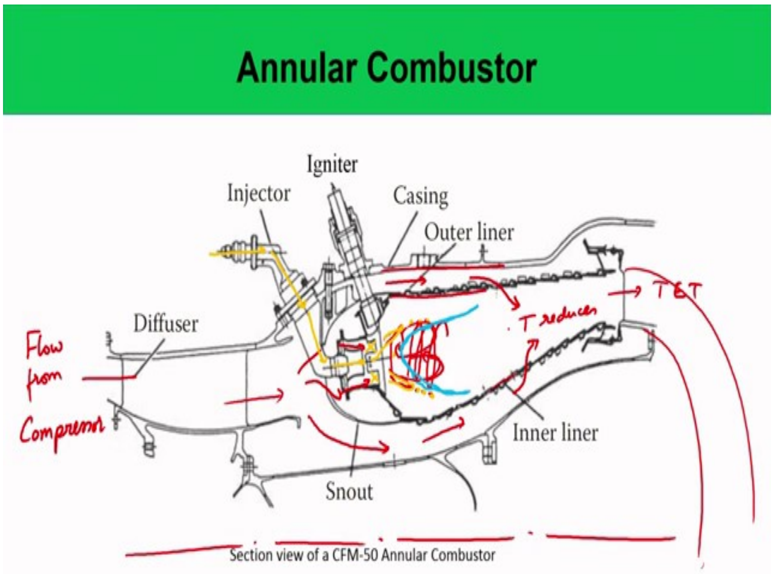

So this is how; this we will talk about more about this annular combustor. So, this is a section V of a C F M 50 annular combustor from journalistic. So, as you see that that this is of course, much more complicated design than this diffuser nozzle that we had shown you previously. So, of course, here you see that what you have is the diffuser where the flow comes in from the compressor. So, the flow is flow entering flow from compressor enters into this and then it passes through this diffuser where as you see the cross section area increases. So, this is bigger and then the flow essentially slows down. So, this as this passes through this thing; of course, you should the here the area is not exaggerated, but you can see it is a full annular.

So, the actual area increases actually quite large then what is you have see in this what can be understood from this picture this. So, the air comes in here and now it can essentially, as you see that here you have the injector. So, bus before that the air essentially can get split into these 2 parts. So, it can come through here and it can also. So, this is the only the central section. So, there is ample space for the air to essentially enter into this region also and then it is essentially enters into this essentially re-circulates; enters into this thing and passes through this solar. Now on which the injector this atom injector is mounted.

So, this injector essentially sends out liquid sheet like this which essentially breaks up and it is not so big. Let us draw it little more accurately. So, this injector sends out a liquid sheet and of course, in a souring environment. So, this whole flow is souring like this and then as if it operates. So, a flam will be formed flame like this can be can be formed as the droplets; the liquid droplets that is injected from here.

So, if I draw this fuel path through this, it comes in; it comes in here, it comes in here and then it goes in and this forms is break, but this solars; these are the solars which essentially solds the flow and the flow is essentially solds and at the same time it also creates this sour numbers are selected. We will see that the sour number here is essentially the ratio of the actual flux of the tangential momentum to the actual flux axial momentum.

So, it is essentially creates a wires that tangential momentum out of rotational motion to the otherwise straight flow; this solars and then these when that they exceed a certain number when this tangential momentum is high enough tangential momentum that has been imparted on the flow that is high enough then there a phenomena called when there is a flow re-circulates. So, you see this kind of flow recirculation and then that helps in essentially stabilising the flame.

So, here you see this flame being stabilising like this and then there is also this air which is coming from here. So, this air is at a very; this flame is at very high temperature which we do not want as you as you remember which we do not want this kind of a high temperature air. So, then this air comes in later through this cooling holes and it reduces the temperature from here essentially T reduces. So, that at this exit you temperature is the turbine entry temperature.

So, these are the different parts the diffuser then you have this; the injector; the igniter, this is the casing and this is the liner. So, liner is essentially the boundary between the combustor this main primary combustor combustion region to the outside casing of the combustor and then this is the inner liner which is essentially part and of course, this is a full you have to see that the axis of symmetry will be somewhere here. So, is essentially a full circumference it has, it is like this. So, that is that one is to understand. So, it is just a small cut section of this annular combustor that we have showing here we will talk little bit about this in the coming slides.

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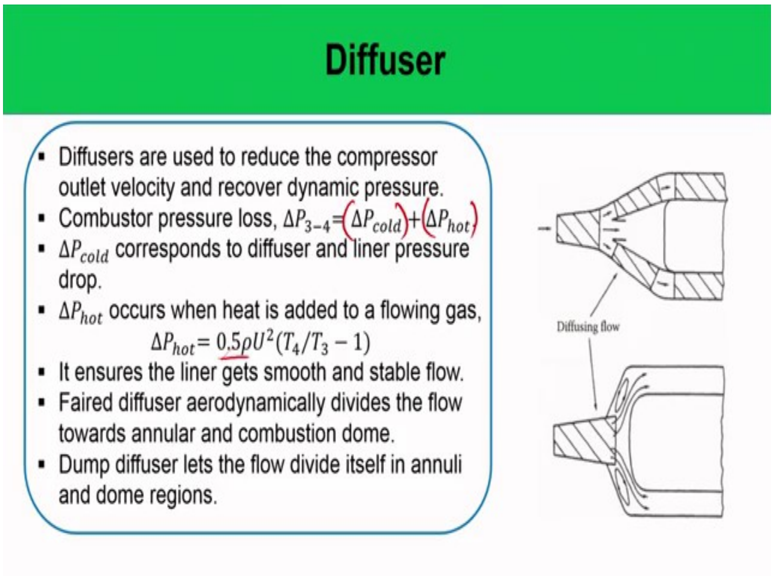

So, as you see that the one of the important parts. So, this is diffuser. So, even though this combustion class we just because it is a important part of the combustor. We will just tell you what the diffuser does as we have seen that the diffuser are used to reduce the compressor outlet velocity and recover the dynamic pressure; what is the main purpose is to reduce the outlet velocity. So, that the pressure loss is less and also doing that it recovers some of the dynamic pressure and the combustion pressure loss can be thought about that is the 3 is the combustor entry point and 4 is the combustor exit and turbine and entry point. So, it can be thought of as having 2 parts; the loss emerges from 2 parts number one is the cold loss and the hot loss.

The cold loss is that because you have to you are pushing in the air it to push in the air, it need to have some kind of pressure drop because there are viscous losses on the walls. So, to maintain the constant velocity it is like a pipe flow that if you want to maintain a constant velocity profile in a fully developed pipe flow, you need to have a constant pressure gradient so that the viscous losses can be; so, that the fluid can overcome the viscous losses in the walls. So, that is for that there is a cold loss all inevitable cold loss and then there is a hot loss and this cold loss is corresponds to the diffuser and the liner pressure drop.

Now in the liner pressure when there is this is the drop essentially also when there is a; this because of the tortuous path, it follows to the liner because of the cooling holes etcetera, it actually creates some turbulence which helps in mixing. So, this loss is cold loss is not so bad, but in the diffuser of course, diffuser also because of the walls it has some losses.

So, now the P hot is that when you add heat into your flowing gas which is if it is subsonic gas; then of course, then there is a pressure loss as we have seen, but and this pressure loss is directly proportional to the curve and which we have done this say if you remember in the governing equations and 1 flame loss. So, this is about 0.5 times rho U square times T four by T 3 minus 1. So, with that we can calculate the pressure loss and to basically reduce this pressure loss we want it to have a low U. So, the diffuser is actually used for that purpose. So, and also it ensures that the liner gets move the stable flow.

So, the diffuser has the multiple purposes and that it not only recovers; it not only minimizes the pressure, but it also ensures that the which is which can be strongly turbulent coming out of the compressor that is that is that process into a very aerodynamic manner into the combustor and there are 2 kinds of diffusers essentially then one is the fear diffuser or aerodynamic diffuser which essentially divides this is the aerodynamic diffuser which divides the flow towards the annular and the annular zone and the combustion dome.

So, the annular zone is this essentially this. So, you see the diffuser essentially guides the flow into the combustor so, but the flow can go either in this manner or it can go into the main com bus in to the main dome combustion dome region. So, how this will happen? How much flow will go in to the centre into the combustion dome region and how much combustion will go into the outside cooling region is completely governed by the diffusers. So, this a diffuser is a very very; this designing the diffuser is a very very important task because see if you have more air going into this outside region and very less air going into this. So, then you will produce; you will have very fuel rich combustion that will produce all sorts of pollutants. So, you do not want that. On the other hand if there is too much air going into this central region and very little air going into the cooling region then your cooling will not be effective and the temperature profile will be bad and also you do not your combustion may be outside the stability margins.

So, this diffuser there is no way to essentially tell the flow that you go this path you go this path. So, all you can do is to guide the; you design the diffuser in a manner. So, that this flow gets divided into the proportion that the combustion designer wants. So, the equivalence ration that will be here will be essentially governed by the all the diffuser is segregating the flow into the main dome region as well as the outside region.

So, this is where the diffuser plays a very important role and you see that there are there are 2 diffusers this aerodynamic diffuser and dumb diffuser and the dumb diffuser; there is a flow distance divided self into the annular and the dome region. So, this dumb diffuser is essentially, there is a certain expansion into this as you see here and off course here you see then dumb diffuser your velocity reduction will be much more than the aerodynamic diffuser. So, depending on the situation you; one can use a dumb diffuser or a aerodynamic diffuser.

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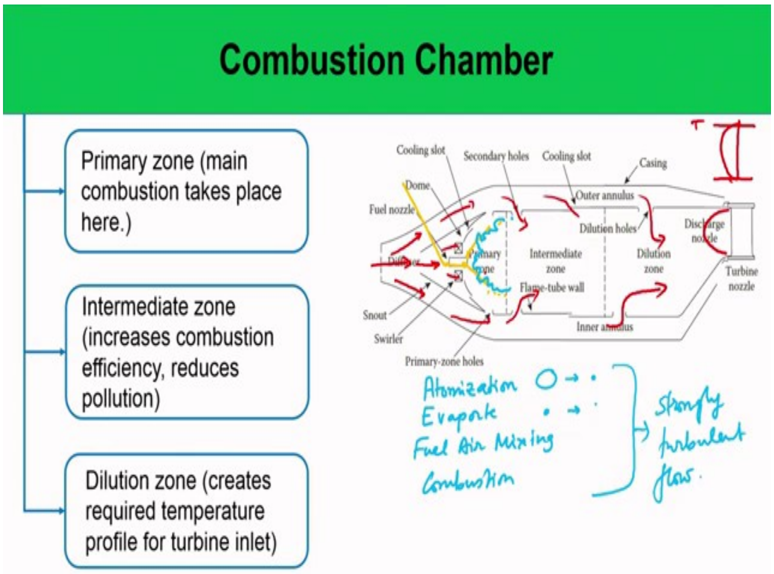

So, they are both varied answer actually seen in the modern engines. So, next let us go into the combustion chamber itself. So, the combustion chamber you have seen that this is the schematic which is essentially this schematic of this part. So, so the combustion chamber essentially you see the flow coming from the diffuser here comes seen to it gets divided into the outside this cooling flow and the main flow that goes into the dome. So, you see that here at the centre you have the fuel nozzle or the fuel will be coming from here and gets injected. So, the fuel will be coming and getting injected from here and it will form this and then the air which is coming from here will pass to this solars and it will develop this tolling flow; it will re-circulate; it will re-circulate here and then as this re-circulates and meets this spray, it will essentially form a; it will mix and then once you have ignite, it will create the flame.

So, the primary zone here you have, the most of the flame inside this inside this primary zone like this and this is the most important region of the combustor because this house is your essentially converts all the chemical energy to this to the to the to the to the to the thermal energy by the process of combustion which we will learn so far and it is a very complex process that happens here. So, you have got a essentially um you have essentially the processes if you if you just see there if you just summarize you have got; you have just got an; you the liquid has to atomize atomization then you have that atomization means the breakup of the liquid sheet into small and small droplets there can be primary atomization secondary atomization and. So, on and then this master fuel this small droplets. So, big droplets go into small droplets. So, then this small droplets must if a product.

So, this evaporates to from this mix to form this and then it must mix. So, it must mix with fuel air mixing. So, you have got to have fuel air mixing and then you have to have this then you can have combustion and depending on the fuel air mixing; you can have some places, you can have most non premix combustion you can have pre mix combustion as you see that in modern ingenious people are going to trying to go have pile lot non premix flame and premix main flame. So, you can have both, but off course these are all happens in a very strongly turbulent flow.

So, and we individually; so, the flame will be not a smooth and nice flame like this. So, the flame will be strongly wrinkled and a strongly turbulent flame when you look at it instantaneously. So, individually you can look into this flame and you can find all the things that you have studied all the things essentially presented involves kinetics it involves oxidation mechanism where involves. So, you need to know this; this whole processes of this fuel air mixing and how it happens is governed to the governing equation and then you have to have a; then individual if it is a non premix flame then locally you can use this; this flame lit approximation that you have seen which involves this solution from the chambered flame and if it is a premix flame one to premix.

If it is a turbulent premix flame, some place you can use this analysis of the one to premix flame that you have seen and apply this stretch concepts to derive more generalized function of flame speed and you can use; if it is a premix flame you can use a G equation to basically find out; how it evolve and off course it will involves limit phenomena also because that limit phenomena will govern you how in what margins it will be stabilized or it will be in where you can ignite it and where you can extinguish. So, all this things is essentially feed into this small combustion combustor of a gas turbine engine that you see. So, all the things you have learned is very very relevant and feeds into this.

So, if you want to simulate this process you need to know all this things. So, that is why this comb this course is we have we have take we have designed this course in that manner. Now this is the primary zone and then we go and then we go into this; into the secondary where you have the secondary holes and some coolings like this and from this cooling which reduces the temperature to some extent and then finally, you have the dilution zone where you feed in lot of air and then this dilution zone will essentially control the temperature profile that comes into this. So, we at the finally, we need a temperature profile in some manner which is governed by the stress situation in the turbine.

So, this cooling hole once again controls; will control this temperature distribution and that will ensure long life of the turbine blades. So, this intermediates to the primary zone is where the main combustion takes place and in the intermediary zone increases the combustion efficiency it reduces the pollutants pollution we see how and dilution zone is essentially creates the required temperature profile for the turbine inlet. So, these are the different processes that must happen.

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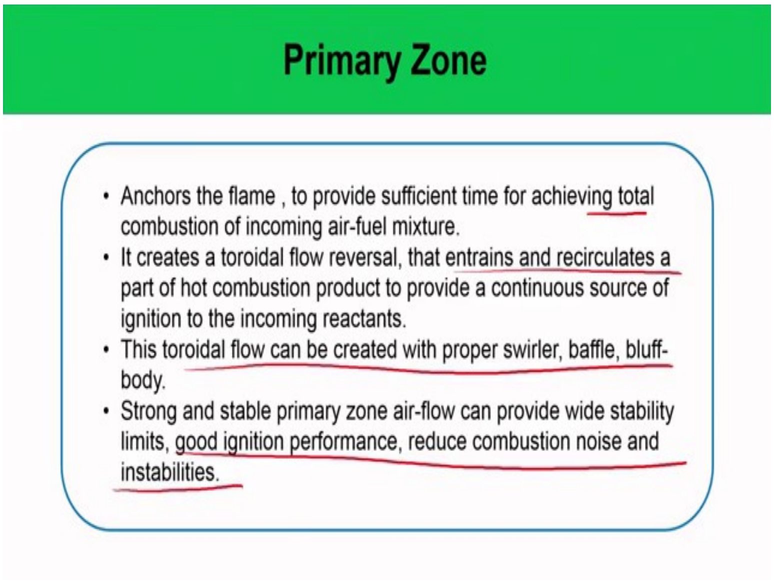

So, as you see that just to recap the primary zone is essentially is used for anchoring the flame and to provide essentially the sufficient time for achieving the total combustion of the incoming air field mixture. So, the primary zone is designed. So, that is why you have solar so that the fuel and the mixture of the sufficient residence time if it was just straight flow coming out of the diffuser. This diffuser flow can be of the order of 50-60 meters per second. So, if that flow you cannot stabilize turbulent flame as this. So, you need to some have some kind of flame stabilizers. So, the turbulent; so, the primary zone essentially houses this injector and the solar. So, the injector is essentially mounted on this solars and it provides this kind of a re-circulating of flow as you see this flow essentially ensures that the flow has sufficient residence time in the primary zone where you can have complete combustion of incoming fuel and mixture.

So, it creates a toroidal flow reversal that enchains and re-circulates smart of the hot combustion products. So, that is the second thing it does. So, once you have a flame stabilized, here once you have a flame stabilized this and then you have recirculation. So, the real mixture comes into here, then it re-circulates and then it comes back again. So, when this comes back again it is in touch with the fresh mixture and this hot product essentially can serve as an ignition source it can transfer the thermal energy by conduction conversion processes into the fresh mixture and that can help in achieving continuous ignition.

And this toroidal flow can be created with the proper swirler baffle bluff body, but typically in aero gas turbine engines swirlers are used where as bluff bodies are used in after borers which we will take up in a later. So, strong and stable primary zone air flow can provide wide stability limits good ignition performance and reduce combustion noise and instability. So, the design of the primary zone is of extreme importance and this part understanding this part and simulating this part is of extremely high importance and there is a basically the most important job of a combustion design of a combustion engineer in working in a aero gas turbine engine.

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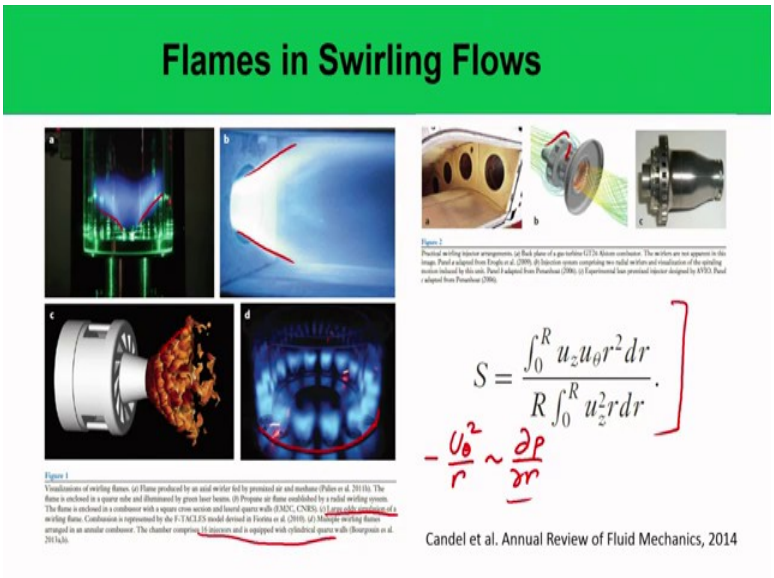

So, here we will take up little bit about swirling flows before because as you see all gas turbine modern aero gas turbine engines use flames in use essentially flames in swirling flows this is how this is how the swirling flame looks like and this is how this is how one actually this is a laboratory experiment, but this is how actually the flame inside a, but annular combustion would look like though this is a laboratory experiment and this is a essentially the flame in strongly swirling flow and this. So, there are all essentially laboratory experiments, but these are essentially different radiations of the flames in swirling flows this is the simulation that you see here it is a large simulation of swirling flame and this is a; this as I said is multiple swirling flames arranged in annular combustor.

So, this chamber comprises of 16 injectors and this is equipped with the quad cylindrical wall for doing optical diagnostic. So, we will talk about optical diagnostics in the later class when we will look take it up flames stabilization and after burn out, but this is how essentially the eng; the back plane of a gas turbine combustor look like. So, looks like and then the flow in as you see it passes through the swirlers and you see that the this develops this; it develops this swirling pattern into this thing.

So, as I said that the swirl number is an important parameter and is characterized by the by the essentially the axial flux of azimuthal momentum to the axial flux of actual momentum and it is governed by this x generalized expression. So, so the thing is that as I said that when the swirl number is about I mean in a swirls swirls does not have centre body at a very small centre body when the flow is fully developed and fully swirling. So, in those cases the swirl number is greater than 0.6 then there is then there is a phenomena called vortex break down and the reason is can be it is complicated mechanical phenomena, but if you write down Navier strokes equation it essentially comes down to U theta square by r is equal is scales as dou p dou r.

So, when U theta square by r is large then there is a then this dou p dou r then there is a pressure gradient in what pressure gradient that develops and essentially it is like a balance view of centrifugal force with the acceleration when. So, then this dou p dou r essentially causes the flow to re-circulate. So, that causes of vortex break down, but this vortex break down phenomena is very important for gas turbine engines because it ensures stable combustion and this continues toroidal recirculation zone helps in continuous circulation of the products. So, that is a very important thing for a gas turbine engine.

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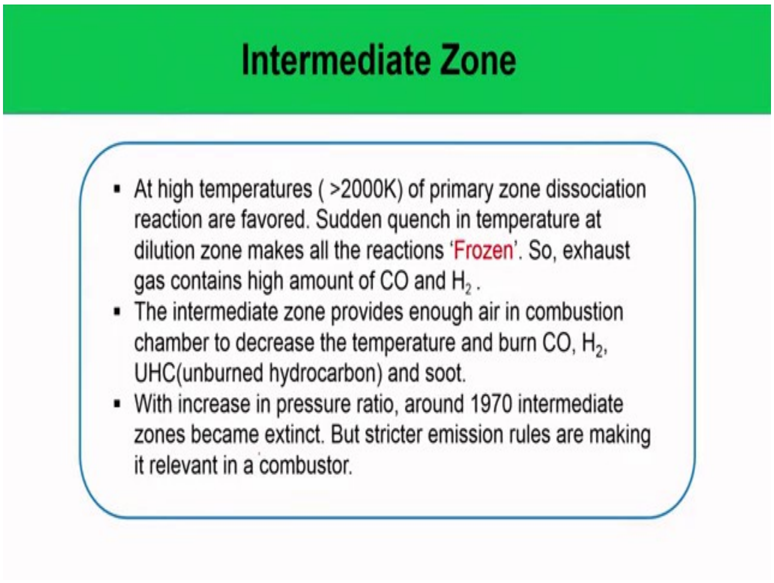

So, what does the intermediate zone do? The intermediate zone which follows the primary zone is at high temperatures the primary dissociation reactions are favoured. So, which we have learned from the chemical equilibrium class in that that causes this dissociation essentially causes the shifting of the temperature peak from the stoichiometric side to to the slightly to the essentially to the rich side.

so that is due to dissociation and the sudden temperature at the dilution zone makes all the reactions frozen actually. So, because there is some cooling air coming it immediately reduces the temperature. So, the reaction zone gets frozen. So, the exhaust gas contains essentially high amount of c o and h two, but this. So, the intermediate zone is essentially invites you enough air in the combustion chamber to decrease the temperature and burn the CO and H2. So, that is the thing; that is if this intermediate zone was directly followed by the dilution zone; the dilution zone puts in lot of fuel lot of air right. So, that would have cooled this temperature to. So, that cooled the high temperature combustion products to.

So, low temperature values that the that the reaction will be will be frozen and that at that point we would like a it flows kind of situation of chemical equilibrium then that that will contain lot of CO and H2. So, you need to rewind a little bit more air in the dilution in the intermediate zone. So, that you essentially can burn up the CO and H2 and if on burn hydro carbon suit any and this can be used to reduce the temperature slightly, but not as much. So, that the temperature; so, that the situation is convincive for the combustion of the carbon monoxide hydrogen un-burnt hydro carbons and so suit and oxidation of the suit. So, this is what the purpose of the dilution zone is it essentially acts as a pollution pollutant control and with increase in the pressure ratio around nineteen seventeen to minutes zone becomes extinct, but stricter emission rules are making it relevant in a combustor.

So, this is the intermediate zones role to essentially reduce the carbon monoxide and hydrogen and the dilution zone essentially as you see here.

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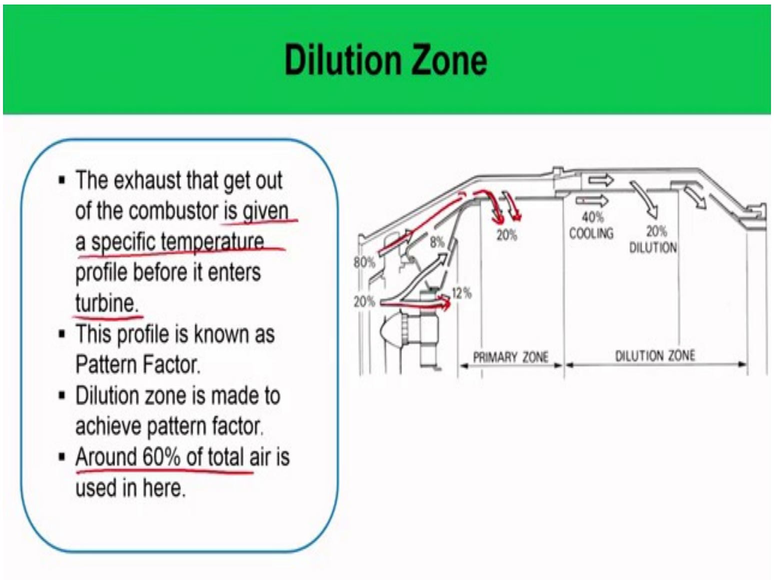

That there is lot of dilution here is breakup of the total air inside the combustor. So, you see that about 80 percent of the air is going out and only the whole about only 12 percent of the air is actually used for direct combustion in the primary zone where as this out of the eighty percent of the air that goes out, 20 percent enters into the primary zone and then there is a lot that slowly enters into the dilution is there is about the remaining 60 percent of the air essentially comes into the dilution zone.

So, this of course, this does not have a intermediate zone. So, you see a bulk of the air is actually used for dilution that is reducing the temperature of the combustion products to acceptable levels for the turbine into temperature. So, this is the purpose of the dilution zone the exhaust that get out of the combustor at combustor is given is given specific temperature profile before it enters into the turbine. So, this profile is known as the pattern factor and the dilution zone is made to achieve the pattern factor.

So, this is control the aerodynamics control in such a manner. So, that the exit temperature profile exactly matches that of that is required by the odd its desired to match that of the that is required most convincive for the turbine and as you see about sixty percent of the total air is used in this one. So, a lot of air do you see that there is aerodynamics air in this combustors is very important because it leads to the cooling and control of pollutants and also for achieving the particular pattern factor. So, this is the purpose of the dilution zone.

So, in the next part of the class we will take up how we basically inject fuel and what are the processes which basically breaks up the fuel into small droplets, and how to basically inject the fuel inside this combustor which is also a very important topic in gas turbine combustion.

So, see you then.