Combustion in Air Breathing Aero Engines

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Aero Gas Turbine Combustors V

So, that is one of the things. So, even if you get that, even if from this analysis you get that the smaller the size of the your droplet, the smaller the size of your liquid jet, you will get smaller droplets, but to get smaller droplets, you cannot make your orifice size of the injector to be arbitrarily small. You will get clogged orifices and nothing will come out. So, you have to have some engineers method by which even with finites orifices, you can make good droplets, ok.

The second concern is that you cannot have a liquid jet which just penetrate straight into the combustion chamber because then it will evaporate, it will break up atomized to very long distances and the length of your combustor will become very big. You need to have small compact combustors because that will cause the weight constraints. The larger the combustor, the bigger the weight. It is because we are housing high pressure gases inside.

So, you have to make complete compact combustors. First of all we produce solars which essentially causes the liquid jet to essentially diverge in this. Sometimes it is hollow cone jet and diverge. So, you typically use a jet cone angle of about 110 degrees inside a combustor to ensure that the length of the combustor is finite.

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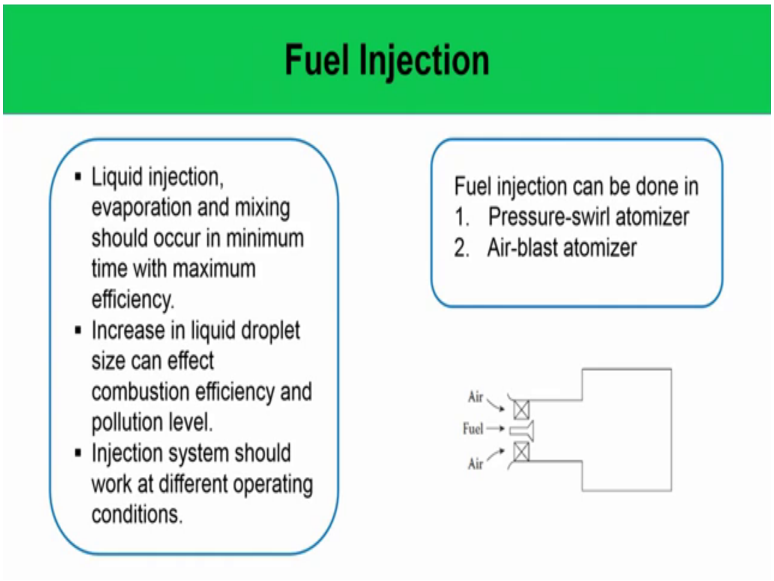

So, with all these criterias in mind, one has to design this fuel injection and essentially the whole purpose is that that you have to create small droplet, so that the evaporate quickly and then, after the evaporation, this liquid vapor can mix with the air and you can have combustion. So, that is the idea.

So, you see that for the liquid injection, the criteria is there. The evaporation mixing should occur with minimum maximum efficiency and the increase in the liquid droplet size can affect combustion efficiency and pollution level. This is very important that if you have very large droplets and they will not burn properly. So, it will create local. If you have very large droplets, they will take too much amount of time to evaporate and then, you will have regions of large vapor cloud, fuel vapor clouds and there will not be proper mixing. So, essentially we will get fuel rich combustion and it will cause purity production of soot nox, server nox. Also, the injection system should operate a different operating pressure because sometimes you need more fuel, sometimes you need less fuel. For example, while you are taking off, you need a lot of power, you need to produce a lot of power and as a result you burn a lot of fuel and you have to inject a lot of fuel, but whereas you are in cruising, you might need lesser fuel. So, that is the thing, ok.

So, typically people do use two kinds of injectors; pressure swirl atomizers and air blast atomizers. So, we will see what they are. We will just give a very brief glance and we will not go into in details.

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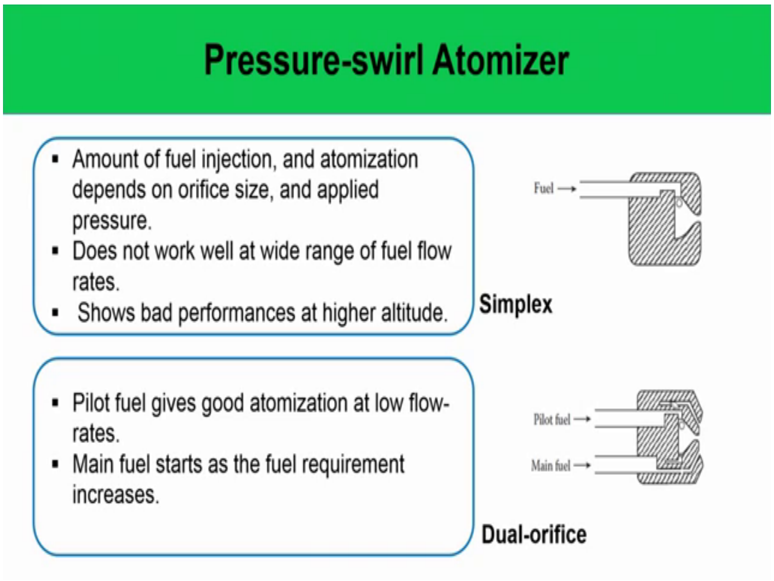

So, first is the simplex type of atomizer, where you basically use this principle that you create a very small orifice and a small liquid jet will vary. The narrow liquid jet will come out at very high pressure and that will quickly break up and atomize, ok.

So, here of course the amount of fuel injection and the atomization depends on the orifice size, but you see on the other hand, you need certain amount of mass flow rate also. So, you cannot have a very small orifice because then you need immense amount of a pressure drop, immense amount of high upstream pressure to basically push through the small orifice.

So, this design does not work well for a wide range of fuel flow rates and it shows bad performance at higher altitudes and this one is a dual orifice atomizers. So, what you have is that this is a cut section. So, it is essentially a circumference like this. So, this is a circumference like this and circumferential and this center, it has basically orifice for injecting pilot fuel and it has an orifice for injecting main fuel and the pilot fuel gives good atomization and low flow rate and the main fuel starts from the fuel requirement increases.

So, this way you can convert a simplex atomizer to basically to operate at no for a range of conditions. So, that is the thing.

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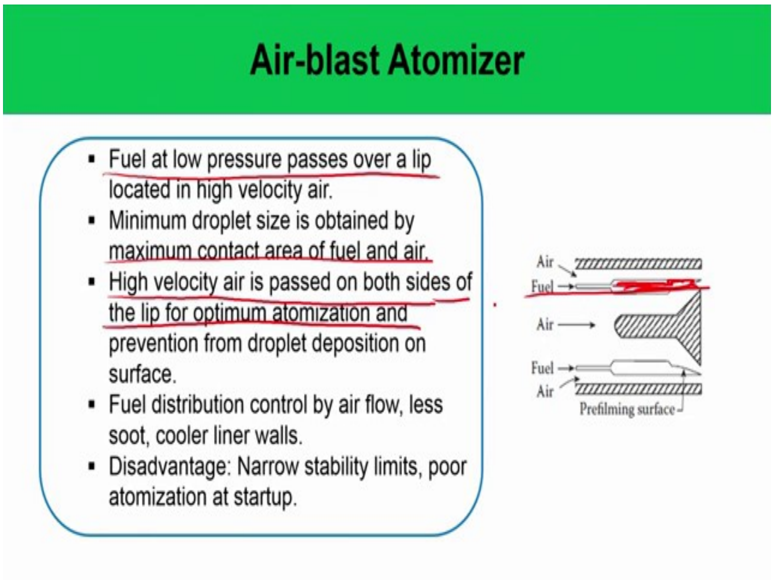

Then, you have this air blast atomizers, where you basically use air to basically cause a shear on the fuel column itself, so that it can even atomized inside and we produce small droplets.

So, basically at this air blast atomizers are widely used in gas turbine engine. So, fuel at low pressure essentially passes over the lip located in high velocity of air and the minimum droplet size is obtained by the maximum contact area of the fuel and the air I mean because the idea is that if you maximize the contact area, then the differential velocity between the air and the fuel creates a shear force on the liquid surface and that basically peels of, makes a kind of ligaments on the droplets surface and it means the ligaments and then, these ligaments can eventually become droplets.

So, that high velocity air is passed. So, high velocity air is passed on both sides of the lip for optimum atomization and prevention of the droplet deposition on the surface. Of course, you cannot allow the liquid droplets to deposit on the surface. Also, it must reach, it must be dragged off by the air and the good thing is that by controlling the direction of the air or by controlling the direction of the airflow, you can control the fuel distribution. As a result, it creates the less soot and cooler liner walls because this fuel intrinsically comes kind of mixed with air and the disadvantage is that it has nano stability limits and we do not get very good atomization at the start.

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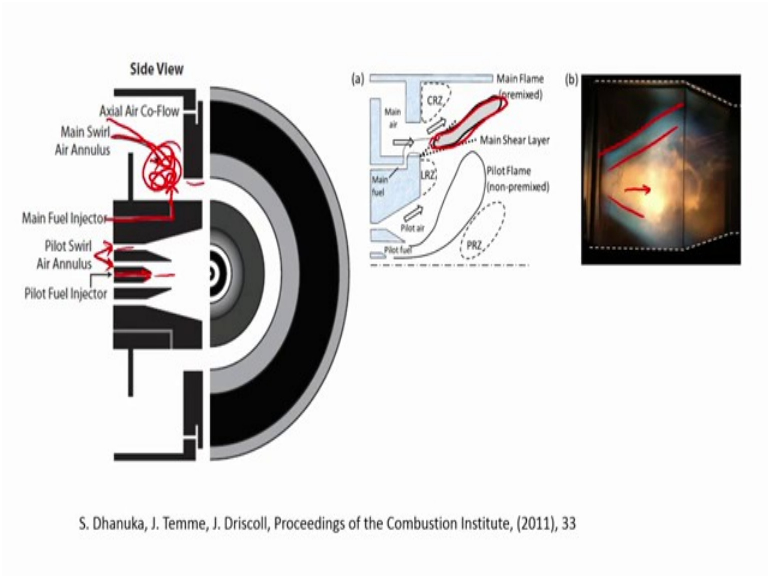

So, this is how a modern atomizer essentially looks like. This is the tuned annular premix wall or atomizer which you have looked which powers this GNX engine for the boeing 787 and you see that here you have this you know you have essentially the main flame and the pilot flame. So, it is kind of a mix of thess different kind of atomizers.

So, this side is the main air annulus which is basically solved and this also is the pilot air annulus and then, from here you have the pilot fuel injector. So, if we go step by step, inside you have this pilot fuel injector goes in and these are the swirl to where the air comes in and it is this pilot swirl, this pilot air is essentially solved and on the sides here you have the main fuel injector that goes into here and the main swirl air annulus comes from here.

So, this is essentially a tuned annular premix solar. So, these tuned annulus that you see here, not only once you have one solar but you have essentially two solar. For the main air, we have for the pilot air and then, we have injection for the main fuel as well as for the pilot fuel. So, these gives you on the sides essentially what you have because you are allowing in this part, you are allowing the fuel and air to meet before it goes into the combustion chamber. So, you get essentially here is essentially a premix flame.

So, that is the good thing about it and it allows. Sorry, it allows this flame that you get here is a premix flame because of the fact that you are allowing the fuel and air to mix if it goes in and this is seen from here, from this, this emission images, this blue flame that you get is essentially premix flame, where as a central flame you get here where you do not have the room for this fuel and air mixing. We do not want that also because we want this stable pilot flame inside which is essentially this orange in color which is due to the soot and that is a pilot flame. So, this cuts down the emission to a great level because of the presence of the premix flame. So, again with this liquid fuel injection, you can manage to get essentially premix flame on the main side, but then that has to be stabilized and there needs to be a continuous pilot flame for the regions on the disguise because your power requirement can vary etcetera.

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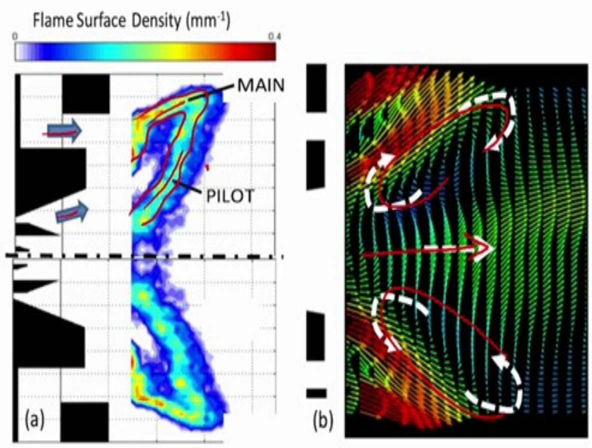

S. Dhanuka, J. Temme, J. Driscoll, Proceedings of the Combustion Institute, (2011), 33

This is how these things looked like in the flame surface density in general we talked about and this is how the piv vector fuels inside the combustors looks like. So, you have your coming out from here, we have coming out from here. So, we have along this region your flame essentially shape like this, ok.

So, these are the main flame regions, this is a pilot flame region and you can see this is a circulation zone structure that is created. This is due to the presence of the solar and that essentially helps in stabilizing the plane, where as central you do not have this circulation zone because from the center you are injecting this straight pilot fuel and air mixture fuel and air separately and then, that creates a pilot flame, ok.

So, this is how modern what we have discussed essentially. So, that is our idea. You should take it slowly and we should also council these books by Lefebvre and Ballal and also, do this analysis. So, once again we have shown in a very condensed manner that despite the fact that the actual atomization or actual jet break up process in a combustor is complex, the fundamental mechanism by which a jet breaks up in absence of anything, in absence of air and in absence of gravity, in absence of surrounding airflow or atomization, this is mechanism you call that instability which is essentially hydrodynamic instability, where wavelengths or wave numbers or wavelengths which are greater than the circumference of the liquid jets are amplified and then, either there is a preferential wavelength of about 9 times the radius which is the maximum and typically the jet breaks up into those wavelengths and we get droplets.

Of course, in an actual process this is in an actual engine. This is much more complex and we need to understand them. One is to look into the literature and to either numerical simulations or to experience and this is our practical engine look like this is an experimental rig which the actual injected from in general restrict and they did these experiments, all right.

So, finally once again you see there is one of the goals, I mean in an engine is that you have to have a very good temperature distribution at the outlet. So, all these atomizations, very good atomizations or we can understand intrinsically that there should be very good atomization. So, you need cooling air etcetera, but finally to certify an engine you need to have certain parameters as an engineer. Certainly to say that if my engine satisfies this parameter, I will call it good. If it does not satisfy this parameter, if it comes below the threshold of this parameter, I will call it bad. So, pattern factor is one such very important parameter, one of the most important and at the same time most difficult designs.

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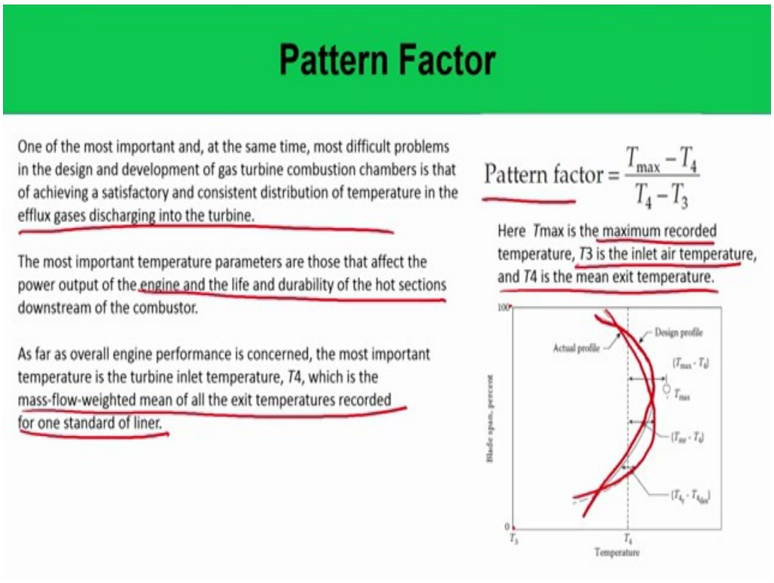

As you see here in the design and development of a gas turbine combustion chamber is that of achieving a satisfactory and consistent distribution of temperature in flux gases discharging into the turbine and the most important temperature parameters are those that affect the power output of the engine and life and durable at the hot sections downstream of the combustor. The hot sections are the starter blades and then, the rotor blades of the turbine as far as and as you see from thermodynamics for on overall engine performance, the most important temperature is the turbine inlet temperature because you see this engines, gas turbine engine so hot on the principle of Brayton cycle and to maximize the efficiency, the most important parameter that you have at your disposal is this turbine inlet temperature T4 higher T4 greater is the efficiency greater is about done.

So, ideally as an engine designer, we would like to have maximum as high T4 as possible which is of course not always possible because T4 immediately goes and hits your turbine blades. So, it is no good if those melts away. So, this T4 is essentially the mass flow weighted mean of all of the exit temperature recorded from one standard of liner and this is what your pattern factor is defined as. It is essentially a normalized version of the difference between your maximum temperature and your average temperature at the exit which is T4, ok.

So, pattern factor is essentially Tmax minus T4 divided by T4 minus T3. So, Tmax is a maximum recorded temperature and it can be anywhere and T3 is the inlet air temperature and T4 is the mean exit temperature. So, this is how you along a turbine blade, this is from 0 span to 100 span. You might desire that, want in a design profile like this, but your actual profile might look like this and then, your Tmax can be something like this

So, the idea is to basically and this design profile comes from structural considerations of the turbine blades materials stresses etcetera. So, this idea is to minimize this pattern factor as much as possible. This Tmax should be as close to T4 because then it means that your entire turbine blade or not only minimum, but you need to have a desired pattern factor that is your Tmax should not be too much away from T4. As much as possible, it should be on the lower side, ok.

So, that is one number that where that is for certifying the combustor. One is pattern factor as a number that is your Tmax should be very small and should not have much deviation from T4, but it should not be exactly equal to T4 also because that is not optimized. If everything is at the constant temperature, then the turbine blades will not be like that.

So, there has to be a particular design profile and your Tmax minus T4 should conform to that exact design profile and that is the best thing that can happen. So, this pattern factor, when you design an engine, when the design consideration for this pattern factor might come from your materials or your turbine considerations, so as a combustion designer what you have to ensure is that the output of the combustor conforms to this desert pattern factor and the output of the combustor temperature profile should conform to the desired temperature profile that comes from your turbine.

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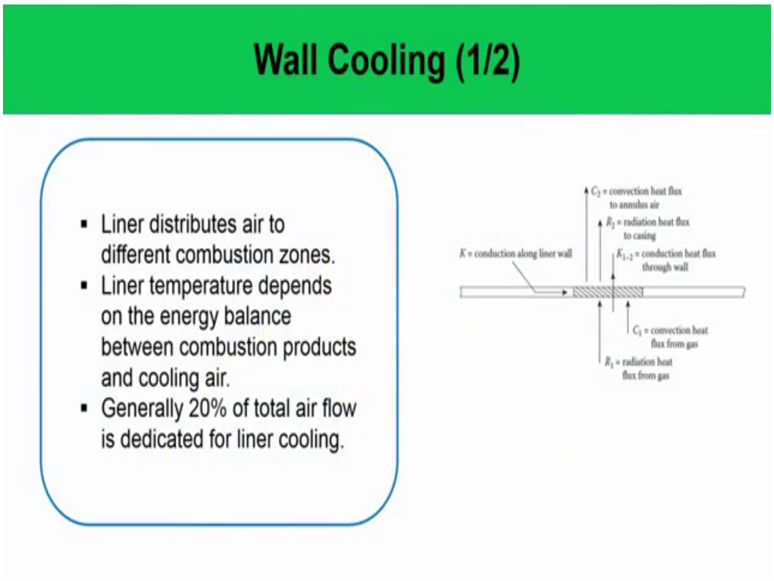

So, other than that there can be other things like wall cooling etcetera. I will not go into that. So, when you design for wall cooling, you have to consider a convection conduction radiation.

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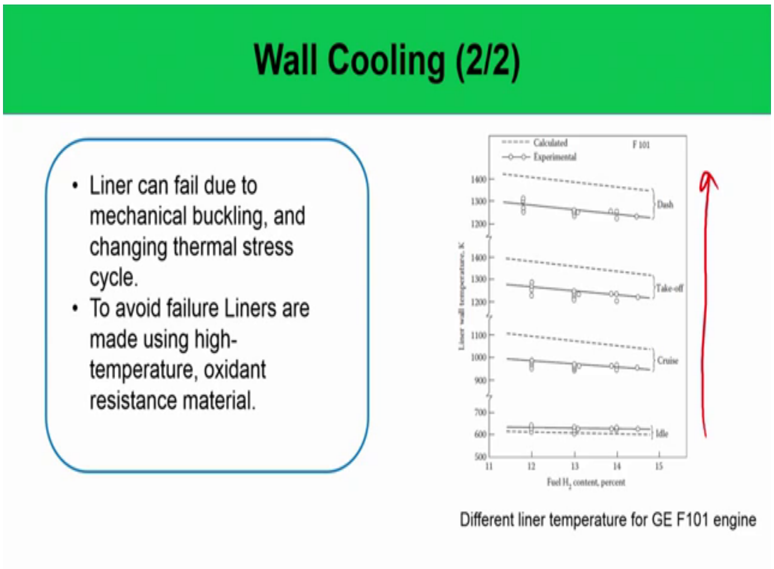

Then, a liner can fail if the wall cooling is not proper. Liner can fail due to thermal stress cycles. To avoid failure liners are made of high temperature oxidant resistant materials because there is a strong oxidation environment and as you see that the different times you go, your liner wall temperature can vary differently.

So, it must be able to take different very high fatigue of it under very high thermal stress cycles. So, that is one very important thing.

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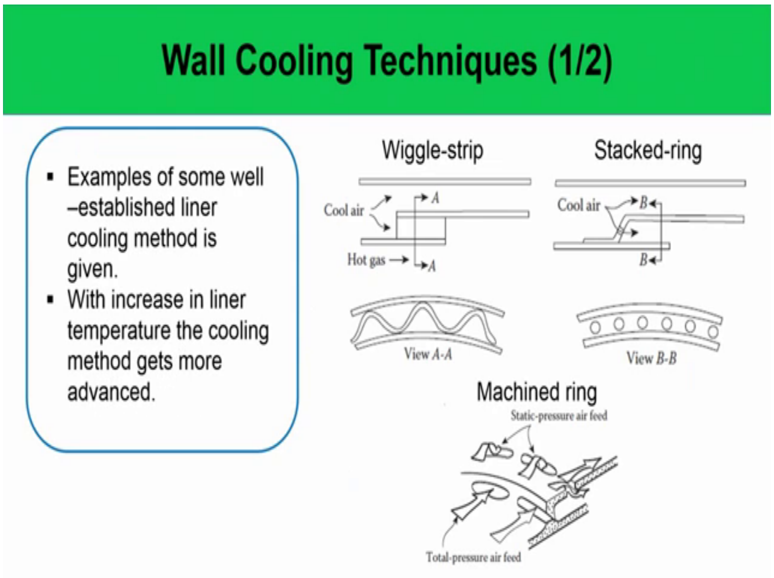

There are different types of cooling like this kind of Wiggle-Strips, Stacked-Ring like wall cooling methods.

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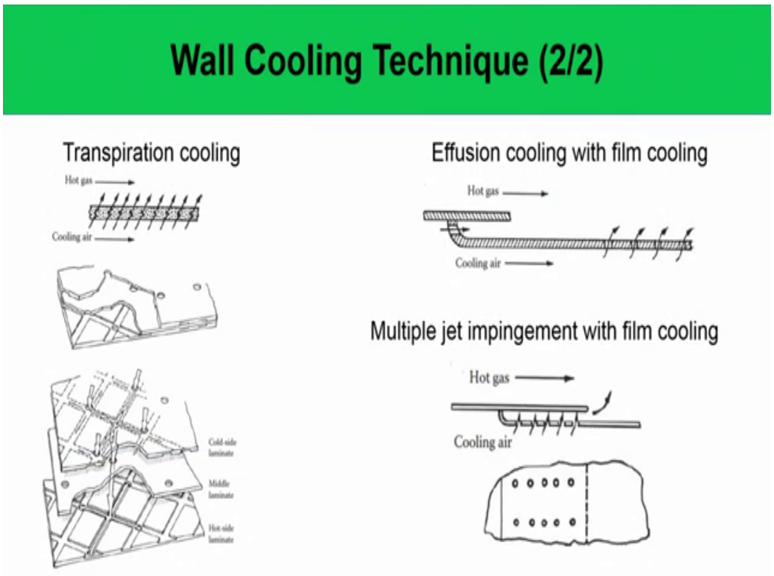

Then, you can have transpiration cooling, effusion cooling. If you are interested, you take a look into this book where these are in detailed, but this is not exactly combustion, but we just show you this for a complete understanding of what the things are required in the combustor.

So, with that we would end our discussion on the main combustor of a gas turbine engine and in the next class, we will go into essentially the afterburners and how one can understand the stability, how flame is essentially stabilized in an afterburner and for that we will also look into some of the cutting edge laser based diagnostics that are used to understand flame dynamics in prototypical engines. So, till then goodbye.