MARINE ENGINEERING

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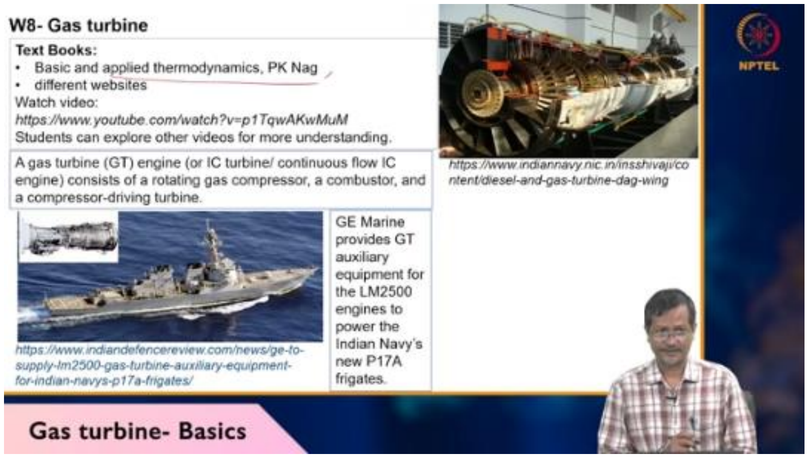
Lecture48

Gas turbine- Basics

Good morning everybody. Today I will start the lecture on gas turbine. So this whole week it will be like gas turbine, some specific nuclear power engine, some other type of engine also I will try to discuss. So basically I will focus on gas turbine engine. So gas turbine you may have seen in your aircraft engines.

Whenever you fly you see this wings will have engine. So that is basically gas turbine engine. You cannot use their ice engine or other type of engine because gas turbine is having some merit. In your naval ships also, especially navy applications, there are several gas turbine engines used in many applications. So, that is why I will try to go through gas turbine engines and basic calculation through this lecture.

And for textbook, again you can follow the book Basic and Applied Thermodynamics, P.K. Nag, that book is available in your library. uh and many websites also there regarding gas turbines and there are big companies are there for example man energy then uh pratt and whitney there'll be mitsubishi several companies are there and in india if you say then gastro in such establishment gtre of drdo's laboratory so they are also working on gas turbine so they are trying to develop light combat aircraft and cover engine many other type of engines So gas turbine is a very important part for your civil life as well as military life or defense system. So in industry also lots of gas turbines are used for example your cogeneration gas power systems or where you need electrical source for city powering let's say continuous grid supply not possible so in that case you want to give local supply so in that case gas turbine can be used



Many big industries they will be using. So your aircraft engines like combat aircraft or military vehicles they can be using. Your INS and naval ships, INS class ships are there. warships those are also run by gas turbine engines okay so here a gas turbine engine or it is also an ic engine internal combustion engine so internal combustion engine we have seen is the reciprocating type engine but here we can see it is not actually reciprocating type it will be continuous flow type engine okay so that means i will have two type of ic engine one will be reciprocating type another continuous flow so this is continuous flow ic engine or internal combustion engine okay so it will be consisting rotary gas compressor combustor compressor driven turbine so this three main part will be there in gas turbine so other many other part will be there but we will not go through the details of everything but the basic three thing compressor combust combustion chamber or combustor and turbine system so three system will be connected together continuously gas or fluid will be flowing and you will get power

And here one example is that GE Marine provides GT auxiliary equipment LM2500 to naval ships. So similar way if you search GE they are producing in the US this company. So they are producing lots of gas turbine engines for military applications also. But other companies also they are producing for military and civil applications. So gas turbine you have seen aircraft.

This one actually aircraft engine. so I'm giving a simple example because you have seen it. So aircraft engine will have you may have seen this one lots of blades will be there you can see rotating and shape will be like this and gas will be coming out through this right. So inside there will be gas turbine engine. So basic beauty is that more power to weight ratio.

So, this same weight if you use IC engine or your Rankine cycle that steam engine their weight will be more than for same power output. But here we are getting more power for same weight. So, it is having more weight power to weight ratio not opposite power to weight. okay especially light combat aircraft or civil or military aircraft systems gas terminals are very very much suitable because you are getting more power and light is weight is lower okay so this will be having thermodynamic process like it will have one compressor system okay so and one turbine system it will be connected directly by a shaft okay this is called compressor This is turbine.

I am putting C here. I am putting T here. This is turbine. And this is shaft. So compressor will be taking air.

And this after compression this air will go to combustion chamber. From combustion chamber it will go to turbine. turbine it will be exhaust okay this is the simplest gas turbine engine this is called brayton cycle okay this is called brayton cycle okay so brayton cycle will have isentropic compression so here then you have to draw on ts diagram when i was saying isentropic compression or something So, pressure will be like this. So, compression isentropic 1, 2, 2, here 1, here 2, here 3, here 4.

1, 2, 2 compression is happening. So, in TS diagram you can see 1, 2, 2 vertical line I am showing isentropic compression. Then 2, 2, 3 what is happening? Same pressure maintaining and you are burning. In combustion chamber, from compressor to turbine, pressure will be same actually.

The combustion will be happening inside combustion chamber. So, that is why this isobaric process, then 2 to 3, Euler's to 3, 3 means where combustion output will be reaching to turbine. So, 3 to 4, your turbine part. And 4 to 1, many books they will be putting on complete cycle. But if you see here gas turbine engine, this type of engine, it is not a complete cycle actually.

Burning happening, exhaust happening, then the same gas you cannot put in your compressor because oxygen is not there. flue gases are there. But that gas, high temperature gas can be used for other purposes we will discuss later. So, basic cycle is that it must have one compressor, one turbine, one combustion chamber. Turbine will be connected to compressor directly.

Why? Because compressor needs some power. Because compressor must be rotating. If you want to rotate compressor, some power required. So, directly that power will be coming from turbine.

So, in TS diagram, it will be like 1, 2, 3, 4. This is basic simple system. so we will draw this one in pv diagram so in pv diagram compression happening first let's say one two two one two two compression happening axial compressor we have then two to three constant pressure pulses okay two to three is constant pressure pulses this is constant pressure okay this is also constant pressure line so combustion is happening at constant pressure okay so one two two pressure increasing volume reducing then two to three constant pressure 2 to 3 constant pressure pulses. Then 3 to 4 what is happening?

Expansion happening. So 3 to expansion happening. So it is like this. Now 4 to 1. 4 to 1.

This is 4. 4 to 1 actually exhaust process. This is a constant pressure process. For example, if your gas is going to atmosphere, it will be atmospheric pressure. So, that is why there is no pressure change 4 to 1.

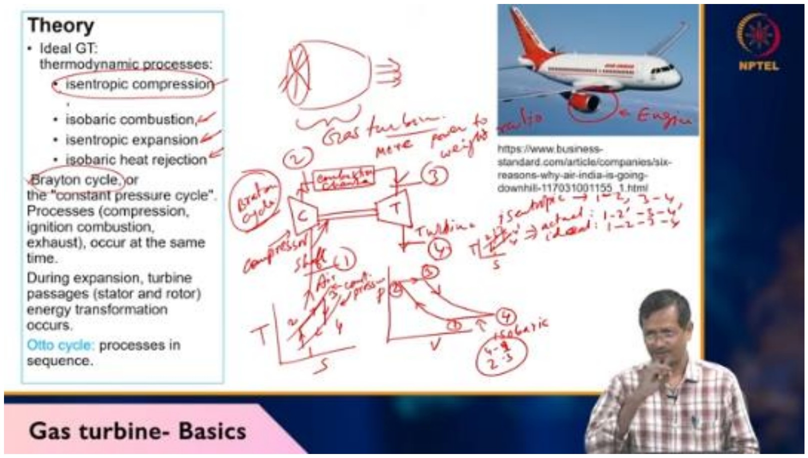
It is constant pressure process. So, this is isobaric process. So, I have two isobaric process 4 to 1 and 2 to 3. Isobaric 4 to 1 and 2 to 3. And isentropic

Isentropic happening 1 to 2 and 3 to 4. 1 to 2 and 3 to 4. So, I have four processes. Isentropic compression. You see this typed text.

Isentropic compression is there. Isobaric combustion. Combustion is happening at constant pressure. Isentropic expansion. Isobaric heat digestion.

So, this is actually ideal cycle. If we want to do practical cycle for example in rankine cycle we have seen if we want to draw a practical cycle on pv diagram or ts diagram so some small changes will be there for example if i draw this one as so actual cycle ts diagram or pv diagram if i do whatever you say okay one two three four this is ideal practically compression power requirement will be higher and your turbine power will be lower two dash four dash okay so uh actual one two dash three four dash okay and ideal one two three four okay you see the difference if you go for actual then actually you are giving more power to compressor and you're getting less power in turbine but in ideal case you are getting more power So, isentropic process.

And whenever you are saying actual process, I draw the lines in dotted form. Dotted form that does mean that it is a irreversible process. Actual process is irreversible process. That is why I draw dotted line. When I say isentropic, I will be drawing solid line.



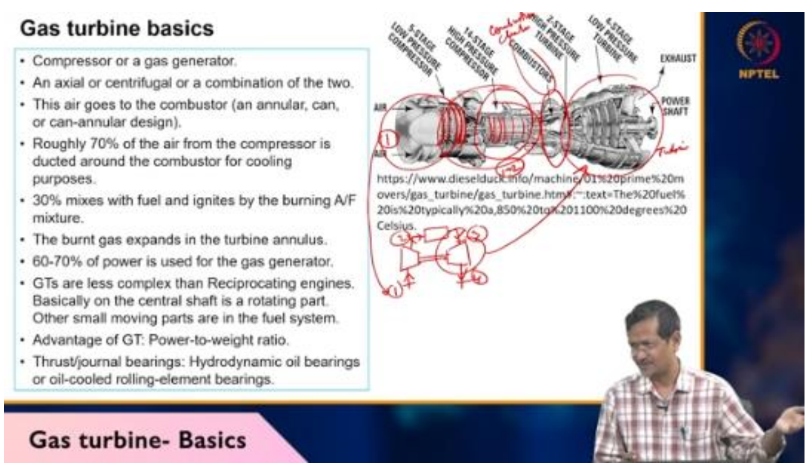
So, you also when you are writing an exam, so you write solid line for isentropic and dotted line for irreversible process. where energy loss is happening entropy increasing okay so you can see one gas turbine engine whatever I have drawn actually you can resemble compressor was there then shaft was there then turbine was there then on combustion chamber entry and exit one two three four the process okay and it is open cycle actually because gas entry same gas is not going back to your compressor okay in many cases for simply simplification people will be adding four to one but practically does not happen okay because same exhaust gas burn gas that is not having any oxygen that you cannot put in turbine compressor again again another issue is that that gas will have a higher temperature so higher temperature gas you are compressing is not suggested So, air atmospheric temperature will be normally 30 degree around. So, if you go to a aircraft engine upper atmosphere their temperature will be much lower but normally say Chennai temperature 30-35 degree.

So, that but exhaust gas temperature will be much higher. So, lower temperature gas compression easier than higher temperature gas compression. So, we will be taking atmospheric air for compression then we will be compressing burning exhaust done. Now I will resemble this one. So air intake is happening here.

So this one I can say 1. I can resemble this part. Air intake is happening here. Then my compressor stage you can see this one. So several stages of compressor will be there actually.

When if you see gas turbine engine. So several stages of compressor, several stages of turbine will be there. okay here also you can see one two three four five many stages compressors are here actually okay so several stages compressor will be there so all together actually you can resemble one to two okay one to two process is your compressor then where is your combustion chamber so here actually combustor is there this is called combustion chamber or combustor okay combustion chamber then your turbine section turbine section again expanding this is turbine section okay so you can see compressor gradually area reducing then combustion happening then again expanding so this actual picture if you google it you will find lots of gas turbine actual engine picture also many companies those are going for business they also put their own compressor system picture so you can see that one So compressor gas compression happening, combustion happening, expansion happening.

So the same thing will be happening for your aircraft engine or your marine engine if you are using gas turbine system or this can be used for your other industrial applications. So compressor they are saying another term is their gas generator. So you are not generating gas actually you are compressing but people use the term gas generator. an axial or centrifugal or combination of two can be used so normally first stage will be axial compressor why axial compressor axial compressor actually they can handle very large volume of air okay you can remember the pump turbine i was teaching that time so axial machine will have very large volume handling capacity but low pressure handling capacity okay so first stage normally it will be having axial type so you take large volume the compressibility bit then you go to centrifugal and other type okay maybe axial or centrifugal so first stage should be axial type take large volume compress it reduce volume then put into a centrifugal or maybe next stage of axial compressor so here also you can see five stage low pressure compressor is there then again high pressure compressor is there so low pressure compressor stage normally it will be



axial then high pressure stage when you are going it may be axial or centrifugal okay so many compact engine people they will be using centrifugal type because centrifugal they can develop very higher pressure okay but low volume handling capacity so in that case reduce volume using axial system then put centrifugal system then you compress you increase oxygen density actually when you are compressing you are giving more oxygen small volume put into your combustion chamber The air goes to combustion. So, this combustor system I will discuss later. Annular, can, can annular, different type of combustion system is there. Roughly 70% of air from compressor is ducted around the combustor for cooling purposes.

So, combustor actually it is burning, fuel will be burning and temperature will be very high. So, high temperature and material strength will be a problem. So, outside that combustion chamber or combustor, lots of air will be flowing. So, that lots of heat will be carried away. Otherwise, it will be melted.

The combustion chamber. 30% mixes with fuel and ignites by burning air. So, 30% air will be used for burning your system. That fuel. Remaining will be just for cooling purposes.

The burn gas expands in turbine engine. That is fine. 60-70% power used for the gas generator. Okay. So, a good amount of power is used for your

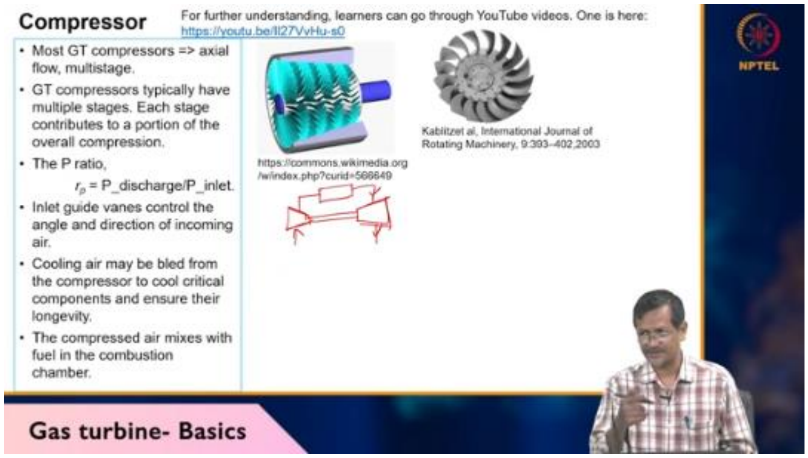
compressor system gas generator means compressor system gas turbines are less complex than reciprocating engines because it is having only one shaft okay one shaft compressor is here turbine is here so compressor compressing turbine rotating so it is giving directly power so there is no other moving element only this one shaft connected your compressor system and turbine system rotating so it is very simple system actually okay So, gas turbines are less complex than reciprocating system. Basically, on the center shaft is rotating part. Center shaft is only rotating. But in reciprocating system, you can remember when piston is moving up and down.

your crank is moving connecting rod is moving then your fuel injection system they will have continuous jerk flow the continuous fluid you cannot give inside even a valve also will be opening closing so lots of moving element is there any mechanical system when moving element is more life and reliability will be lower it will be requiring more maintenance when there is no moving element or very limited your life will be longer okay So gas turbines are less complex than reciprocating engine because it is not having continuous opening closing valves or cam mechanism to move up and down or crank or gaussian pin or piston nothing is there right. Other small moving parts are in the fuel system. So fuel system will have some small moving part but that is also not major thing. Advantage of gas turbine is the power to weight ratio.

So it will give you more power for same weight. thrust journal bearing ok so it will have several bearings later we will discuss different types of bearings and journals ok so that I may not cover in this week but I will be considering this thrust bearing journal bearing later when I will be discussing about power transmission system from engine to propeller so gas turbine engine I already told compressors must again I am drawing in certain way so you should not draw in opposite way or you should not do any mistake otherwise I may not give you marks ok So, compressor means volume reducing that is why this is converging nozzle, converging type shape and turbine diverging type shape because volume increasing. And this same diagram actually you have drawn for your steam turbine also. There steam was expanding, here your burn gas expanding.

So, here you are not using water. Here direct whatever burn gas you are getting the same gas is running your turbine. So, very high temperature is there. But in steam turbine you produce steam you took water to produce steam that steam was running turbine where here I am not using any water. My burn gas directly hitting turbine blades and turbine blade is getting energy.

so most gas turbine compressor axial flow multi-stage already you have seen so here one picture i have taken it is there in wikipedia also how this turbine blade will be there one rotor blade one steel blade rotor blade stabilizer this way it will be rotating now gas turbine compressors typically have multiple stages each stage contributes to a portion of the overall compression rate compression so in pump system also you have seen that each stage will be developing certain amount of pressure certain amount of pressure certain amount of pressure in pump we said head but here we say directly pressure So how much pressure is increasing? So one stage may be one bar. Again one bar, one bar. So multiply it.



So that way multiple stage will be helping. Pressure ratio. Here I am writing P ratio means pressure ratio actually. So, the pressure ratio is P discharge divided by P inlet. So, outside pressure here P discharge may be P discharge P inlet.

So, this ratio is called pressure ratio. So, how much pressure ratio required based on this formula you can calculate. Inlet guide vane controls the angle of direction incoming air. So, whenever you are talking about multiple stages in maybe in compressor turbine. So, let us say one stage will have some air foil.

Airfoil will be getting fluid. It will be diverting. Then again you need another airfoil to redirect the fluid to another blade. So there will be one blade system called guide vane or stator blade. So guide vane or stator blade purpose will be to direct the flow to next blade.

So I will discuss later about this one in details. And cooling air may be blade from the compressor to cool component ensure their longevity. So cooling air also will be required to cool systems. Let us say gas turbine combustor also was getting 70% air. right and some cooling air will be required for turbine blade cooling later we'll discuss how to cool turbine blade because combustion the burnt product will have temperature more than melting point of the blade but still blade should be surviving so how to survive that blade within more than melting point environment okay so we'll discuss later the compressed air mixes with fuel in the combustion chamber okay it's obvious

So flow through stages how it is working. So let us say first stage turbine blade is here. Many turbine blades are there. For example this one, two, three, four many blades are there. So and fluid is coming here, fluid is here, fluid is here.

You can see this airfoil. Actually, these blades are actually airfoil. These rotating blades are there. These are actually airfoil cross section will be there. So, one airfoil from top if you see like this, it will be like this, each blade.

So, here also these blades will have this type of some shape will be there. It is not looking like any airfoil shape, but normally there will be airfoil shape. When airfoil shape is there, let us say air is coming from here. air will be getting diverted it will get proper angle again this is just a stator rotor blade stator blade ok so what is happening stator blade will be diverting fluid so that rotor blade will get proper angle so you can remember the angle of attack so any airfoil if it is not getting proper angle of attack let's say this is your chord line and fluid direction is here so this is called angle of attack so all the airfoil should get proper angle of attack if angle of attack is very low it will not get any power if angle of attack is very high again it will not get power so it should have an optimal angle of attack for any airfoil

you can remember the lift so blade will get lift if you have proper angle of attack it is 10 to 15 degree about angle of attack would be there but in any case a fluid direction changes an angle at angle of attack become 50 degrees 600 degree so in that case blade will not get proper angle of attack so it will not give proper force to the blade okay so that's why let's say one airfoil is here For example, I have one airfoil like this. So airfoil, fluid is hitting this angle perfectly fine. But if fluid is hitting in this angle or this angle, so it will not get proper power.

what you have to do? you have to give another level of airfoil here. So that will be directing fluid towards this with proper angle. So here also you can see my stator blade is giving actually the direction that task they are doing. It will be in proper direction so that my rotor blade which is harnessing power.

So rotor blade is harnessing power. So turbine blade will be like one rotor is there. One blade, two blade, three blade, four blade, five blade, 36 blade will be there. 36, 35, many number of blades possible for different types of turbine. So stator blade will be giving angle only.

It will not be harnessing any energy. So it is fixed blade. It is directing fluid. now i will have here rotor blade so rotor blade will be harnessing energy so rotor blade must get that proper angle so stator blade purpose to give proper angle not to harness any energy not to do anything okay then my rotor blade will be harnessing energy so it must get proper angle after exiting from rotor blade again fluid will be diverting here and there so so again i will have one another level of stator blade it will be redirecting with next stage turbine blade one stator, rotor, stator, rotor, stator, rotor that assembly will be there.

So one stator, one rotor is called one stage. So one rotor, one stator is called one stage. here I can see here rotating. this is one stage. This is rotating and unrotating part actually here.

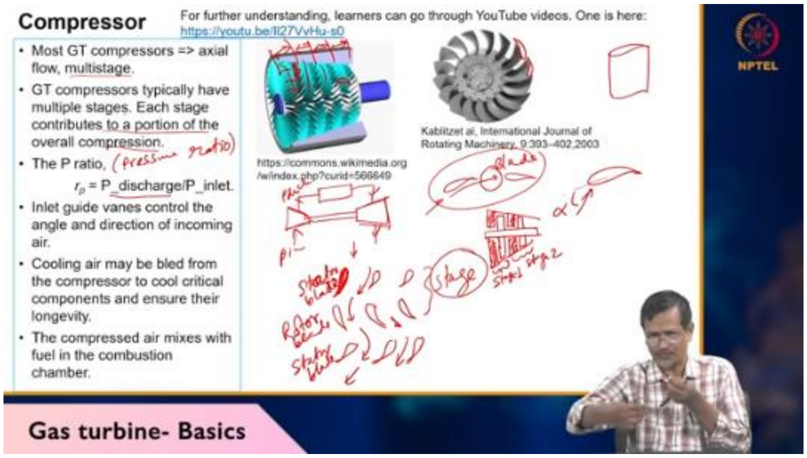
I cannot see here. So, here rotating, unrotating, so two stage, so three stage, four stage. I have four stages actually, this rotating part you can see. one rotating, one unrotating or static or not rotating part. together call stage.

stator will not harness any energy, it will direct fluid to give proper angle for rotor blade. After rotor blade fluid will be diverted here and there. Again stator will say hey fluid be in proper direction. Then rotor will be harnessing again. Again rotor will be harnessing.

rotor will be connected on one common shaft. and what will get total power okay so compressor or turbine whatever you say same mechanism actually rotor rotor stator rotor stator rotor stator rotor stator stage one stage two stage three stage four so all together total power how much gate we are getting we can calculate and again ah in compressor first stage rotor height will be higher because first stage compressing little bit again little bit lower little bit lower little bit lower little bit lower because compression happening every time right So, that is why you can see my compressor I am drawing here like gradually decreasing because compression is happening. In turbine, what is happening? Initially, you get a very high pressure gas.

You stage one, little bit expanded, expanded, expanded, expanded. When it is expanding, it is giving some energy to rotor, not stator. My stator will not harness any energy. You say, okay, you take fluid. I am guiding you.

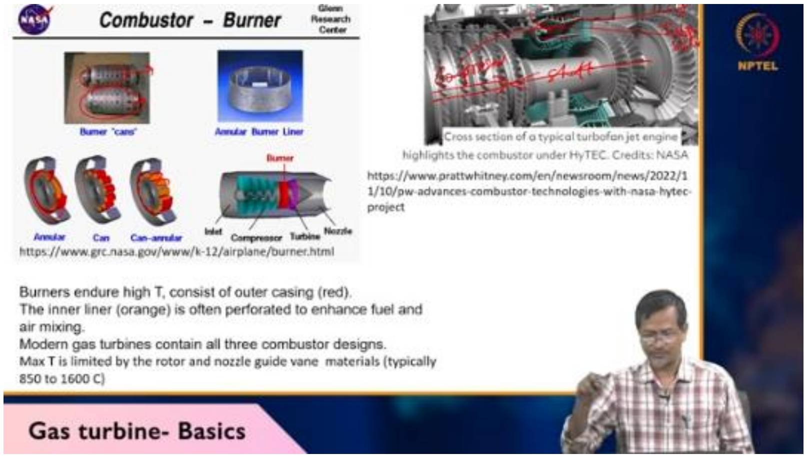
rotor will take energy fine so then one stage means one rotor and stator and stator blade guiding rotor blade harnessing energy fine okay now one more thing i have to explain here that compressor if i draw properly actually it will be like looking like this my casing is here my compressor not like this it will be like this compressing so let's say one stator rotor stator is here rotor is here again stator is here rotor is here okay so one stage gradually you can see stator is connected to my casing so that stator will not be rotating with shaft so this stator I am shedding only just you can see the stator is connected to your casing part outer casing that is not rotating rotor is connected on shaft so rotor when it is getting force from fluid it will be rotating my shaft So, that means my stator is not giving any power. It is just fixed.



So, this way you can see this compression happening and my dimension also going down. Next is combustor. I told that after compression the gas or air, compressed air will go to combustor. So, combustor or combustion chamber. So, different types of combustion chambers will be there.

Like here one picture right side top corner you see this combustion chamber actually here they will get fuel air mixture and air will be entering okay combustion will be happening from there it the turbine blade this is a turbine blade okay this is a compressor this is shaft okay so compressor Air will be entering to combustion chamber, burning will be happening, then it will go to turbine and compressor will get power from shaft from turbine directly. So, just I have copied from Pratt Whitney, actually the compressor manufacturer company, big company actually. So, from their website. And left side you see this NASA webs from NASA website I have taken different types of combustor section because that combustion will be controlled combustion.

You cannot give random combustion here one spot very high temperature another spot very low temperature it must be ok. combustor will be giving uniform flow with uniform heating uniform pressure so that's why they'll be putting like can combustor or annular combustion or ring type combustor will be there can means like small small things are there you can see this small small cans so combustion will be happening one two so many cans will be there all around the shaft okay in annular if you see then one continuous combustor will be there so that will be delivering high pressure fluid to your turbine high pressure fluid means combustible burnt gas flue gas in boiler case actually flue gas was going out we are not using actually for turbine running purpose we are using the heat that's fine but in this case the same flue gas we are using for running turbine directly No water is there. So, burners endure high temperature.



Consideration of outer casing. Outer casing is here. Outer casing. And it will be facing very high temperature. This combustion is happening here only.

So, modern gas turbine contains three combustion design. Maximum temperature limited by the rotor and nozzle guide vane material. Typically 850 to 1600 degree centigrade. So normally steel and other material temperature melting point will be 1200 around but you are getting combustion temperature 1600 that means you must have some cooling arrangement otherwise heat will be accumulated and your system will be melted. Things will not work.