Aircraft Propulsion

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Lecture 05

Aircraft engines

Welcome to class till time we have seen that there are different types of arrangements for a gas turbine based power plant. And then we have seen that there are different attachments also for a gas turbine based power plant. Now we are going to see in the today's class what are the different ways by which aircraft's performance can be measured? And what are the different types of aircraft engines.

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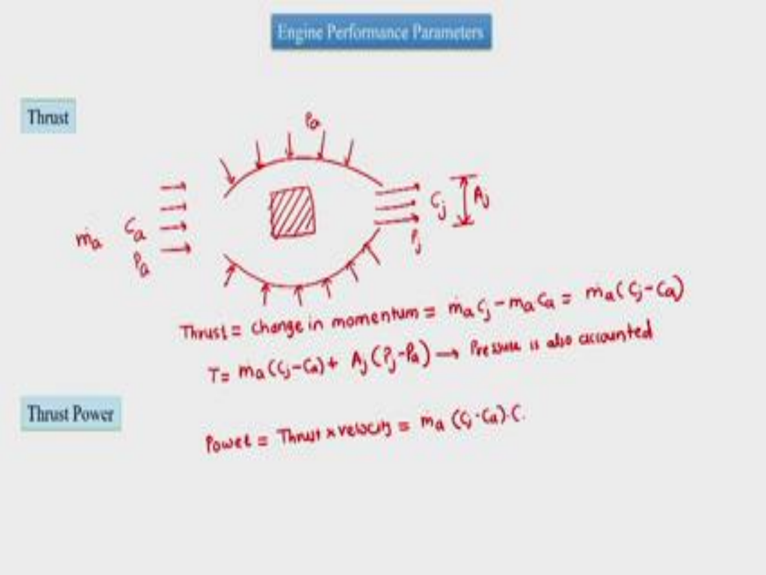

Engine Performance Parameters

Thrust

Thrust = change in momentum = $\dot{m}_a C_j - \dot{m}_a C_a = \dot{m}_a (C_j - C_a)$

$T = \dot{m}_a (C_j - C_a) + A_j (P_j - P_a) \rightarrow$ Pressure is also accounted

Thrust Power

Power = Thrust x velocity = $\dot{m}_a (C_j - C_a) \cdot C$.

So, let us start with the today's class so engine performance parameter first is thrust. So, let us consider that we are having an aircraft let us draw a schematic of an aircraft engine. And this is an aircraft engine where we are considering it as a control volume or practically a black box where there is some air which is coming with velocity C a and then there is jet which is going out with velocity C_j and the area of the jet is A_j.

Further the atmospheric pressure which is acted upon the aircraft or which is present in the ambience of the aircraft from which it is breathing the air is P_a. And the jet pressure at the exit is P_j, so having said this as the operating condition of an aircraft engine we can write thrust of the engine is equal to change in momentum. So, thrust of the engine

$$Thrust = Change\ in\ momentum = \dot{m}_a C_j - \dot{m}_a C_a = \dot{m}_a\left(C_j - C_a\right)$$

So this is the thrust produced by the engine. Further we are assuming here that the pressure acting on the exit of the jet is almost equal to atmospheric pressure or this is almost a static thrust. However if we consider the pressure component of the thrust then we get the formula for thrust also having pressure which is

$$T = \dot{m}_a\left(C_j - C_a\right) + A_j\left(P_j - P_a\right)$$

Pressure is also accounted thus this is the formula for thrust. Now let us find out what is the thrust power. So, the thrust power is

$$Power = Thrust \times Velocity = \dot{m}_a\left(C_j - C_a\right).C_a$$

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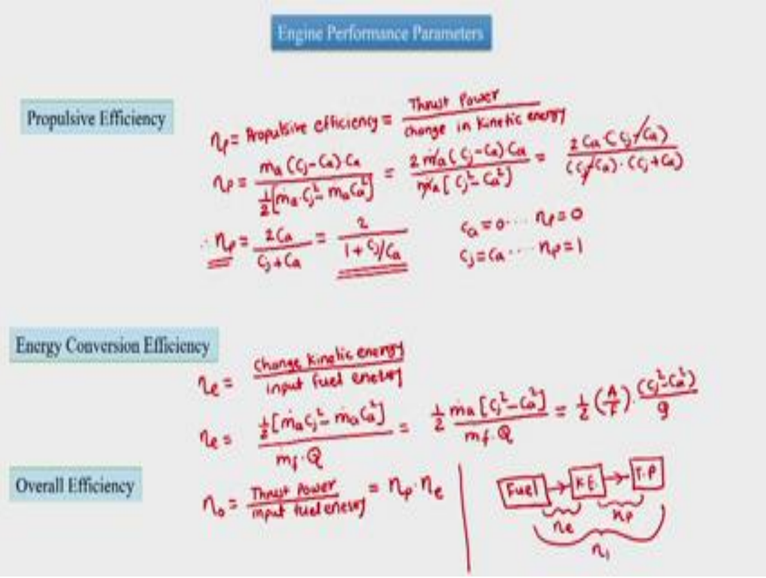

Engine Performance Parameters

Propulsive Efficiency

$$\eta_p = \text{Propulsive efficiency} = \frac{\text{Thrust Power}}{\text{change in Kinetic energy}}$$

$$\eta_p = \frac{\dot{m}_a(C_j-C_a)\cdot C_a}{\frac{1}{2}[\dot{m}_a\cdot C_j^2 - \dot{m}_a C_a^2]} = \frac{2\cancel{\dot{m}_a}(C_j-C_a)C_a}{\cancel{\dot{m}_a}[C_j^2-C_a^2]} = \frac{2C_a\cancel{(C_j-C_a)}}{\cancel{(C_j-C_a)}\cdot(C_j+C_a)}$$

$$\therefore \eta_p = \frac{2C_a}{C_j+C_a} = \frac{2}{1+C_j/C_a}$$

$C_a = 0 \cdots \eta_p = 0$

$C_j = C_a \cdots \eta_p = 1$

Energy Conversion Efficiency

$$\eta_e = \frac{\text{Change Kinetic energy}}{\text{input fuel energy}}$$

$$\eta_e = \frac{\frac{1}{2}[\dot{m}_a C_j^2 - \dot{m}_a C_a^2]}{\dot{m}_f\cdot Q} = \frac{1}{2}\frac{\dot{m}_a[C_j^2-C_a^2]}{\dot{m}_f\cdot Q} = \frac{1}{2}\left(\frac{A}{F}\right)\cdot\frac{(C_j^2-C_a^2)}{Q}$$

Overall Efficiency

$$\eta_o = \frac{\text{Thrust Power}}{\text{input fuel energy}} = \eta_p\cdot\eta_e$$

Fuel → K.E → T.P

η_e η_p

η_o

Now let us move on and find out what is the propulsive efficiency of an aircraft. So, here we have to first define what do we mean by propulsive efficiency. So,

$$\eta_P = propulsive\ efficiency = \frac{Thrust\ power}{Change\ in\ Kinetic\ energy}$$

$$\eta_P = \frac{\dot{m}_a\left(C_j - C_a\right).C_a}{\frac{1}{2}\left[\dot{m}_a.C_j^2 - \dot{m}_a.C_a^2\right]} = \frac{2C_a.\left(C_j - C_a\right)}{\left(C_j - C_a\right)\left(C_j + C_a\right)} = \frac{2C_a}{C_j + C_a} = \frac{2}{1 + \frac{C_j}{C_a}}$$

$$C_a = 0 \ldots \eta_P = 0$$

$$C_j = C_a \ldots \eta_P = 1$$

So, this is the definition of propulsive efficiency of an aircraft. Propulsive efficiency is one of the performance parameters of the aircraft engine. Next performance parameter of the aircraft engine is energy conversion efficiency. Let us define energy conversion efficiency

$$\eta_e = \frac{change\ in\ kinetic\ energy}{Input\ fuel\ energy}$$

$$\eta_e = \frac{\frac{1}{2}\left[\dot{m}_a C_j^2 - \dot{m}_a C_a^2\right]}{\dot{m}_f . Q} = \frac{\frac{1}{2}\dot{m}_a\left[C_j^2 - C_a^2\right]}{\dot{m}_f . Q} = \frac{1}{2}\left(\frac{A}{F}\right)\frac{\left(C_j^2 - C_a^2\right)}{Q}$$

So, this is the formula for energy conversion efficiency of an engine. So, this is second performance parameter rather in terms of efficiency of an engine. Now we will define a new parameter as overall efficiency of the engine and overall efficiency is

$$\eta_o = \frac{Thrust\ power}{Input\ fuel\ energy} = \eta_P . \eta_e$$

So, in all we are faced feeling that there is fuel which has chemical energy in it and this fuel's chemical energy is used to convert the kinetic energy of the air and this kinetic energy gives thrust power. So, there is an efficiency which is between thrust power and kinetic energy that we are calling it as propulsive efficiency. There is an efficiency between fuel energy and kinetic energy that we are calling it as energy conversion efficiency.

And then there is overall efficiency which is between thrust power and fuel energy. So, these are the three efficiencies which are related with the performance of the engine.

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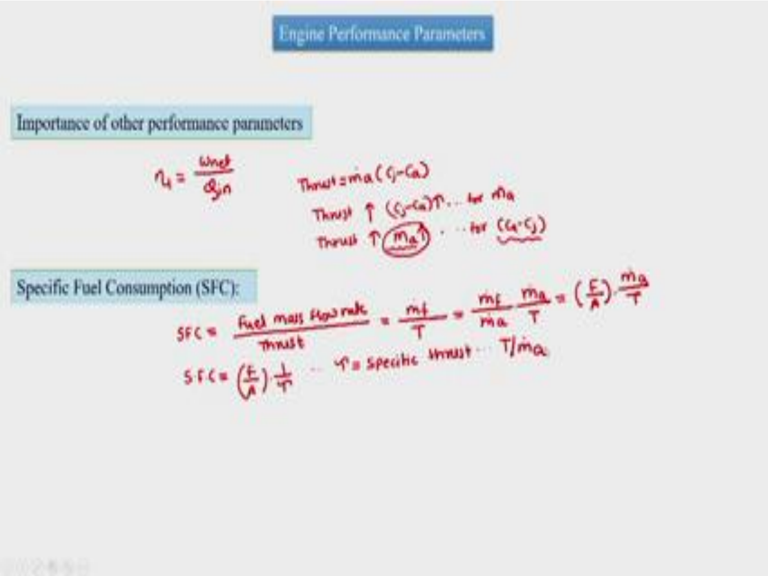

Engine Performance Parameters

Importance of other performance parameters

$\eta_t = \frac{W_{net}}{Q_{in}}$

$\text{Thrust} = \dot{m}_a (C_j - C_a)$

$\text{Thrust} \uparrow (C_j - C_a)\uparrow \ldots \text{for } \dot{m}_a$

$\text{Thrust} \uparrow \boxed{\dot{m}_a \uparrow} \ldots \text{for } \underline{(C_a - C_j)}$

Specific Fuel Consumption (SFC):

$SFC = \frac{\text{Fuel mass flow rate}}{\text{Thrust}} = \frac{\dot{m}_f}{T} = \frac{\dot{m}_f}{\dot{m}_a} \cdot \frac{\dot{m}_a}{T} = \left(\frac{F}{A}\right) \cdot \frac{\dot{m}_a}{T}$

$SFC = \left(\frac{F}{A}\right) \cdot \frac{1}{\psi} \ldots \psi = \text{specific thrust} \ldots T/\dot{m}_a$

However we can we should note here that the only thermal efficiency of the gas turbine power plant should not be thought for the best performance parameter. We have seen that there is thermal efficiency of the engine and which was the $\frac{W_{net}}{Q_{in}}$ and this should not be thought as the best performance parameter for the engine. Since there are various requirements for designing a given aircraft engine so there is a requirement something like static thrust or thrust at the sea level where we encounter maximum temperature in the engine.

Further there is requirement for the takeoff kind situations. So, in such cases we get different performance parameters and those performance parameters should also be having equal weightage while designing the aircraft engine from the thrust equation we can see one more thing that we say that thrust is equal to $\dot{m}_a(C_j - C_a)$ here we can see that thrust of an engine can be increased by changing the velocity more this is one way to increase the thrust if $(C_j - C_a)$ is high for given m dot a this is one way where we are handling small amount of mass and increasing large velocity change.

And bringing in large velocity change this is one way to increase the thrust and other way to increase the thrust is to increase the mass flow rate for small or given velocity change. So, here we are handling more amount of mass but having small change in velocity change small change in velocity. So, these two are the basic ways by which we can get different thrusts or we can increase the thrust and based upon this concept we have different types of aircrafts.

So as what we have seen this also becomes one of the parameters for designing an aircraft. Basically we might need to handle more amount of mass of air something like if we are travelling at lower altitudes we will handle more amount of mass of air as it is handled by the turboprop engines or the piston prop engines they handle more amount of mass but they do not begin more amount of change in velocity.

So, but if we consider turbojet like engines they handle less amount of mass comparatively but they bring in large change in velocity so only thermal efficiency should not be thought as a basic parameter. Further at cruise speed or at level flight then at that time economy becomes more important and all such parameters should be considered. Then in one such parameter is thrust specific fuel consumption. So, SFC is defined as

$$\text{SFC} = \frac{Fuel\ mass\ flow\ rate}{Thrust} = \frac{\dot{m}_f}{T} = \frac{\dot{m}_f}{\dot{m}_a}.\frac{\dot{m}_a}{T} = \left(\frac{F}{A}\right)\frac{\dot{m}_a}{T}$$

$$SFC = \left(\frac{F}{A}\right).\frac{1}{\tau}$$

$$\tau \rightarrow Specific\ thrust = \frac{T}{\dot{m}_a}$$

So, here we can use this thrust specific fuel consumption to compare between two engines which are operating at two different conditions.

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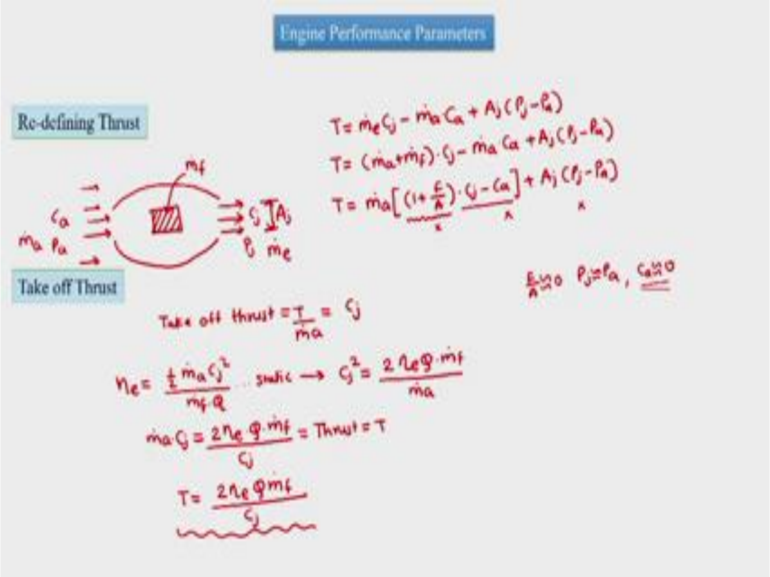
Engine Performance Parameters

Re-defining Thrust

$$T = \dot{m}_e C_j - \dot{m}_a C_a + A_j(P_j - P_a)$$

$$T = (\dot{m}_a + \dot{m}_f)\cdot C_j - \dot{m}_a C_a + A_j(P_j - P_a)$$

$$T = \dot{m}_a\left[\left(1+\frac{f}{A}\right)\cdot C_j - C_a\right] + A_j(P_j - P_a)$$

$$\frac{f}{A} \approx 0 \quad P_j \approx P_a, \quad C_a \approx 0$$

Take off Thrust

$$\text{Take off thrust} = \frac{T}{\dot{m}_a} = C_j$$

$$\eta_e = \frac{\frac{1}{2}\dot{m}_a C_j^2}{\dot{m}_f \cdot Q} \quad \text{static} \rightarrow C_j^2 = \frac{2\eta_e Q \cdot \dot{m}_f}{\dot{m}_a}$$

$$\dot{m}_a \cdot C_j = \frac{2\eta_e Q \cdot \dot{m}_f}{C_j} = \text{Thrust} = T$$

$$T = \frac{2\eta_e Q \dot{m}_f}{C_j}$$

Then let us consider our aircraft engine where we are redefining thrust we neglected few terms and we will redefine the thrust by considering the terms which we did not account. So, this is an aircraft engine we are seeing that air is coming with C_a velocity going with C_j velocity and then jet area is A_j and then we have $\dot{m}_a$ as mass of air but while leaving we have added $\dot{m}_f$ amount of fuel.

So $\dot{m}_e$ is exit mass flow-rate having said this we can really find the thrust

$$T = \dot{m}_e C_j - \dot{m}_a C_a + A_j\left(P_j - P_a\right)$$

$$T = \left(\dot{m}_a + \dot{m}_f\right)C_j - \dot{m}_a C_a + A_j\left(P_j - P_a\right)$$

$$T = \dot{m}_a\left[\left(1 + \frac{F}{A}\right).C_j - C_a\right] + A_j\left(P_j - P_a\right)$$

So what did we derive in earlier case a we said in earlier case was only $\left(C_j - C_a\right)$ we had not accounted this term which basically accounts air fuel ratio. Here our assumption was that air fuel ratio is negligible. So, when we accounted air fuel ratio the formula got changed to $\dot{m}_a\left[\left(1 + \frac{F}{A}\right).C_j - C_a\right]$+ pressure component of the thrust.

Now let us use this formula for finding out takeoff thrust where we are again going to discard some more terms. So, takeoff thrust is also called as static thrust and in that thrust is actually obtained at very low speeds or at the static condition of the engine and then that thrust is

$$Take\ off\ thrust = \frac{T}{\dot{m}_a} = C_j$$

$$\left(\frac{F}{A}\right) \approx 0; P_j \approx P_a; C_a \approx 0$$

So let us use the energy conversion efficiency and understand this further. So, energy conversion efficiency is

$$\eta_e = \frac{\frac{1}{2}\dot{m}_a C_j^2}{\dot{m}_f Q} \ldots static \rightarrow C_j = \frac{2\eta_e Q.\dot{m}_f}{\dot{m}_a}$$

$$\dot{m}_a . C_j = \frac{2\eta_e Q \dot{m}_f}{C_j} = Thrust = T$$

$$T = \frac{2\eta_e Q \dot{m}_f}{C_j}$$

So, from this formula it is evident that for given energy conversion efficiency and fuel used and further mass flow rate of fuel thrust is inversely proportional to the jet velocity. Thus it means that if we handle more amount of mass and have a smaller velocity jet then we can have more amount of static thrust. So, this is one of the performance parameters of the aircraft.

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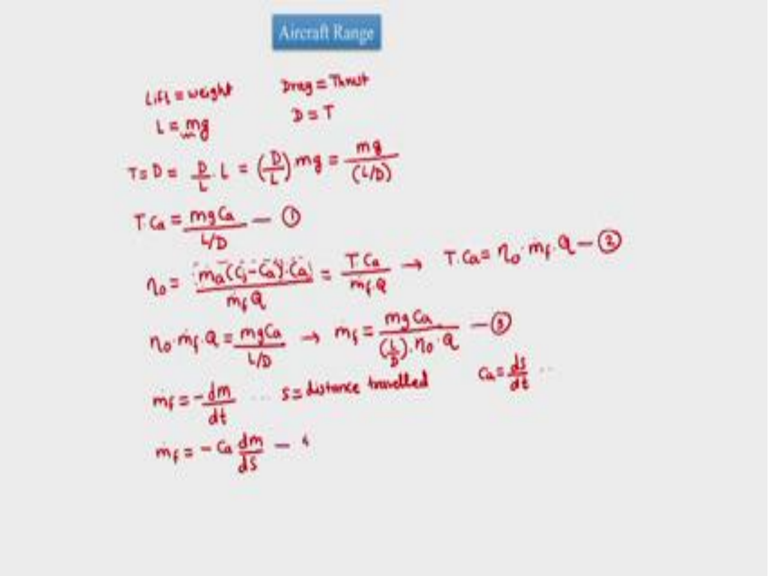

Aircraft Range

Lift = weight   Drag = Thrust

$L = mg$ $D = T$

$T = D = \frac{D}{L}\cdot L = \left(\frac{D}{L}\right)mg = \frac{mg}{(L/D)}$

$T\cdot C_a = \frac{mgC_a}{L/D}$ — ①

$\eta_o = \frac{\dot{m}_a(C_j - C_a)\cdot C_a}{\dot{m}_f Q} = \frac{T C_a}{\dot{m}_f\cdot Q} \rightarrow T\cdot C_a = \eta_o \cdot \dot{m}_f \cdot Q$ — ②

$\eta_o \cdot \dot{m}_f \cdot Q = \frac{mgC_a}{L/D} \rightarrow \dot{m}_f = \frac{mgC_a}{\left(\frac{L}{D}\right)\cdot \eta_o \cdot Q}$ — ③

$\dot{m}_f = -\frac{dm}{dt}$ s = distance travelled $C_a = \frac{ds}{dt}$

$\dot{m}_f = -C_a\frac{dm}{ds}$ — 4

So next parameter what we can see is called as aircraft range. So, when we are considering range we are meaning that there is certain amount of fuel in the aircraft and that aircraft is travelling from a place to the other and for a given amount of fuel the distance travelled by the aircraft this is what we mean by saying a range of the aircraft. So, a range of the aircraft we are targeting the cruise condition or level flight and for the level flight there are two things one is lift is equal to weight.

$$Lift = weight\,;\;\; Drag\; = \;Thrust$$

$$L = mg; D = T$$

$$T = D = \frac{D}{L}L = \left(\frac{D}{L}\right).mg = \frac{mg}{\left(\frac{L}{D}\right)}$$

$$T.C_a = \frac{mgC_a}{\frac{L}{D}} \ldots (1)$$

$$\eta_0 = \frac{\dot{m}_a(C_j - C_a).C_a}{\dot{m}_f Q} = \frac{TC_a}{\dot{m}_f Q} \rightarrow T.C_a = \eta_o.\dot{m}_f Q \ldots (2)$$

$$\eta_o.\dot{m}_f Q = \frac{mgC_a}{\frac{L}{D}} \rightarrow \dot{m}_f = \frac{mgC_a}{\left(\frac{L}{D}\right)\eta_o Q} \ldots (3)$$

So this is the formula for mass flow rate of the fuel but what we mean by mass flow rate of a fuel so that is what it is getting consumed and so $\dot{m}_f = -\frac{dm}{dt}$ where m is the total mass of the aircraft. As we have used it for the formula for lift. So, total mass of the aircraft is changing with respect to time and that is due to the consumption of fuel.

Further we are interested in finding out range let s be the distance travelled in the direction of velocity and then

$$C_a = \frac{ds}{dt}$$

$$\dot{m}_f = -C_a\frac{dm}{ds} \ldots (4)$$

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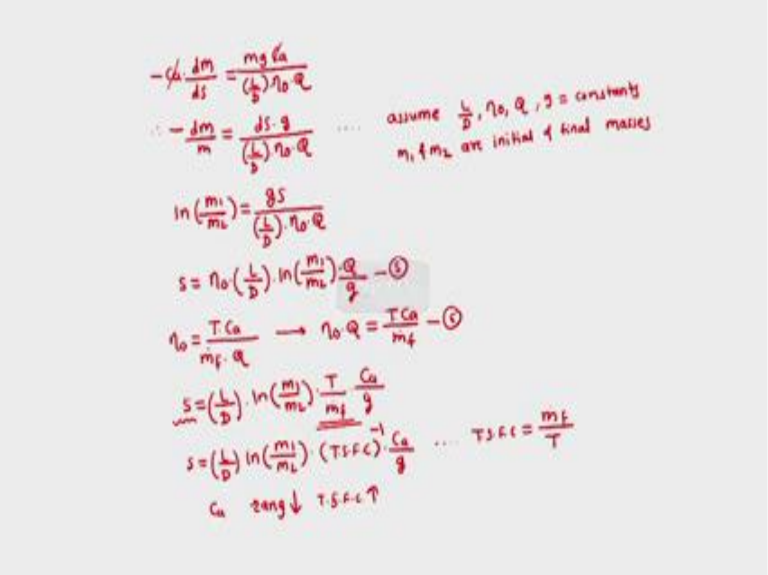

$$-\cancel{C_a}\frac{dm}{ds} = \frac{mg\cancel{C_a}}{\left(\frac{L}{D}\right)\eta_0 Q}$$

$$-\frac{dm}{m} = \frac{ds \cdot g}{\left(\frac{L}{D}\right)\eta_0 Q}$$

… assume $\frac{L}{D}, \eta_0, Q, g$ = constants

m_1 & m_2 are initial & final masses

$$\ln\left(\frac{m_1}{m_2}\right) = \frac{gs}{\left(\frac{L}{D}\right)\cdot\eta_0\cdot Q}$$

$$s = \eta_0\left(\frac{L}{D}\right)\cdot\ln\left(\frac{m_1}{m_2}\right)\cdot\frac{Q}{g}$$ – ⑤

$$\eta_0 = \frac{T.C_a}{\dot{m}_f \cdot Q} \longrightarrow \eta_0 \cdot Q = \frac{TC_a}{\dot{m}_f}$$ – ⑥

$$\underset{\sim}{s} = \left(\frac{L}{D}\right)\cdot\ln\left(\frac{m_1}{m_2}\right)\cdot\frac{T}{\underline{\dot{m}_f}}\cdot\frac{C_a}{g}$$

$$s = \left(\frac{L}{D}\right)\ln\left(\frac{m_1}{m_2}\right)\cdot(TSFC)^{-1}\cdot\frac{C_a}{g}$$ … $TSFC = \frac{\dot{m}_f}{T}$

C_a rang ↓ T.S.F.C ↑

$$-C_a \frac{dm}{ds} = \frac{mgC_a}{\left(\frac{L}{D}\right)\eta_o Q}$$

$$-\frac{dm}{m} = \frac{dS.g}{\left(\frac{L}{D}\right)\eta_o Q}$$

Assume $\frac{L}{D}, \eta_o, Q, g$ as constants. m_1 *and* m_2 are initial and final masses.

$$\ln\left(\frac{m_1}{m_2}\right) = \frac{gS}{\left(\frac{L}{D}\right)\eta_o Q}$$

$$S = \eta_0 \left(\frac{L}{D}\right) \ln\left(\frac{m_1}{m_2}\right) \frac{Q}{g} \ldots (5)$$

$$\eta_o = \frac{T.C_a}{\dot{m}_f Q} \rightarrow \eta_o.Q = \frac{T.C_a}{\dot{m}_f} \ldots (6)$$

$$S = \left(\frac{L}{D}\right).\ln\left(\frac{m_1}{m_2}\right).\frac{T}{m_f}.\frac{C_a}{g}$$

$$S = \left(\frac{L}{D}\right).\ln\left(\frac{m_1}{m_2}\right)(TSFC)^{-1}\frac{C_a}{g};\ \left(\frac{L}{D}\right).\ln\left(\frac{m_1}{m_2}\right); TSFC = \frac{\dot{m}_f}{T}$$

So, it is evident from this formula that for a given speed of the aircraft range decreases if thrust specific fuel consumption increases. So, range of the aircraft is inversely proportional to the thrust specific fuel consumption. So, we have seen that there are different parameters like overall efficiency energy conversion efficiency thrust.

Thrust power then we have overall efficiency we have specific fuel consumption we are range of the aircraft has different parameters which are deciding the performance of an engine based upon that there are different engines which we are going to see the aircraft engines.

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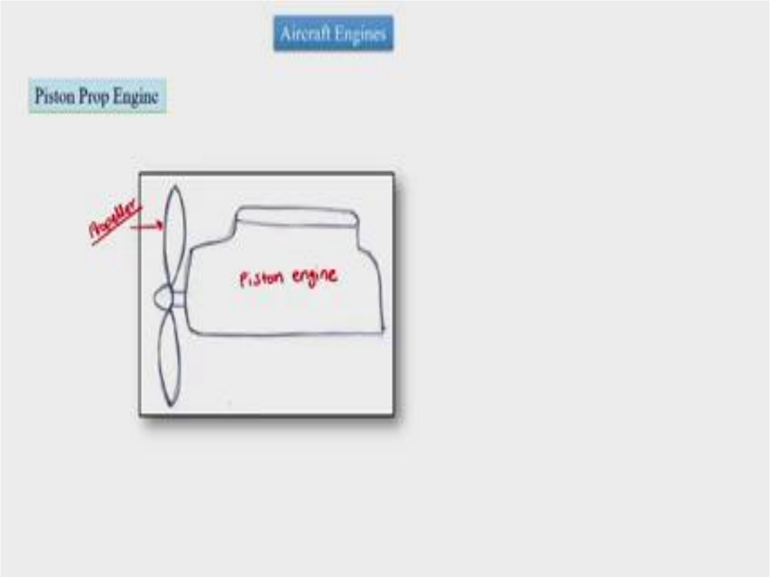

Aircraft Engines

Piston Prop Engine

First is the turbo prop engine where we have first is piston prop engine where this engine has the piston engine which is our automobile engine and this automobile engine is connected with a propeller and the motion of the propeller would be governed by the engine and then we have basically thrust generated due to the motion of the propeller so this engine is piston prop engine basically here we are not having any jet to produce the thrust.

Here thrust is produced from the propeller this engine is more suitable for lower altitudes and at lower speeds. Further this engine also cannot be used for high thrust application since those thrust conditions the weight of the piston increases and this engine also cannot handle large amount of mass flow rate as what we have seen while differentiating between the reciprocating engines and the aircraft engines based upon the turbo applications.

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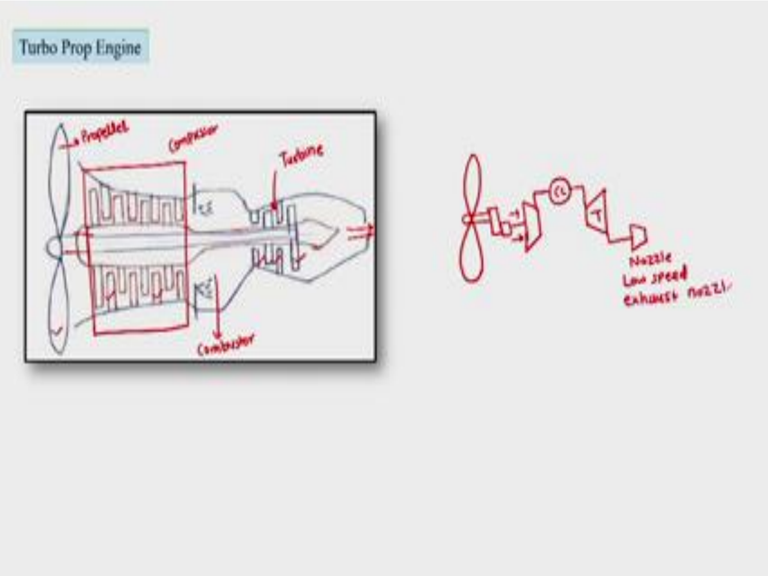

Turbo Prop Engine

So second is turbo prop engines so in the turboprop engine we have major thrust coming from the propeller and this propeller is rotated by the turbine we can see here the typical arrangement as what we had seen earlier and then that arrangement was triple spool arrangement. And in the triple spool arrangement we are seen that propeller will be connected by lowest speed turbine compressor low pressure compressor will be connected by the intermediate turbine.

And high pressure compressor will be connected by high pressure turbine. So, here we are having propeller and then this unit is the compressor and then this is combustor and then this is turbine. So, most of the energy extracted from the fuel and the flow is used to rotate the propeller and rest is passed through the nozzle. So, there is partially small amount of thrust generated from the nozzle as well. So, turboprop engine gets major thrust from the propeller and this engine also gets used at the low speed applications and lower altitudes.

The problem at high speed applications is for the propulsive efficiency of the aircraft further the noise of the propeller becomes an issue and it needs to have a special design of the propeller. So, turboprop engines are not generally used for high speed applications basically if we see the schematic of this aircraft is as what we could draw this is the propeller and this propeller is connected with a gearbox to a compressor to a compressor.

And then air goes parallel into the compressor then there will be combustion chamber and then after the combustion chamber then there will be turbine and an air would be passed from the turbine to the nozzle. And in this nozzle is low speed exhaust nozzle. So, this is typical schematic of a turboprop engine.

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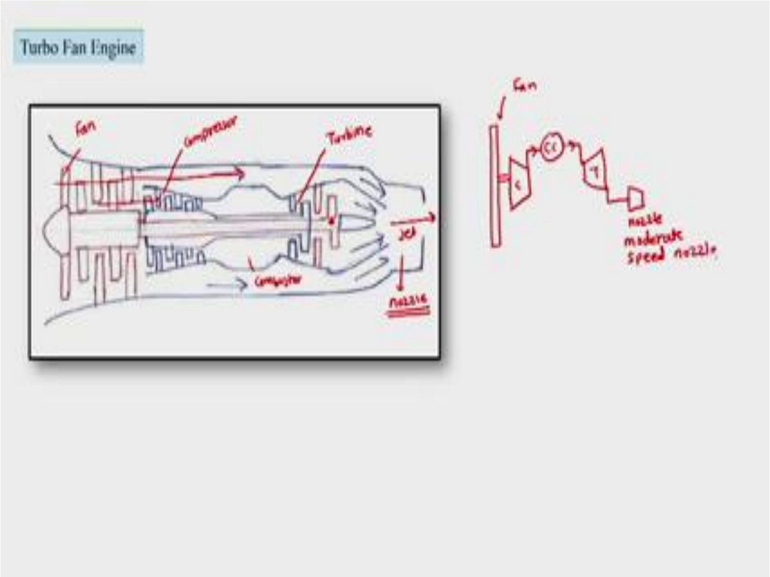
Turbo Fan Engine

So, next is turbofan engine and in the turbofan engine we have fan which is connected with the low-speed turbine this is fan and then there will be some air which is going from the fan and getting compressed further and then it is following a route which is called as cold path and then that is generating a thrust which is called as cold thrust. But some air will go from the fan into the compressor.

So, this is compressor after the compressor it will go into the combustor and then it will go over the turbine. So, this being a turbofan so some part of the thrust will be from the fan and rest of the thrust will be from the jet so that is from the nozzle. So, this aircraft is basically having advantage of having lower noise due to presence of fan. So, here we can draw schematic of the aircraft like this so this is fan and this fan is practically connected with a compressor.

And then this compressor is passing the air to the combustion chamber and from the combustion chamber air will go to the turbine and after the turbine it will go to the nozzle. This is moderate speed nozzle. This engine is generally used at moderate altitudes and moderately high speeds.

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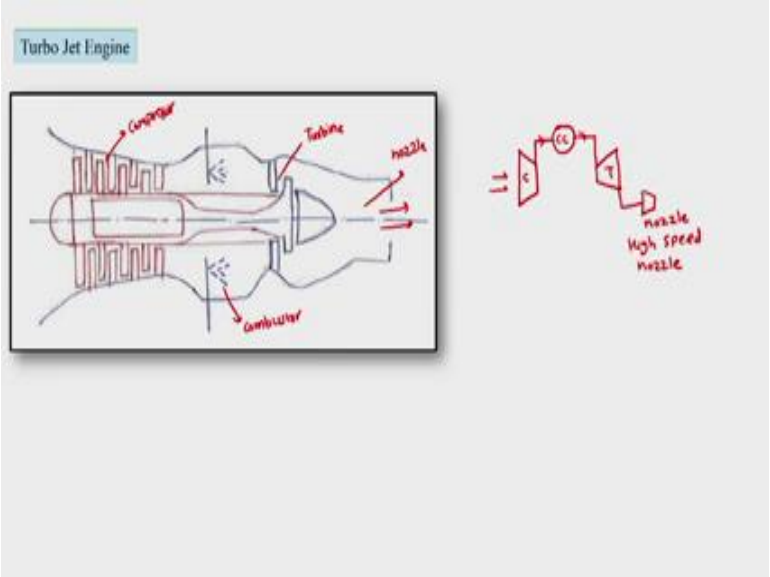

Then we have turbo jet engine turbo jet engine has complete thrust based upon the jet and this has components like compressor and then it has combustor. And it has turbine and nozzle, so there is no propeller there is no fan. So, complete thrust is generated using the jet and so this is a turbojet engine and here this engine is generally used for high altitude and also at very large speed applications. And then we can draw simplest schematic of this engine where we have compressor which will take air and it will pass to the combustion chamber.

And then it will pass to the turbine after the turbine it will go into the nozzle where we have this as high speed nozzle. Practically turbojet engines can operate at supersonic speeds. So, this engine would have nozzle which would lead to have a jet which is a supersonic jet.

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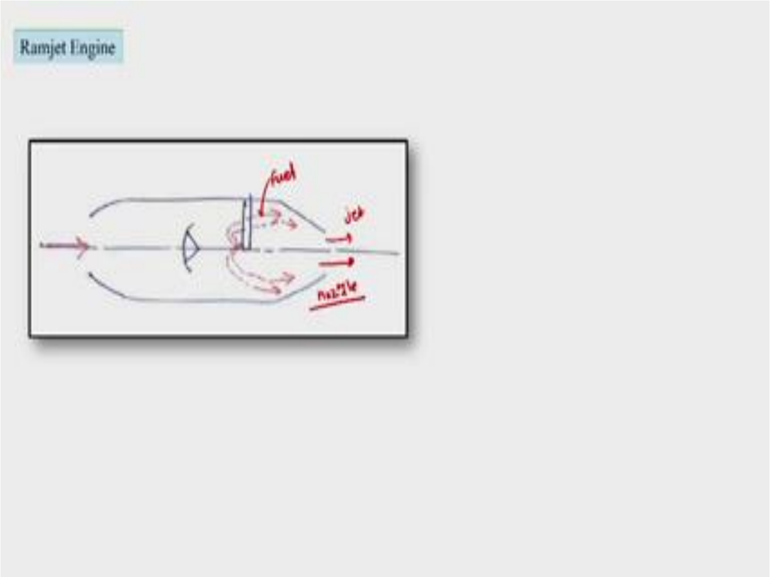

Ramjet Engine

Then last engine what we will be seeing here is a ramjet engine basically RAM effect is the effect where the inlet momentum of the air is used to compress it to avoid the rotating compressor which is present at the intake of the engine or at the entry of the engine. So, this ramjet engine does not have any moving part. So, it compresses the air with its momentum. So, at the inlet there will be a duct which will compress the air to the desired pressure and desired temperature.

And then fuel will be injected as what we can see here this is fuel and then this will lead to combustion and then this engine would generate a jet through the nozzle. Practically ramjet engines who are parasite engines which would operate at the supersonic speeds since we will have supersonic entry of the air and then the jet will be obtained after combustion of the fuel into the engine.

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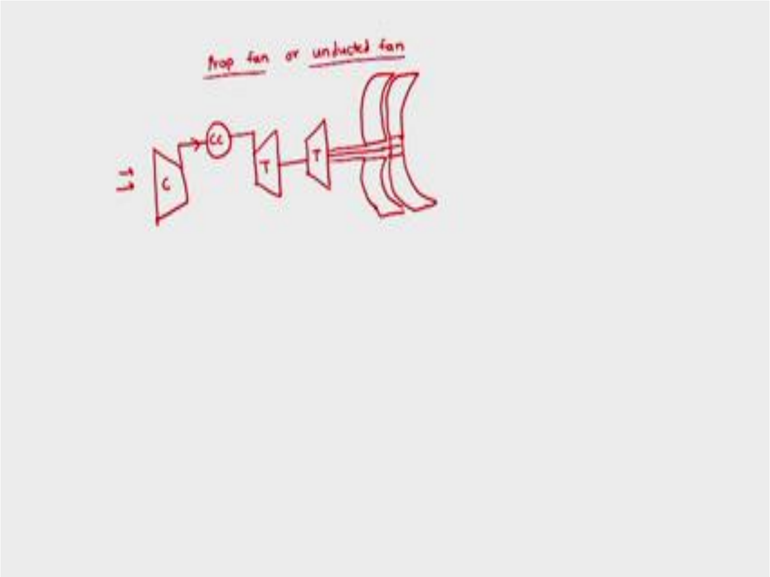

Having said this there is one more type of an engine which is called as prop fan or unducted fan. Prop fan or unducted fan so this engine is basically having a compressor which will take the air. And then it will go to the combustion chamber and after the combustion chamber there is a turbine and then there is one more turbine and then there will be one propeller which will be fitted and connected to the low-speed turbine.

And one propeller is connected to the high-speed turbine like this. So, this engine has propellers which are connected counter-rotating to propellers with our multi blade propellers which are connected to the turbines and they generate the thrust. So, this is also called as the prop fan or unducted fan kind of propeller. However this kind of engines need special attention for design of the Aero foils or section of the propellers.

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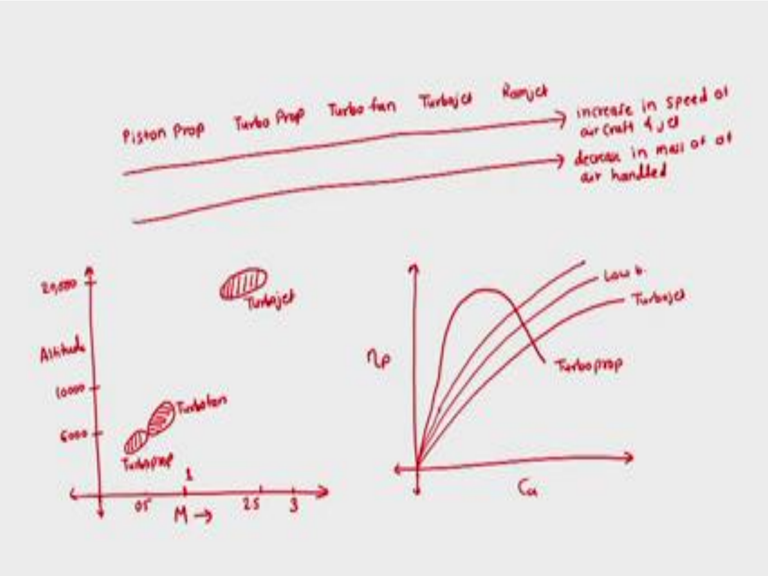

So, having said this we can note down the engines and then their corresponding limitations. So, piston prop and then we have turboprop then we have turbofan then we have turbojet and then we have ramjet. So, these engines and in this direction we are having increase in speed of aircraft and jet. And in the same direction however we have decrease in mass of the air handed.

So, piston prop handles large amount of mass as equally by the turboprop however ram jet and turbo jet would handle lower amount of mass than the piston prop engine. So, if we plot a graph of altitude versus mach number where mach number is defined as speed of the aircraft divided by local speed of sound. So, this is this is turboprop this is turbofan and here we will get turbojet where this range we will have around .5 Mach number.

And we can go around 6000 meter of altitude then it is 10000 meter of altitude and here we will have mach number lower than 1 or around 1 and then turbojet engines would go around 20000 altitude and then they can also go for the mach number of 2.52 or in that range. So, this is where we can see that turboprop engines are operating at lower altitudes. Since they handle more mass flow rate and their thrust is based upon the amount of mass handed.

Further if we plot propulsive efficiency versus flight speed in meter per hour flight speed then we can see that propulsive efficiency is like this for turboprop engines. But turbojet engines would have this kind of propulsive efficiency trend and then we have two trends for the turbofan engines. So, this turbofan engine is low bypass this turbofan engine is high bypass.

Basically here we mean by bypass that the large amount of air the rather the amount of air which were passed through the cold circuit and generate the cold thrust.

A lower amount of air were passed through the cold circuit and more amount of air would pass through the turbo part and generate more thrust. So, this is the trend of propulsive efficiency and speed of the aircraft. So, this is how we have seen that there are different kinds of aircrafts and then there are different performance parameters which are needed to evaluate performance of an aircraft. So, next we will see in the next class thank you.