Introduction to Airbreathing Propulsion
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Lecture – 32
Performance/ Cycle Analysis: Turbofan (Contd.,) Turboramjet

Okay, so continue the discussion on the turbofan engine. So, we have looked at now first we started of simple turbofan and mixed turbofan, single and two spool and then in the last session we have looked at what happens when you have the mixing and we have looked at the mixing with afterburning process and that is pretty much I mean the mixed turbofan engine is quite popular these days.

Not only in military application, also in civilian application, but for military application there would be added component like afterburner because that also used to energize the mixed gases more which can give you sudden acceleration or more maneuverability and things like that.

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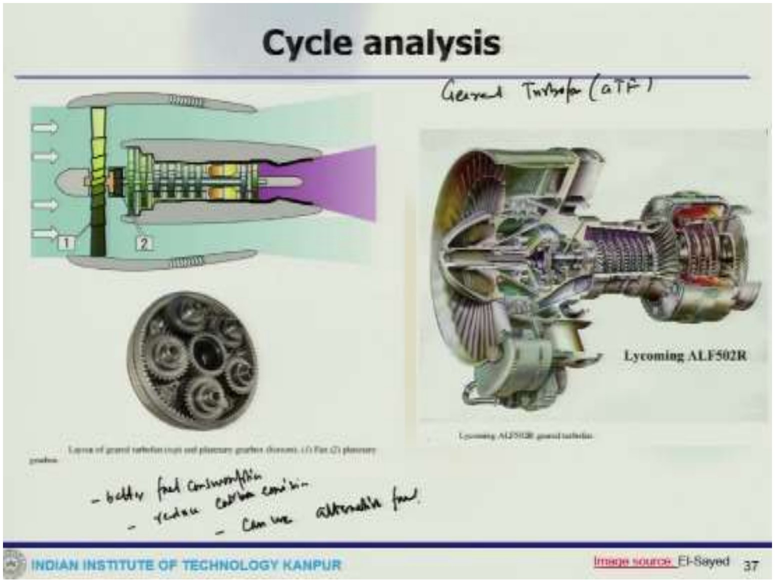

So with that now we will move to another kind of thing which like called the geared turbofan so GTF so geared turbofan. So, we will just which may not go into too much of detail, but just to give you an idea how they look like so that you will have an idea. So this is called the gear turbofan. These are some of the example and this is how the gearbox looks like and this is where it is used.

Now here the fan is normally part of the low spool both fan and LPT are turning at the same speed, however, often it is a compromised because fan really operates more efficiently at low rotational speed while the rest of the low spool is more efficient at higher speed. Now, there is a reduction gear which is put in between the components makes it possible the fan and the low spool to run in their optimum speed.

So, this is an example of that thing which is a Lycoming ALF502R engine. This produced by Lycoming and then later on Honeywell Aerospace. So this kind of gear turbofan has some advantages. So, if you see this kind of gear turbofan, so it has advantages like it improves the fuel burnup compared to today’s best engine. So like when the fuel consumption is actually so better fuel consumption or burning you can say.

So which can save lot of money for the aircraft industry or aviation industry everyday nearly huge money nearly 1.4 to 5 million money which can be saved then also it reduced the carbon emission. So it cuts the carbon emission by more than 3500 ton per aircraft per year so this is huge. This could be equivalent to effect of planning more than an almost 1 million, roughly 1 million I mean trees to be planted.

But it will be really to power aircraft well with bio fuel since it has successfully tested with alternative fuel so can use alternative fuel. So these are the some of the advantages. Now when you say that also it reduces some NOx’s now concerning thermodynamic analysis of this gear turbofan.

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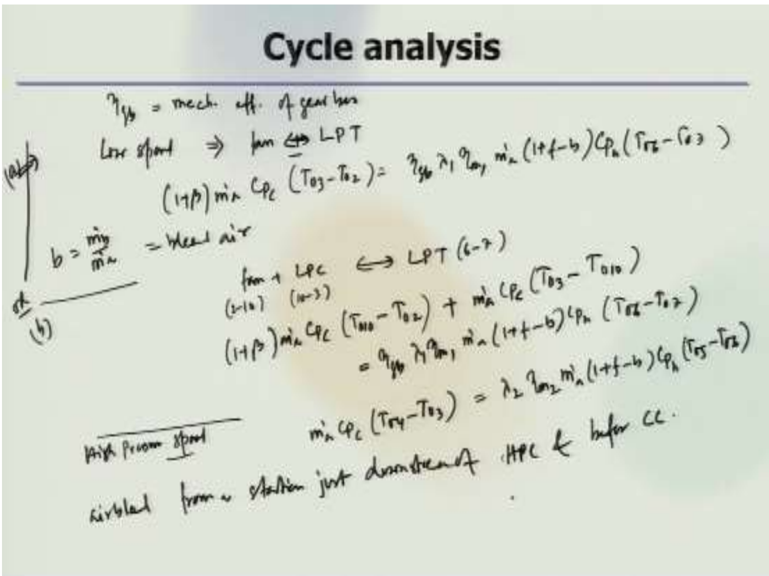

If let say η_{gb} is the mechanical efficiency of the gearbox then first let say at the low spool is composed of fan and turbine, so at low spool this has fan plus LPT. So the fan states are 2 and 3 and LPT states are 6 and 7. So if we go by the continuous numbering then the energy balance from here what would give

$$(1+\beta)\dot{m}_a C_{Pc}(T_{03}-T_{02}) = \eta_{gb}\lambda_1\eta_{m1}[\dot{m}_a(1+f-b)C_{Ph}(T_{06}-T_{07})]$$

Where

$$b = \frac{\dot{m}_b}{\dot{m}_a} = bleed\ air$$

then in the second case where the low pressure turbine that 6 and 7 drives the fan and low pressure compressor so that could be one scenario, other scenario let say LPT drives the so here this is combining this. So that is what it sending then the other case it could be let say that is possibility one, other possibility fan plus LPC would be derived by LPT.

So let us say this is state between 6 to 7 and this one is 2 and 10 and LPC is 10 and 3 then one can write the energy balance

$$(1+\beta)\dot{m}_a C_{Pc}(T_{010}-T_{02}) + \dot{m}_a C_{Pc}(T_{03}-T_{010}) = \eta_{gb}\lambda_1\eta_{m1}[\dot{m}_a(1+f)C_{Ph}(T_{06}-T_{07})]$$

Now when you come to this could be one option or this could be second option. So these are or high pressure spool the air bleed from a station just downstream of HPC and prior to combustion chamber.

So what we can write in the high pressure side high pressure spool what we can write

$$\dot{m}_a C_{Pc}(T_{04}-T_{03}) = \lambda_2\eta_{m2}[\dot{m}_a(1+f-b)C_{Ph}(T_{05}-T_{06})]$$

So now this is where the air bleed from a station just downstream of HPC and before combustion chamber. Now the other case if the air bleed is from the station within the HPC compressor.

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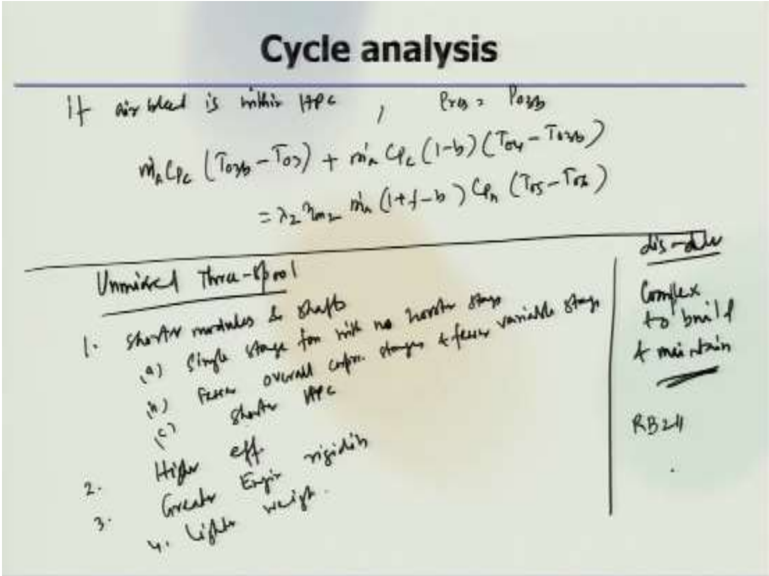

So if air bleed is within HPC so then that the pressure would be identified the pressure would be there P_{03b} then the energy balance of the high pressure spool would give us

$$\dot{m}_a C_{Pc}(T_{03b} - T_{03}) + \dot{m}_a C_{Pc}(1-b)(T_{04} - T_{03b}) = \lambda_2 \eta_{m2}[\dot{m}_a(1+f-b)C_{Ph}(T_{05} - T_{06})]$$

So that is how you can do then now we can move to another engine which is called the probably unmixed three spool. So that means we have three different spool, so there is an advantage associated with that.

The advantage which are there this three spool configuration is that it has shorter modules and shafts. So which result in a short run so that means a small engine, so single stage fan with no booster stages could have fewer overall compressor stages and fewer variable stages that reduces that C shorter high pressure compressor, shorter HPC. Second, it could have higher efficiencies, third greater engine rigidity, fourth, lighter weight.

But there is a drawback of this three spool engine or the main drawback they are quite complex. So disadvantage one can say or drawback is that complex to build and maintain. So, that is one of the. So, some of the example like Rolls-Royce RB211 is a three spool engine, then Rolls-Royce Trent is a three spool engine.

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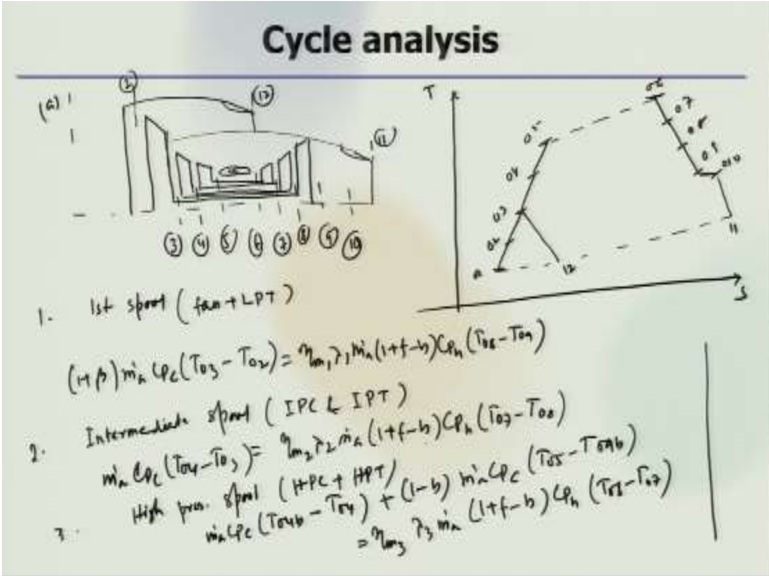

So if we draw an engine like that this is unmixed, so we can have this and so this goes there, so this comes so which also goes like this. Now then we have another spool which goes here then we have the third one which comes like this, this is CC. So that is takes the nozzle and this guy takes the nozzle here. So this station could be a, this is 2, this is 3, 4, 5, 6, 7, 8, 9, 10, 11 and then finally this is 12 and equally if we draw the TS diagram.

So this will look like I have a, 2 to 3, 4, 5, 6, 7, 8, 9, 10 then we get 11 and here 12. So that is how this diagram would like. Now if we do the analysis first the energy of the first spool. So, fan plus LPT which means

$$(1+\beta)\dot{m}_a C_{Pc}(T_3 - T_2) = \lambda_1 \eta_{m1} \dot{m}_a (1 + f - b) C_{Ph}(T_{08} - T_{09})$$

if there is a bleed. Second is the intermediate spool which is IPC and IPT then what we could write

$$\dot{m}_a C_{Pc}(T_{04} - T_{03}) = \lambda_2 \eta_{m2} \dot{m}_a (1 + f - b) C_{Ph}(T_{07} - T_{08})$$

And then third is the high pressure spool. So which is high pressure spool which is HPC plus HPT that is

$$\dot{m}_a C_{Pc}(T_{04b} - T_{04}) + \dot{m}_a C_{Pc}(1 - b)(T_{04} - T_{04b}) = \lambda_3 \eta_{m3} \dot{m}_a (1 + f - b) C_{Ph}(T_{06} - T_{07})$$

So similarly like this is how the spool balancing can be done and then rest of the procedure like calculation of the other part and all these they will also follow the calculation like. So we are not doing the rest of the calculations because that would be pretty straight forward and we have done enough that kind of calculation.

So it would be good idea, one has to pick up from there, but this will give you an idea, but obviously here one has to note that this bleed position. So depending on the bleed position this balance equation may slightly deviate from here and there. So that gives you a fair amount of idea.

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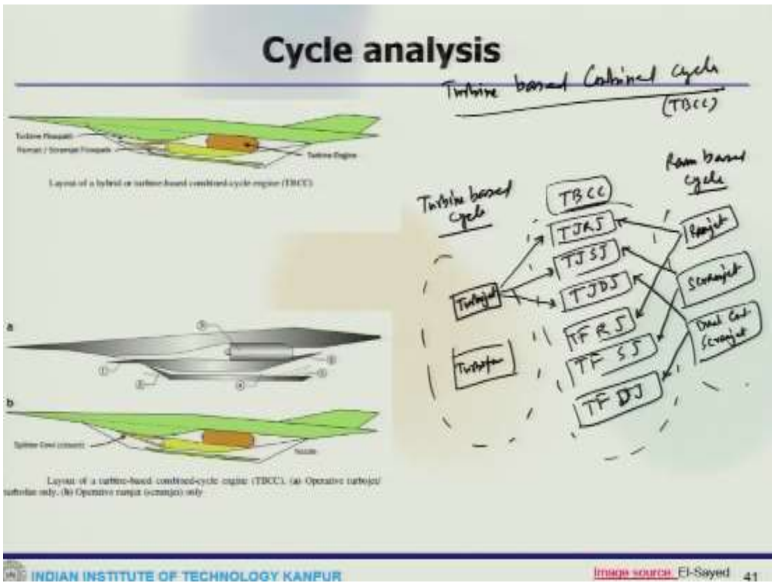

Now will move to the one which is another important topic is turbine based combined cycle. So why you are doing so much of detail analysis on turbofan because turbofan engines are primarily is the engine which are I would say extensively used in today's life whether it is a civilian application or the aircraft fighter applications so these are TBCC. So, this is of a layout of a hybrid or turbine based combine cycle.

You can see which is a powering a future basically this one is powering a future supersonic or hypersonic vehicle and this one also like that which shows here and that kind of and now so this one illustrate sort of hybrid engine layout for lower modulate speed operation where turbojet or turbofan engine is active while ramjet and scramjet is inoperative and this guy is showing that ramjet or scramjet engine with inoperative turbojet return during high speed operation.

So, it can be looked into different group this TBCC. So, if I put let us say TBCC here then there would be turbine based cycle and this side would be your RAM based cycle. So it is an hybrid engine where you used both turbine based cycle where you have the rotating component and RAM based cycle is. So where either we could have turbojet or we could have turbofan.

So then in this category we can have TJRJ which is turbojet and ramjet that is one then turbojet and scramjet which is TJSJ and then we could have TJDJ turbojet and dual combustion ramjet.

So these are three possibility and at the same time there could be TFRJ which is turbofan and ramjet, turbofan scramjet and turbofan dual combustion jet. So this is that block then here we can have ramjet, we can have Scramjet and we can have dual combustion scramjet.

So now how these blocks can link this has this, this or this. So the ramjet goes here and here. Scramjet goes there and there, dual mode goes there and there. So these are the sort of blocks that is possible with this variance. So these are one can see that in this hybrid TBCC these are the 6 different variations which are possible that can have. Now these blocks show these combinations and then you can have a like multistage vehicle which is operating on TBCC.

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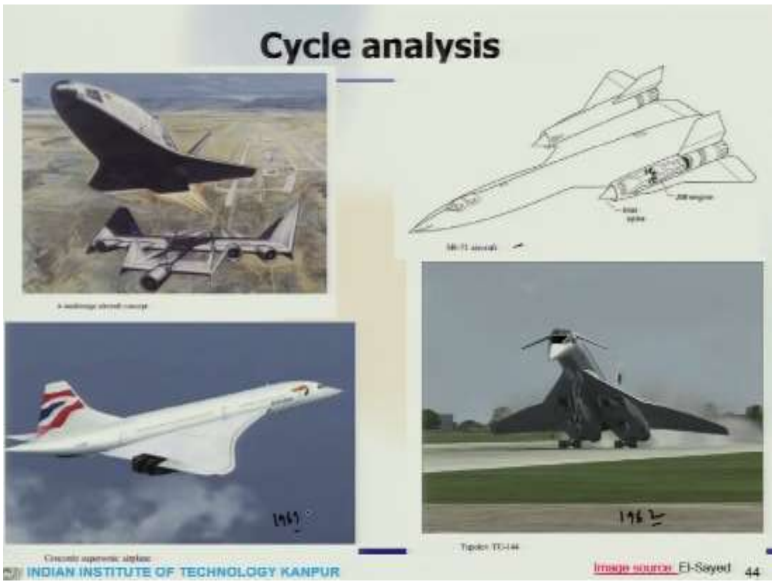

And you can see that kind of a vehicle like this is a multistage vehicle which is operating on TBCC. So this is an example just to show here if the vehicle is composed of two vehicles or two stages you can see that. One, having the turbine engine to enhance the take off or acceleration to supersonic speed where the second vehicle or the stage is driven by the ramjet or scramjet to the hypersonic or supersonic high speed.

Then there is I mean obviously there is an history behind that and all this started with the supersonic aircraft programs and all these which started when we had two airliner, one is Concorde and then Tupolev Tu-144 which are actually they were operational for civilian purposes and that is where the actually supersonic aircraft program started and then we started with like 1947 and then so 1964 I think this SR-71 aircraft which came in.

So you can see that image which is there on Lockheed SR-71 which was there flying mach number was around 3 plus and then this guy was the T-144 which was first commercial supersonic transport aircraft. It was in 1962 which was first constructed and this was Soviet Union aircraft and then later on we had other aircraft in place like then you can see this is a Concorde which came into.

So this is the British Aircraft Corporation which was jointly developed by the Aerospatiale and the British Aircraft Corporation. It was in 1969 when this came into the picture then other countries are also in that and then there are hypersonic vehicles are also which are in place.

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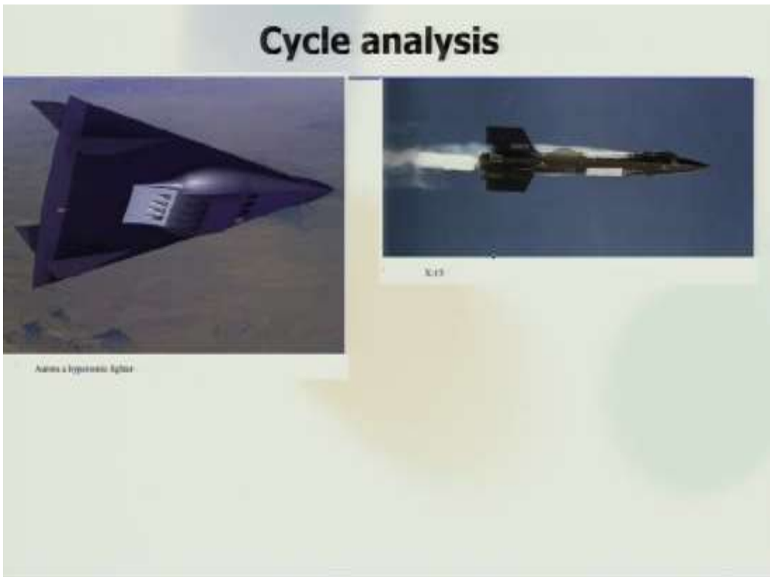

Like this is Aurora hypersonic fighter, this is X-15. These engines are now being developed or getting tested in different hypersonic program.

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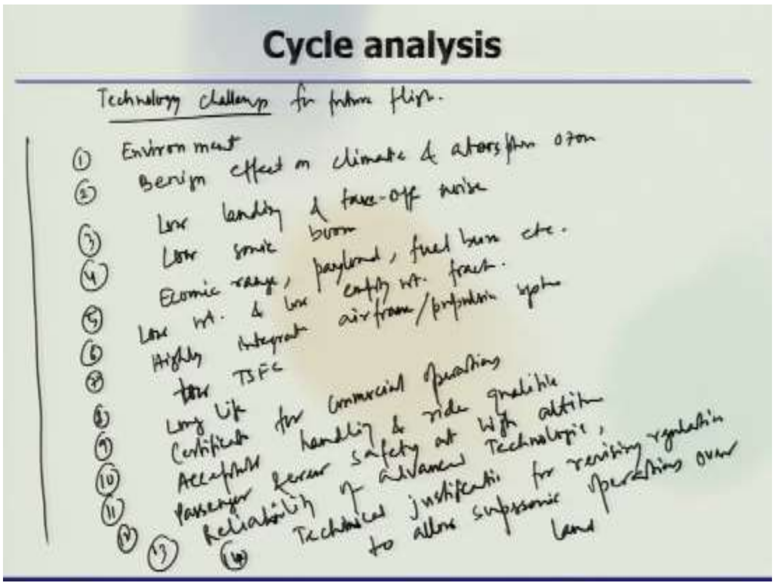

Now the technology challenges of the future flights, so if someone has to look at that technology challenges for future flight. So it has to have one is obviously environment, there is environment is one important concern then benign effect on climate and atmospheric ozone. Third low landing and take-off noise fourth low sonic boom, fifth economic range payload fuel burn etcetera.

Sixth low weight and low empty weight fraction, seventh highly integrated airframe or propulsion systems or unit, eight it could be low TSFC thrush specific fuel consumption. Nine long life, 10 certification for commercial operation then acceptable for acceptable handling and ride qualities, 12 passenger and crew safety at high altitude, 13 reliability of advanced technologies.

Then 14 technical justification for revising regulations to allow supersonic operations over land. So these are if someone has to list it down there are lots of factors. It may not include everything there could be some other factors which may be, but this is what one can think about important factor one has to and these are the technological challenges that one has for future flights.

I mean to have something in operation you have these challenges and both like engine manufacturer or the aircraft industry rather the aircraft manufacturer or engine manufacturer or in total the aviation industry they need to address. So, we will stop here and continue the discussion in the next lecture.