Introduction to Airbreathing Propulsion
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Lecture - 33
Performance/Cycle Analysis: Turboramjet (Contd.,)

So let us welcome back and continue the discussion on this turbofan engine rather right now we are talking about this hybrid engines. So the hybrid engines, that means either one side you could have the ram-based cycle, the other side you could have turbine-based cycle and the turbine-based cycle could be of turbojet based or turbofan based and the ram-based cycle could be of ramjet or dual mode, dual combustion scramjet.

And then there are different configurations, which are possible and we have seen some examples also, and also talked about the future technological challenges for this radiation industry together. Now we are going to look at some of these engine details. Let us start with some TBCC engine and the propulsion system integration.

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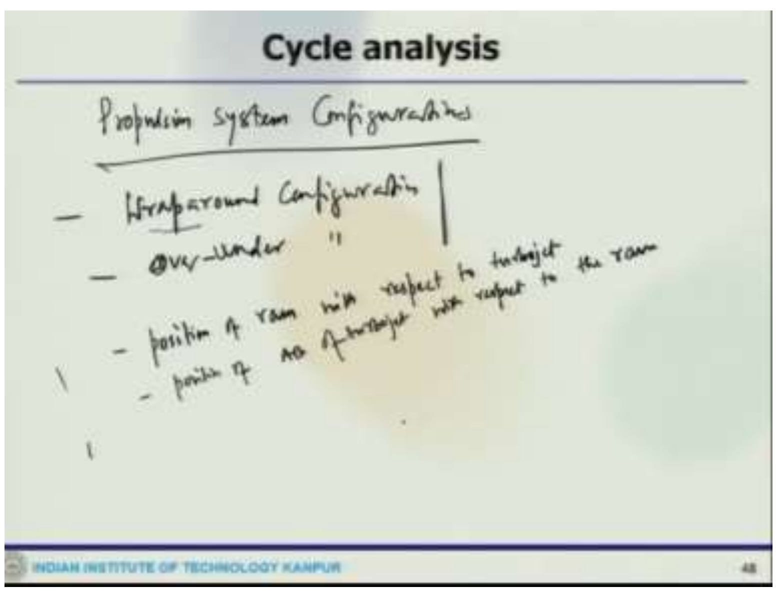

So the propulsion system integration, obviously we are talking about this hybrid engine, where you have either ram-based cycle or the turbine-based cycle and there could be important aspects of propulsion system configuration, so which means either we could have wrap around configuration and we will see some example, so that we will get an idea about what we are talking about here or over-under configuration.

And the difference is between these two primarily are where let us say the position of ram with respect to turbine-based cycle or turbojet cycle also the position of AB of turbojet, let us put it very specifically AB of turbojet with respect to the ram. So that is what we said the propulsion system integration is also important and the installation configuration of, let us say, wrap around configurations, we can see like.

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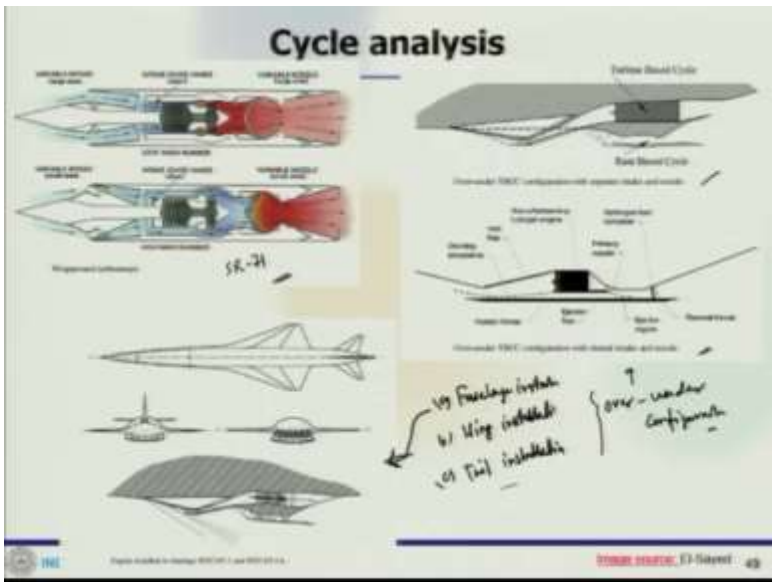

This is one of the wrap around configuration, which is for engine is SR71 and that is what it is and the other one which is there like one can have also; this is one of the example. Other could be that which could be fused like VF12, though I do not have the picture here, but you can see that that is also fuselage kind, but here you can see. This is the turbine-based cycle. This is ram-based unit and that is a combination. This is just an example. This is wrap around cycle.

Now when we talk about over-under configuration or over-under turboramjet, then there could be possibility like this is over-under TBCC configuration where this is a separate intake and nozzle, so this could be one cup configuration or here it could have shared intake and nozzle, so it already can give you an idea, how they look like. These also come under over-under configuration and this example here is like that.

Even in an over-under configuration, there could have, one can have fuselage installation and this is exactly what it is here. This is a fuselage installation that could possibly have wing installation and there could possibly have tail installation. So that means over and under configuration, that means either the turbine-based cycle or the ram-based cycle, one of them would be top of the other and that also can be done in a different way, like where we configure that, depending on that, it could be.

Now when it is a wing, this is fuselage kind of installation. There could be wing-based installation, where in the wing one could be on top of the other or some could be the tail based installation, so as there could be installation, but you can see these pictures in some book or internet.

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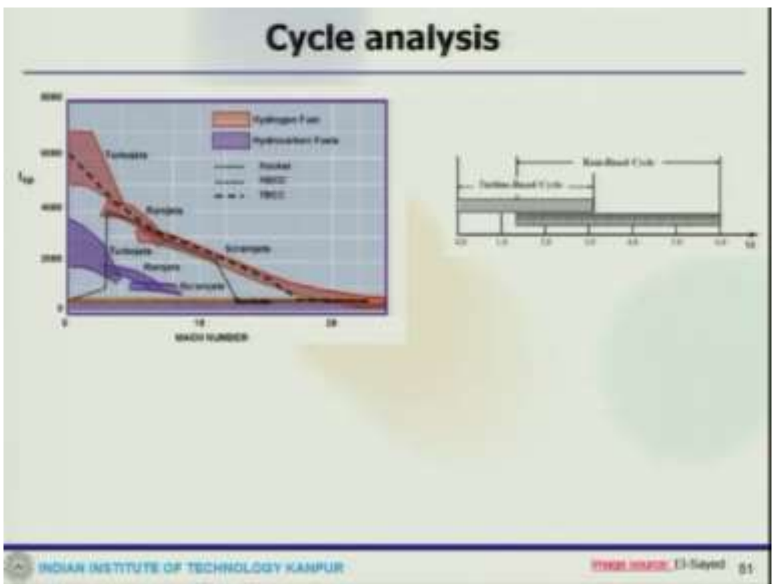

Now another thing which would be important to the performance of this, performance of TBCC. So that is also important, because when we look at this performance of TBCC or hybrid engines, so there is a range where this could be operated and there is like you can see this is where the specific impulse is and this is where turbojet works, where ramjet or scramjet and this is different fuel when you use and then the different dotted lines, which were used for rocket TBCC.

And if you look at this aspect, where this shows the variation of the Mach number and with the cycle variation. This is the turbine-based cycle and this is the ram-based cycle and that is where the hybridization gives an advantage over this. Now we can look at some analysis of this hybrid engine.

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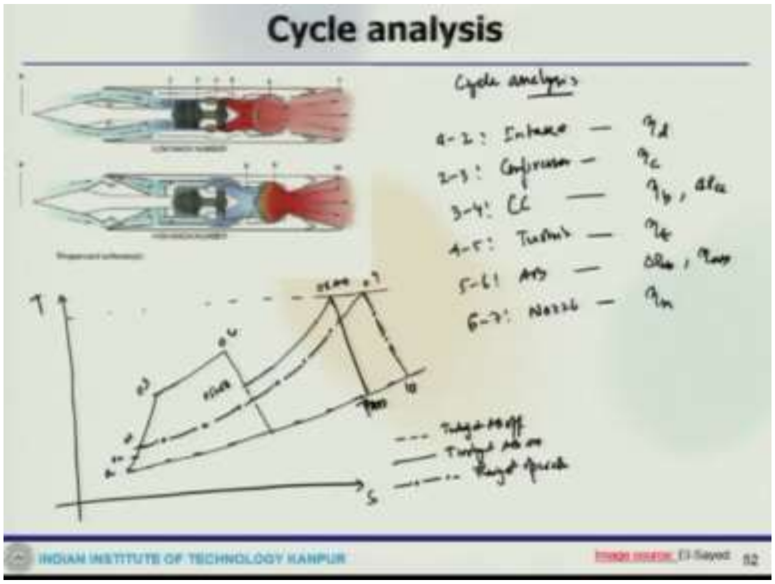

This is one wrap around turboramjet. So let us look at that cycle analysis for that. So operation as already we have done a lot of detailed discussion now, we can draw the schematic TS diagram for the same. Let us say, if we put that TS diagram, then this is point a, this goes to somewhere 8 or in between somewhere 2. Then this goes to 3, then goes to 4, then this is 5, 6, then this goes to, let us say, 06AB, then we can mark separate way, this is, let us say 2.

So mark this 2, 8, this is 09, then 7AB. This is 10. So here this is a solid line. This will also go solid line. This will come solid line and this also go also as a solid. Here, the dot dot dot, this is, let us say this goes to dot dot dot and this is like dash dot, this could be dash dot like that. So dot dot dot is turbojet AB off, solid is turbojet AB on, dot dot this is ramjet operation. So this is different situation and already if you see that means, a to 2 is intake, where the compression process with isentropic efficiency of η_d

Then 2 to 3 is compressor, where the compression takes place with isentropic efficiency of η_c. Then 3 to 4 is combustion chamber where the heat addition at constant pressure takes place with little pressure drop and combustor efficiency and delta P_{cc}, then 4 to 5 is your turbine, where again expansion takes place with isentropic efficiency of η_t.

Then 5 to 6 is afterburner, where again the second round of heat addition takes place with delta Pab and eta ab and 6 to 7 is nozzle, where again expansion process with isentropic efficiency of eta n and the other detailed cycle analysis of different conditions, these are already done in detail.

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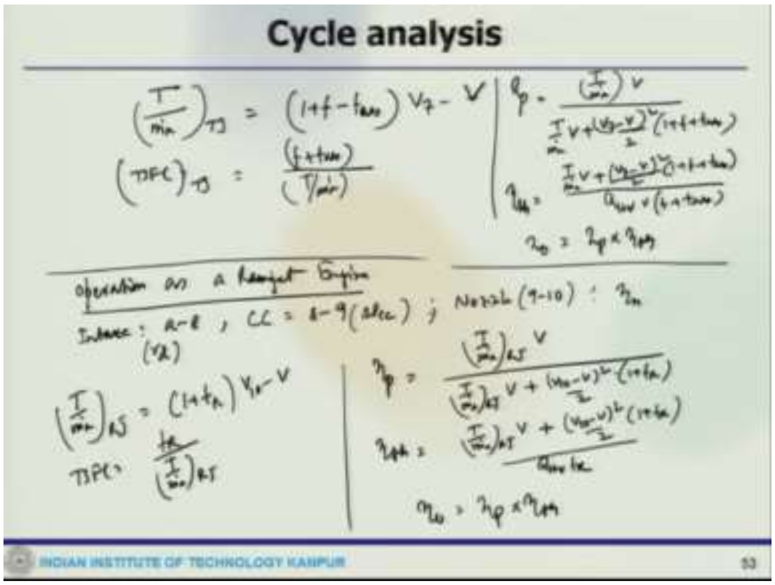

So the performance like specific thrust if we look at it, like

$$\left(\frac{T}{\dot{m}_a}\right)_{TJ} = (1 + f - f_{ab})V_7 - V$$

And TSFC would be TSFC of turbojet, which is

$$(TSFC)_{TJ} = \frac{(f + f_{ab})}{\left(\frac{T}{\dot{m}_a}\right)}$$

Similarly, propulsive efficiency

$$\eta_p = \frac{\left(\frac{T}{\dot{m}_a}\right)V}{\left(\frac{T}{\dot{m}_a}\right)V + \frac{(V_7 - V)^2}{2}(1 + f + f_{ab})}$$

and thermal efficiency would be

$$\eta_{th} = \frac{\left(\frac{T}{\dot{m}_a}\right)V + \frac{(V_7 - V)^2}{2}(1 + f + f_{ab})}{Q_{HV}(f + f_{ab})}$$

and overall efficiency is propulsion into thermal.

So these are the things, which can be calculated. Now we can look at if the operation has a ramjet engine only. So if its operation is ramjet, the flow is passing through the processes and so like what are the parts would be, it will only have intake, a to 8, then combustion chamber 8 to 9. So intake the compression process will take place with a pressure issue r_d, combustion chamber where the combustion will take place with delta P_{cc}, and the nozzle which will be 9 to 10.

But the expansion will take with η_n, that means when it operates as ramjet, so these are the stations which would be sort of active and then we can calculate the parameter like performance parameters like let us say,

$$\left(\frac{T}{\dot{m}_a}\right)_{RJ} = (1 + f_R)V_{10} - V$$

and TSFC would be

$$(TSFC)_{RJ} = \frac{f_R}{\left(\frac{T}{\dot{m}_a}\right)_{RJ}}$$

and our propulsive efficiency would be

$$\eta_p = \frac{\left(\frac{T}{\dot{m}_a}\right)V}{\left(\frac{T}{\dot{m}_a}\right)_{RJ} V + \frac{(V_{10} - V)^2}{2}(1 + f_R)}$$

Thermal efficiency would be

$$\eta_{th} = \frac{\left(\frac{T}{\dot{m}_a}\right)_{RJ} V + \frac{(V_{10} - V)^2}{2}(1 + f_R)}{Q_{HV} f_R}$$

and overall efficiency equals to

$$\eta_o = \eta_p * \eta_{th}$$

So this is when it operates as a ramjet.

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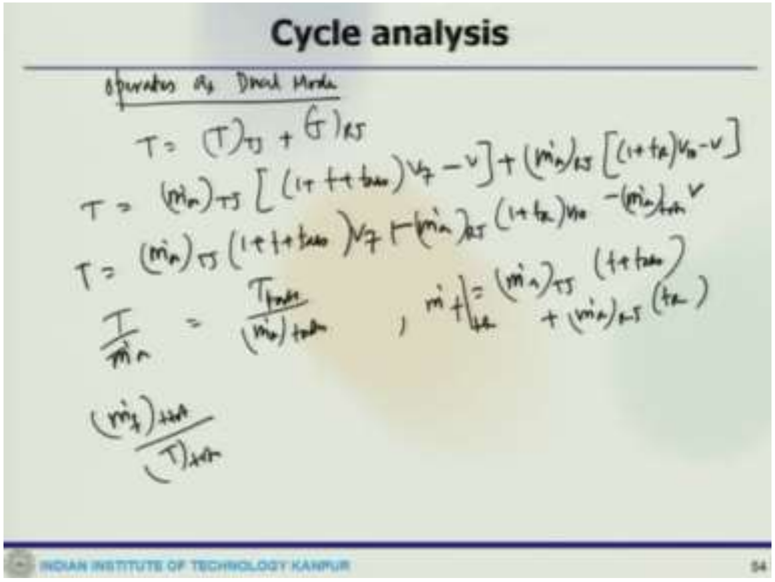

Now when it operates as dual mode, so what would happen that time? So when it operates as dual mode, then you get thrust would be of turbojet plus thrust would be combination of ramjet, then the total thrust would be

$$T = T_{TJ} + T_{RJ}$$

$$T = (\dot{m}_a)_{TJ}[(1 + f + f_{ab})V_7 - V] + (\dot{m}_a)_{RJ}[(1 + f_R)V_{10} - V]$$

$$T = (\dot{m}_a)_{TJ}(1 + f + f_{ab})V_7 + (\dot{m}_a)_{RJ}(1 + f_R)V_{10} - (\dot{m}_a)_{total}V$$

So similarly the specific thrust would be

$$\frac{T}{\dot{m}_a} = \frac{T_{Total}}{(\dot{m}_a)_{total}}$$

so we can calculate and total fuel mass flow rate would be

$$\left(\dot{m}_f\right)_{total} = (\dot{m}_a)_{TJ}(f + f_{ab}) + (\dot{m}_a)_{RJ}(f_R)$$

and specific thrust

$$TSFC = \frac{\left(\dot{m}_f\right)_{total}}{T_{Total}}$$

So that is what it happens. Now also one can look at the over-under turbojet.

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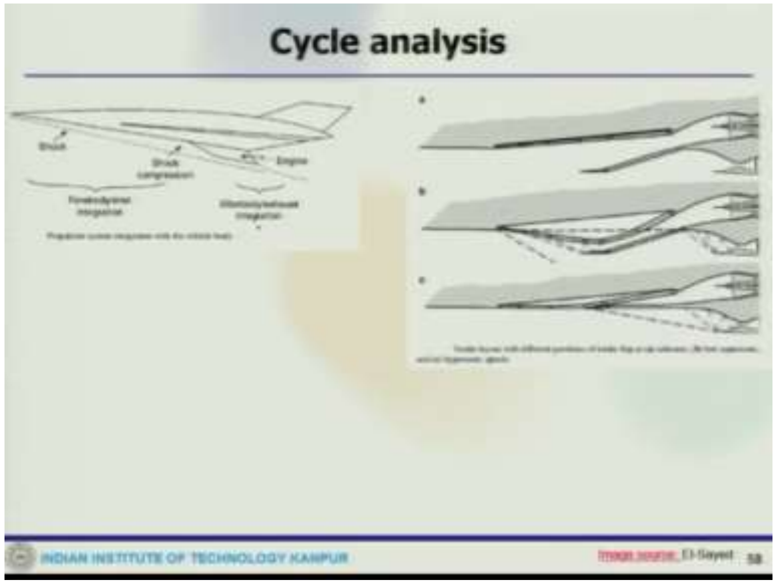

And over-under turbojet, this is some of the example, so where the propulsion system integration is done by this is a ramjet mode of that over-under turbojet and then this is another intake layout with different positions of the intake flap with subsonic and these things.

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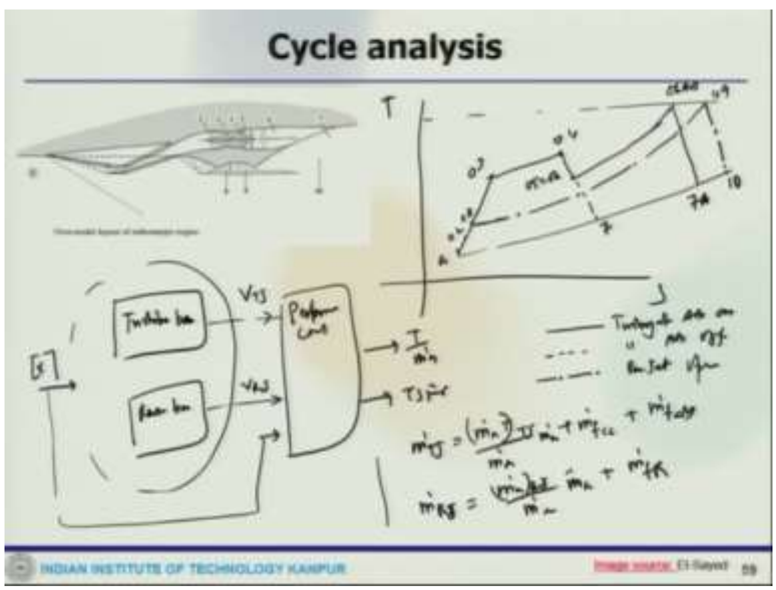

Now you can have one over-under ramjet and can have a look at this. So this is quickly the TS diagram. So this is a, 02, 8, 3, 04 comes to 6, so 06ab, this is 05, 06 and this is again like. So this will come 7 maybe, so this is 10, this is 09, and this is 7. So again same thing, so solid line is turbojet AB ON dot turbojet AB off, this ramjet operation and the general block diagram would be like you have turbine based cycle, then you have ram-based cycle, then you get all the performance calculation.

So from this combined cycle, where it goes, let us say something comes here and then it goes V, so from here it goes V turbojet, from here it goes V ramjet and then finally got $\frac{T}{\dot{m}_a}$ and TSFC, all these you can calculate. So these are the calculations, which you can do where again like

$$(\dot{m}_a)_{TJ} = \frac{(\dot{m}_a)_{TJ}}{\dot{m}_a}\dot{m}_a + \dot{m}_{fcc} + \dot{m}_{fab}$$

And

$$(\dot{m}_a)_{RJ} = \frac{(\dot{m}_a)_{RJ}}{\dot{m}_a}\dot{m}_a + \dot{m}_{fR}$$

So there is two different fuel mass flow rate calculations, which you can check.

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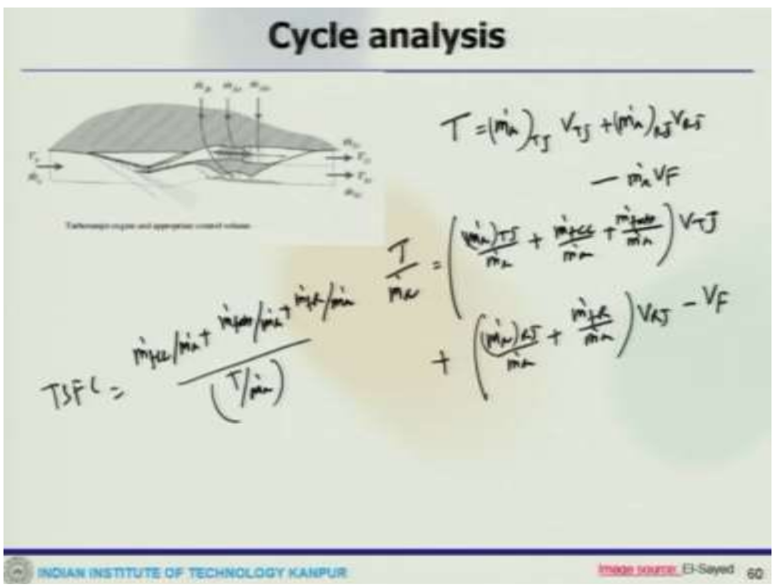

And so this is how it looks like and so then your thrust would be

$$T = (\dot{m}_a)_{TJ}V_{TJ} + (\dot{m}_a)_{RJ}V_{RJ} - \dot{m}_a V_F$$

and

$$\frac{T}{\dot{m}_a} = \left(\frac{(\dot{m}_a)_{TJ}}{\dot{m}_a} + \frac{(\dot{m}_a)_{fcc}}{\dot{m}_a} + \frac{(\dot{m}_a)_{fab}}{\dot{m}_a}\right)V_{TJ} + \left(\frac{(\dot{m}_a)_{RJ}}{\dot{m}_a} + \frac{\dot{m}_{fR}}{\dot{m}_a}\right)V_{RJ} - V_F$$

So similarly TSFC

$$TSFC = \frac{\frac{(\dot{m}_a)_{fcc}}{\dot{m}_a} + \frac{(\dot{m}_a)_{fab}}{\dot{m}_a} + \frac{\dot{m}_{fR}}{\dot{m}_a}}{\frac{T}{\dot{m}_a}}$$

This is how the performance parameters can be calculated for this dual mode kind of operation and then one can have the design procedure.

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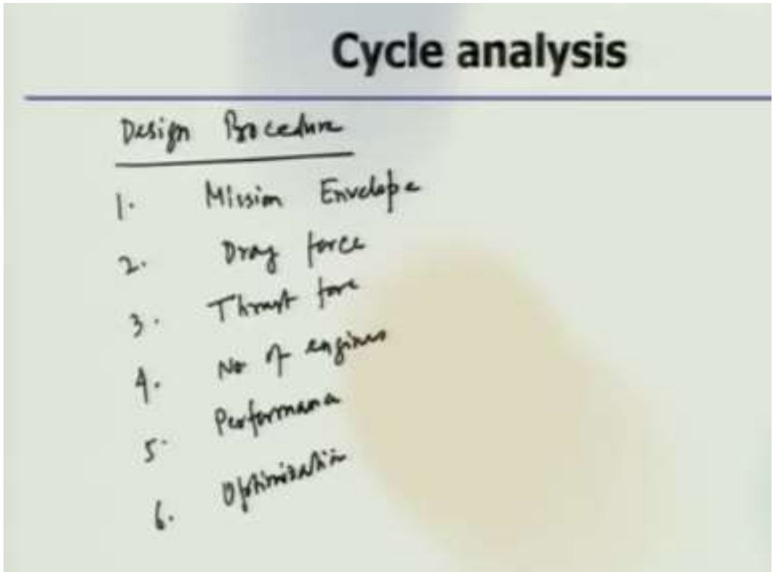

The procedure could be summarized like some basic design procedure, which would be put into place like one is basically what you need for hypersonic or supersonic aircraft propulsion integration. First is the mission of flight envelope to be selected. So mission envelope to be selected. Second, the cruise altitude, which is important for fuel economy point of view, take off line acceleration, then we can calculate the drag force.

Based on the drag force, we get Mach number and all these. So calculate the thrust force. If it is greater than the drag force or over this Mach number, then some margin of percentage to be selected, then the number of engines, which could be decided upon based on the minimum thrust, which is suggested for the hybrid engines of different modes, then performance calculations of each constituents of this engine separately.

Let us say for example hybrid engine has ramjet, turbojet, and scramjet. So each module has to be examined separately and then finally the integration. Sixth is optimization, that means this is very, very important of this hybrid engine for different steps like specific thrust, TSFC and then the switching point between, when it is supposed to switch between ramjet and turbojet and which Mach number and all those things.

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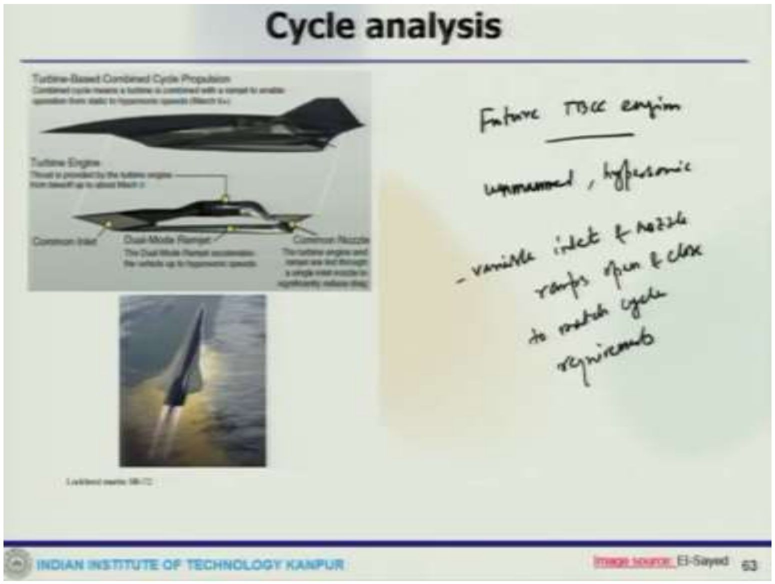

So just to conclude all these discussion with this schematic vehicle of the feature TBCC engine. So this is a Lockheed Martin SR72, which is sort of conceptualized unmanned hypersonic aircraft intended for intelligence, surveillance, reconnaissance, and this SR72 was also put to operation by 2030, because it is again what you see here, it is over-under configuration, here is the turbine engine, here is the dual mode engines and it will be based on turbine TBCC cycle.

Turbine engine will be used initially to take off up to Mach 3 and then this dual mode ramjet engine will accelerate the vehicle to hypersonic speed and something like that. So the turbine and the engine shares the common inlet that provides air supply to both the turbine engine and the ramjet engine and also they have a common nozzle, which is here. You can see this conceptualized or the sort of futuristic vehicle.

So it has also variable inlet and nozzle. Nozzle rams open and close to match the cycle requirements. So that is what you can see and that sort of pretty much concludes the discussion on all these turbine-based cycles and also the hybrid engine and this gives you good idea about how this different kind of engines, which are in place today and what is going to be futuristic vehicle and how would they operate and what are the kind of this common cycle performance parameters and sort of thing. So we will stop here and continue the other discussions in the next lectures.