Introduction to Airbreathing Propulsion

Prof. Ashoke De
Department of Aerospace Engineering
Indian Institute of Technology – Kanpur

Lecture – 25
Performance/Cycle Analysis: Pulsejet (Contd.,), Ramjet

So, let us continue the discussion on pulse jet engine. Now we have started looking at the Aero thermo dynamical analysis of different engine. So, started with pulse jet and then we will move to Ramjet and scram jet before moving into the engines like turbo jet or turbofan where you have the rotating component. So the biggest difference between this pulse jet, Ramjet or scram jet engines with the other section of turbojet or turbofan is that whether it is a non-rotating part existence of the non-rotating part of the rotating part and that one which we are now discussing like the pulse jet or Ramjet they do not have any rotating components like compressor turbine.

So that is the advantage. So, it is a geometrical configuration which does the compression with along with the diffusion so that the proper flow rate can get into the compressor.

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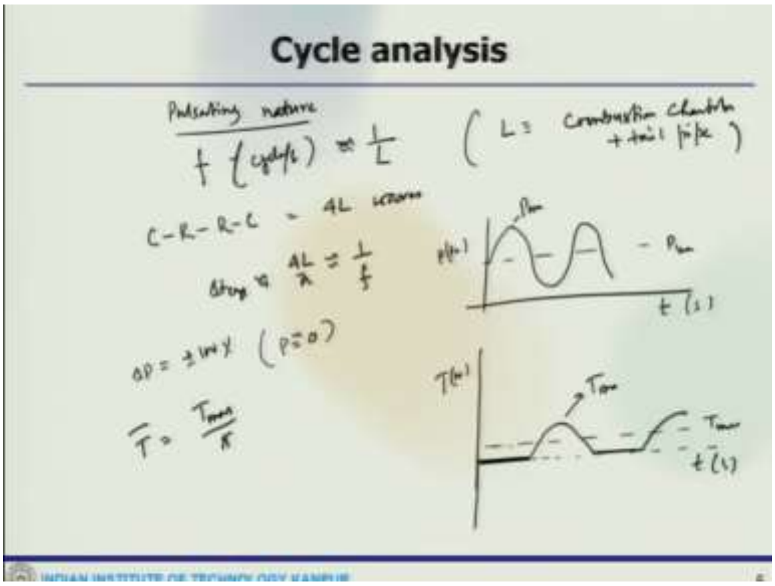

So, this is what we stopped the for the pulse jet.

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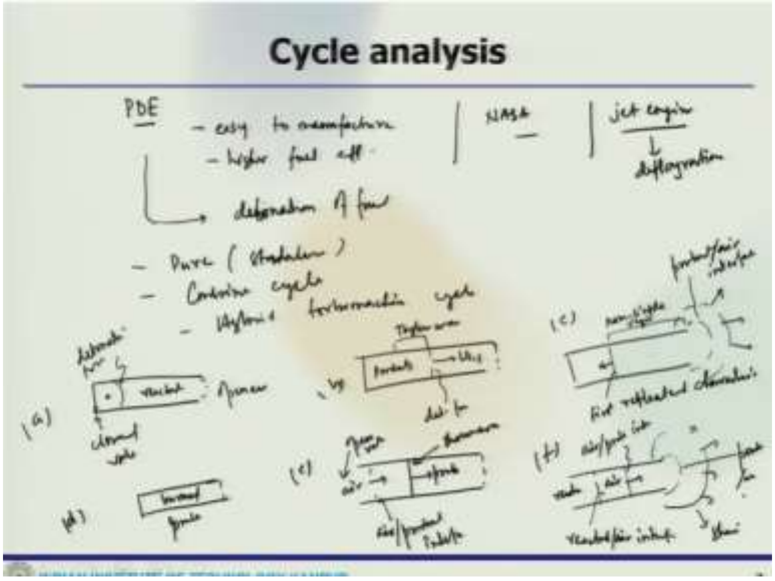

Now the one which we go of looking at the pulse detonation engine and we have since the different approach of the pulse detonation engine. So, this makes a new approach towards non continuous combustion they are also very easy to manufacture that is obvious and also having higher fuel efficiency compared to turbofan engines or something like that. Now so actually to date no practical PDE engine has been put into the production.

But several testbed engines have been built by Pratt & Whitney, General Electric that have been proven the basic concept. Extensive work which has been carried out or being carried out in different NASA centre but theoretically it can produce an engine with the efficiency for surpassing the gas turbine with almost no moving parts probably this is an futuristic engine what could be used.

Now the difference between regular jet engine where the regular jet engines the operate on a deflagration of the fuel that is rapid but relatively gentle subsonic combustion. But in pulse detonation engine it is concept of active development to create engine which operates on the detonation of fuel. So, it is based on the detonation mode. So now so this is what the nature of a pulse detonation engine which one can look at it.

So, when we are talking about like this pulse engine. So, this portion is not there so this is a typical nature which is also possible for pulse detonation engine and engine and now this can be classified into pure standalone which is standalone which could be combined cycle and hybrid turbo machinery cycle okay. So, the pure one which could be based on the pure detonation tube and other ones are the combines one.

So, which can be now one can look at how this process can go on like we have a chamber let us say this is what this is the closed valve condition let us say closed valve this is the detonation front this is reactance this is open end. Then in the second phase you could have where the products here this is the situation where you have this is the Taylor wave this is again detonation front and you will have detonation speed.

Now then you could have like the front going this side this is the first reflected characteristic then you can have which is going like this. So non simple region which is non simple region and then so this could be product or a interface. Now then you can go to completely like this where this is brand product then you can now have like this is product, this is shockwave now this is open valve here coming in.

So, this is the air and product interface or again it could go like this where this is the thing. So, this is this is reactant this is air reactants air interface this is air product interface and this would be product your interface and these are the shockwaves and all this.

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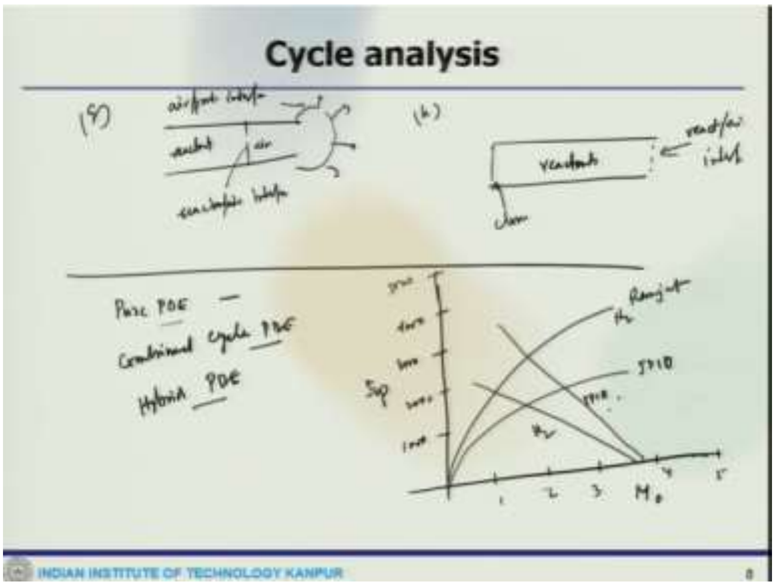

So, and other cycle pattern could be like this when you have this is air this is reactants. So, these are reactants here interface this is air product interface and or so this is again closed valve this is completely reactants this is again reactant air interface. So, you can see different sequence so unlike like the pulse jet combustion and PDE supersonic effectively an explosion instead of bonding and shockwave of the combustion front inside the fields of the purpose of shatters the valve pulse jet.

This is also can be looked at that now that other one is that we said pure PDE engine so that is array of detonation tubes and nozzle so pure PDE this has array of detonation tubes and nozzle. So, the application primarily is in military application because they are light and easy to manufacture and have higher performance around Mach 1 than current engines. So, another thing is that when you go to that range basically the noise and there is a drop in efficiency at higher Mach number that is why when you increase the Mach number this is not very often desired solution for the higher Mach number application.

Now the combined-cycle PDE is provide the most exciting possibilities for an aviation adding a PDE to a flow path of Ramjet or scramjet would make the engine capable of operating between Mach 5 or higher or you could have hybrid PDE which use the detonation detonative combustion in place of constant pressure combustion usually combination with turbo machinery.

So this could be also again two types there are different could be hybrid turbofan PDE or it could be the one thing one can look at it is that when you go by the Mach number let us say this is 1, 2, 3, 4, 5 and this is ISP your specific impulse let us say 1000, 2000, 3000, 4000, 5000 then this goes like this these are for the Ramjet for different fuels now at the same time your PDE engine would be like this this is for H2 this is with JP 10 then this is H2 this is JP 10 like that. So, this is how now in hybrid turbofan PDE that we will have a look at that while we are talking about the turbofan engine and with this kind of discussion.

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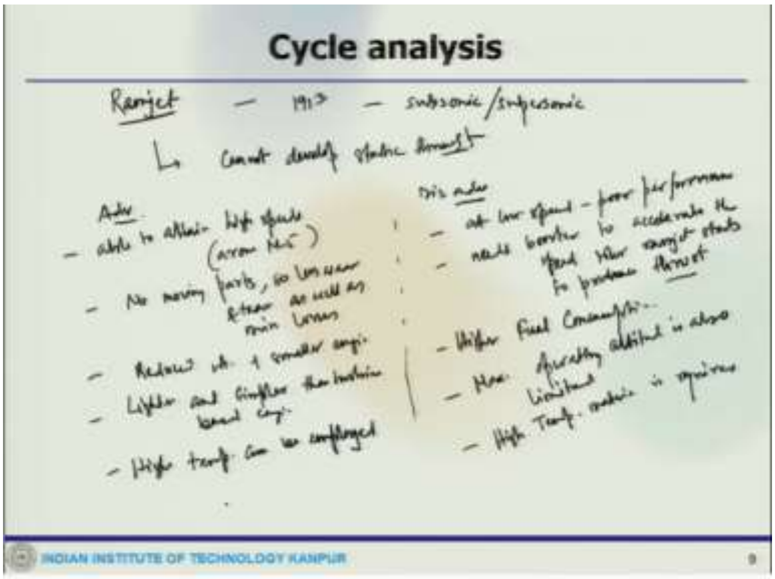

Now we will move to Ramjet so that is the so it is a another type of engine to just first proposed in 1913 by 13 so it may be either subsonic or it could be supersonic but one of the biggest problem is that with the Ramjet the thing is that the in the Ramjet it depends on the compression of the incoming air through geometric modifications. So, it cannot develop static thrust that is one of the issues with this the vehicle must first therefore cannot from the standing it cannot start.

So it has to be accelerated by other means so to reach a sufficiently high speed and then the Ramjet could be in operation. But although the ramjet can operate at subsonic flight speed the increasing pressure rise accompanying higher flights with render the Ramjet most suitable for supersonic or most efficient at speed around Mach 3 or so. So, the it has some let us say advantage and some disadvantages.

Let us look at it able to attain high speeds that is around Mach 5 no moving parts so less wear and tear as well as minimum losses reduced to it plus smaller engine size then you have lighter and simpler than turbine-based engines you have higher temperature can be employed. So, these are some of the notable advantages but obviously every advantage come with some sort of an disadvantage so at low speed poor performance.

So that is one so it needs booster to accelerate the speed needs booster to accelerate in the speeds where Ramjet starts to produce thrust then higher fuel consumption then maximum operating altitude is also limited is also limited then high temperature material is required. So, this is what it needs so these are now some of the advantage and disadvantages of Ramjet.

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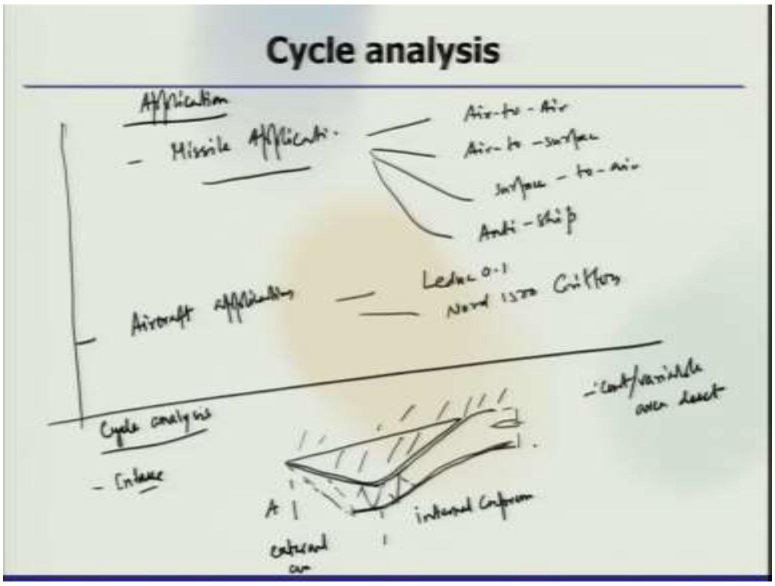

Then the other thing is that one can look at where the applications are one of the important applications is that missiles okay. So it can be used in missiles for let us say it could have air-to-air missiles then it could be air to surface missile then like air to air missiles it can enable medium-range missiles to maintain higher average speed for example MBDA meteor others are M120, Amraam like that Gorgon IV air to surface.

These are the examples like ASAT, mesquite something like that then you can have also you can have air to ground missile like by mirage IV 2000 liquid fuel ramjet to capability range 20-kilometer then you have surface-to-air missile again the examples like MBDA these are for us-based then you can have anti-ship missile which are again were.

So these are different missiles application then you can have aircraft applications okay so where you end up your Ramjet is coupled to other type of engine like piston or turbojets or turbofan to power the aircraft then one could be example of which we have seen the Leduc one or the Nord 1500 Griffon. So these are the one which are coupled with the thing and then others countries like Germany, Japan they also have these things Soviet Union Maldives.

So there are two primarily kind of application one is the missile applications where this is very handy other applications of these aircraft applications when it could be coupled with the now we can look at the cycle analysis for cycle analysis or thermodynamic analysis we have different modules let us see the first the intake module. So, intake module looks like this is how the intake module looks like this and goes like this.

So here you have internal compression here you have external compression where you can see there could be shock waves oblique shock and there could be lot of cross shocks which will form here like this. So, this is an intake module is a quite important in the sense this does not have any rotating part so the intake does the compression process for this. So, it could have different shape or it could be also having a constant or it can may be constant or variable area duct okay.

So some also it has the supersonic one has some spike which allows this kind of shock interaction to take place. So, what we can look at so now if you see this one and let us say this is a station at which is A and this is a station at somewhere at B.

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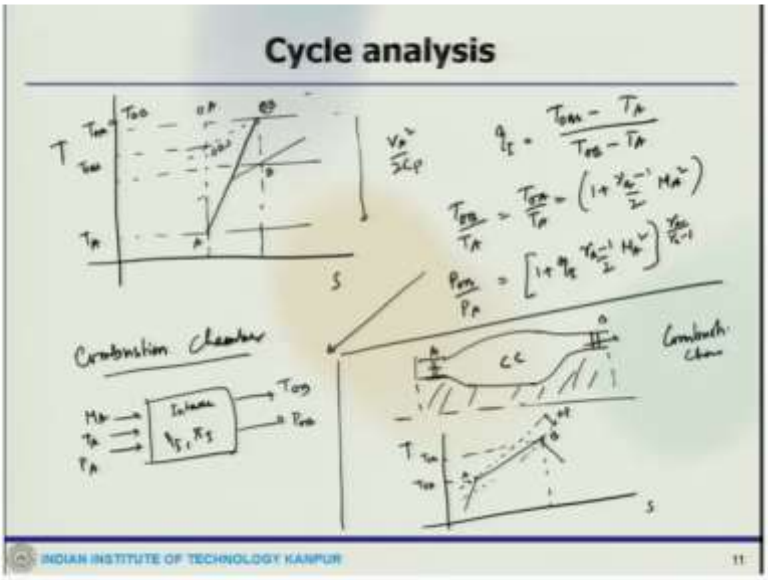

Then the TS diagram would look like the TS diagram so this is what I am here going there so like this so that is point A that is point let us say B. So, this is B this is 0A so this is 0BS. Now we have this temperature is T_{0A} which is T_{0B} this temperature is T_{0BS} then we have this portion which is completely $\frac{V_A^2}{2C_p}$ this is T. So that is how the TS diagram would look like.

So what one can write the isentropic efficiency is for the intake

$$\eta_I = \frac{T_{OBS} - T_A}{T_{OB} - T_A}$$

Where

$$\frac{T_{OB}}{T_A} = \frac{T_{OA}}{T_A} = \left(1 + \frac{\gamma_a - 1}{2} M_a^2\right)$$

and

$$\frac{p_{OB}}{p_A} = \left(1 + \eta_I \frac{\gamma_a - 1}{2} M_a^2\right)^{\frac{\gamma_a}{\gamma_a - 1}}$$

where the static temperature TP and the total condition all with a 0. So that is how you can look at the intake module and now we can see the second module is the combustion chamber or burner.

So this we can see a sort of an diagram the combustion chamber could be where this is you have intake now you have η_I, π_I. so π_I is the pressure ratio you got input M_A you got T_{0B} you got P_{0B} and you have T_A you got P_A. So that is what happened in the intake now what happens in the combustion chamber. Now this is what is happening at the intake that means what you give input you get it.

Now the combustion chamber let us say we have a sort of an combustion chamber like this and the geometry of like that. So this kind of things so let us say this is point A this is B this is the combustion chamber so this is drawn in an axi-symmetric fashion just to show you so here the TS diagram for the combustion chamber. So this portion is the combustion chamber so the TS diagram would show like this A to B. So that is the Delta P this is A T_{0A} and this is T_{0B} so the two point where it happens again we can use the first law of thermodynamics and continuity equation.

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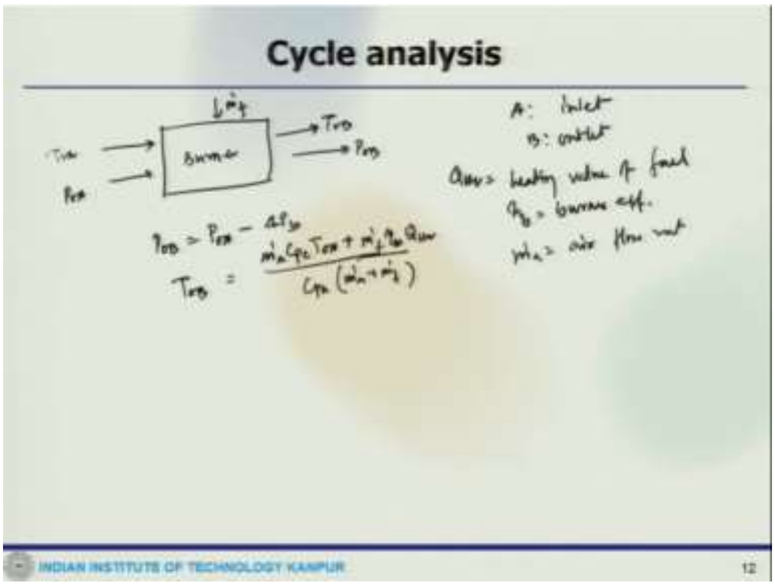

Now the block diagram for the combustion chamber could be like this this is the burner let us say what comes in T_{0A} what goes out P_{0A} here $\dot{m}_f$ and this goes out T_{0B}, P_{0B} and so here A is so every time inlet B is outlet. Similarly, for the integral so we have used that kind of fashions so now here the and Q_{HV} let us say heating value of fuel and air mass flow rate and $\eta_b$is burner efficiency.

So what we can write like

$$p_{0B} = p_{0A} - \Delta p_b$$

and

$$T_{0B} = \frac{\dot{m}_a C_{p_c} T_{0A} + \dot{m}_f \eta_b Q_{HV}}{C_{p_h}(\dot{m}_a + \dot{m}_f)}$$

So $\dot{m}_a$ is the air flow rate and the C_{p_c} is cold air specific heat and the C_{p_h} is the hot ait specific heat. So that is how so first what we are going to look at like this different individual modules like we have looked at the intake and then now looking at the burner.

Similarly, we look at the nozzle before moving into the complete set of complete engine analysis for the Ramjet. So, we will look at these components like what we have done then we move to the next one. So just we will stop the discussion here and continue the discussion in the next class.