Introduction to Airbreathing Propulsion

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Lecture - 36
Stationary Components: Intakes

So we have now discussed so far all the RAM-based cycle and turbine-based cycle, that means essentially and also the hybrid engine, all the discussion on the cycle analysis, performance analysis, all this. Now we are going to look at some of the components of these things and we will start with some of the components, like start with intake, then we look at some of the discussion we will do on combustor and then do some discussion on nozzle and then we will move to the turbo machinery part, where we will look at compressor, will look at turbine in detailed analysis and how individually they perform, their design consideration and all this.

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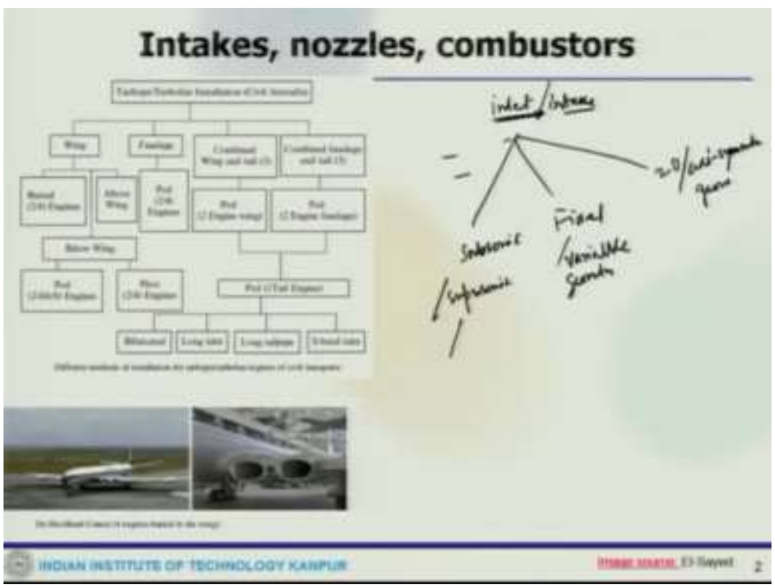

So let us start the intake, I mean, basically any air breathing engines which are installed in aircraft, they must be provided with an air intake. Now essentially this is a classification of different kind of things, which is possible but the performance of an air inlet which should give our intake that should like deliver exact amount of air, which is required for flight phases. So then it should diffuse air with maximum static pressure rise with minimum total pressure loss.

Then recover flow directions, distortion or separation, achieves least possible external drag to the system, then provides good starting stability, achieves low signatures like noise and all these and also minimum these things. So essentially these can be classified into three categories; one is subsonic, then it could be fixed or variable-geometry, or it could be subsonic or supersonic fixed or variable-geometry or 2D or axi-symmetric geometry, so sort of these things.

Now first thing, we can start with the looking at the subsonic aircraft. So the subsonic aircraft also like it could have, for example the subsonic aircraft can have turbojet or turbofan engines. So even turbojet or turbofan, there are different kind of methods which are used one could be wing installations, like so there could be wing installation. There could be fuselage installed, a fuselage even number of engine, wing or tail combination. So in these, first thing we start with the turbojet and then in the wing installation also there could be like this kind of buried in the wing, where 2 or 4 engines are there.

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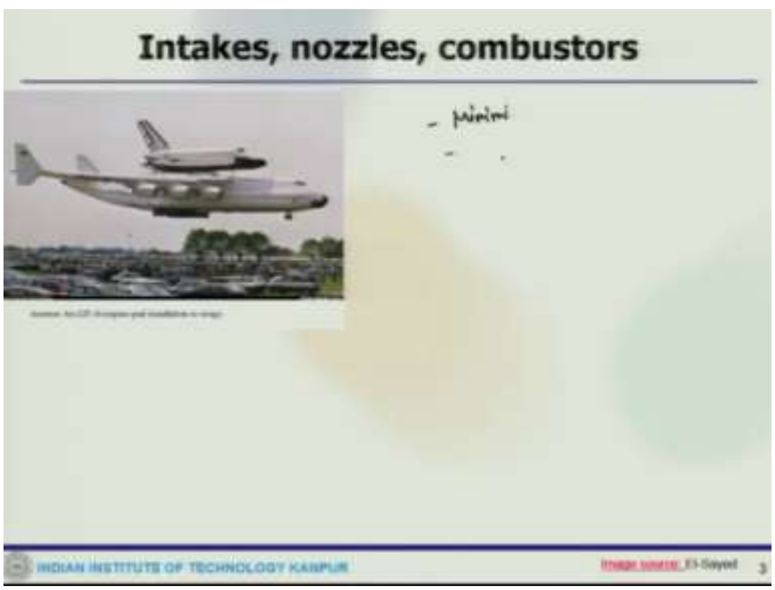

Or there could be this kind of, so when you talk about this let us say the buried wing, this also has some advantages like minimum parasitic drag or probably minimum weight, then minimum yawing moment in case of engine failure, but some disadvantages are there. It poses a threat to the wing structure in case of failure or something. Now also very difficult to maximize the inlet efficiency, larger diameter engine is required, difficult accessibility.

These are some of the disadvantages, so which eliminates the flap in the region. Now you can have this is a pod installation. So this type of installation, the engines are attached to the wing via pylon. Most engines nowadays have pod installations, like this, like Boeing 737, 757 and all these. So this type and Airbus 320, 330, 340, 350, 380 whatever you can think about. So it has some advantages also like it minimizes the risk of one structural damage in case of engine fire or the blade risk.

It is also simple to obtain high ram recovery in the inlet for this angle of attack, since the angle of attack at the inlet is minimized, then easy engine maintenance, less noisy, the weight of the engine reduces the wing team operating. Then also has some disadvantages like low wing aircraft like Boeing 737, the engines are mounted close to the ground. So that may tend to stuck dirt, pebble, rock or something like that.

The high temperature or high dynamic pressure exhaust impeding the flap can increase the flap load also weight and may require titanium structure, which is more expensive, strongly yaw effect and some of this.

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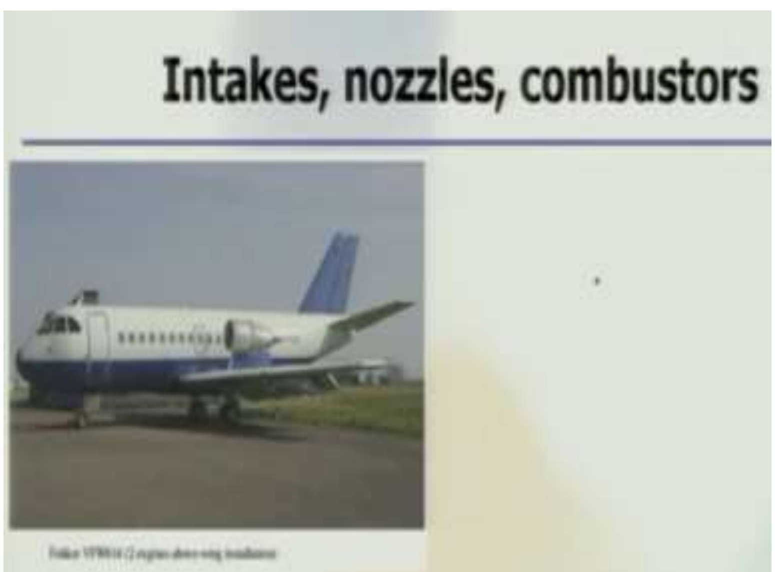

Then another possibility could be above the wing, when you can install like this. So these are airplane where above the wing it has another different kind of advantages like it prevents foreign object into the engines, water ingestion into the engine for sea planes during takeoff or landing, improves wind lift due to blowing over the wing upper surface, reduces also noise level, but at present and in future increasing stringent civilian aviation noise regulation also will require the design and manufacture of extremely quiet commercial aircraft.

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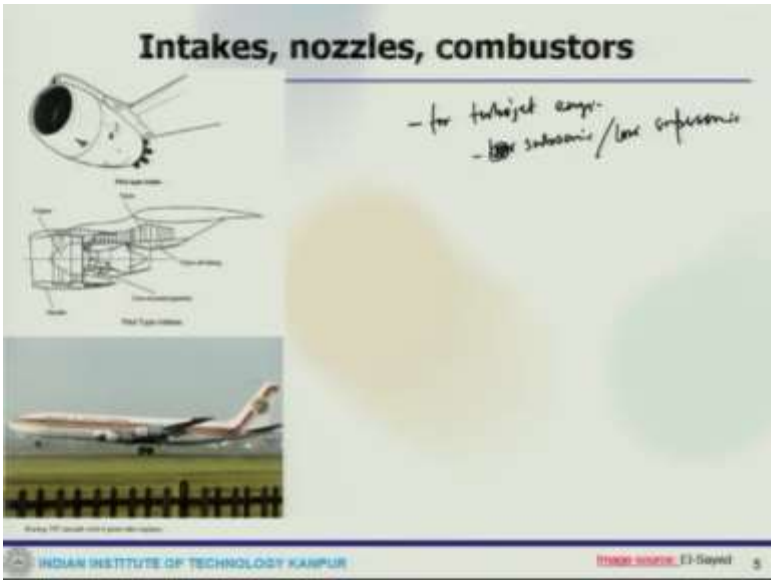

So now another option could be, this is another which is Boeing 707, where this is a pitot type. Pitot type is an ideal air intake for turbojet engine. This is for turbojet engine, flying it low subsonic or at subsonic or low supersonic, so a Boeing 707 airbus 300 aircrafts, like there. Then other one could be you can have like fuselage kind of installation.

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Like this is a fuselage kind of installations where aircrafts are either powered by two engines. So this has also advantages like greater maximum lift coefficient, less drag due to wing pylon, exhaust flap interface, less asymmetry yaw. However, this installation has also some disadvantages, like center of gravity of the empty airplane is moved aft on weight runway that will kick water at very high angle out of the knuckle with blank at T-tail and may cause tall vibration and noise. So these are also some possible issues with that kind of installations.

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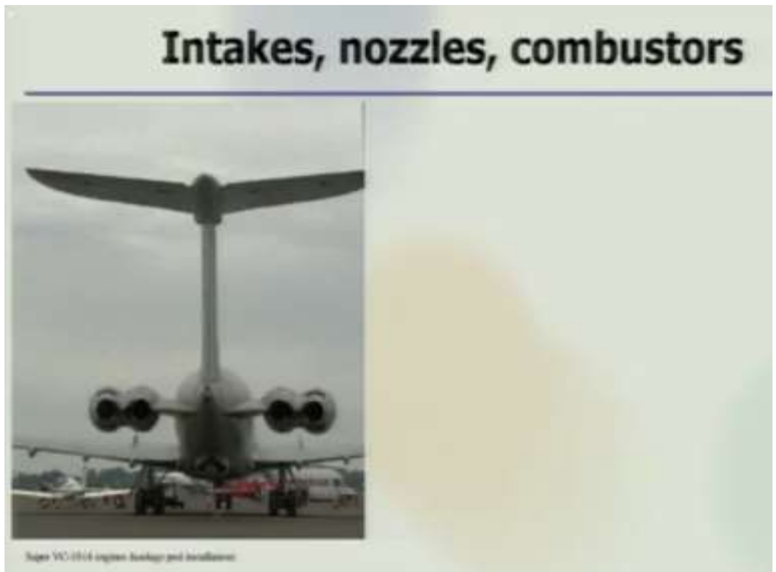

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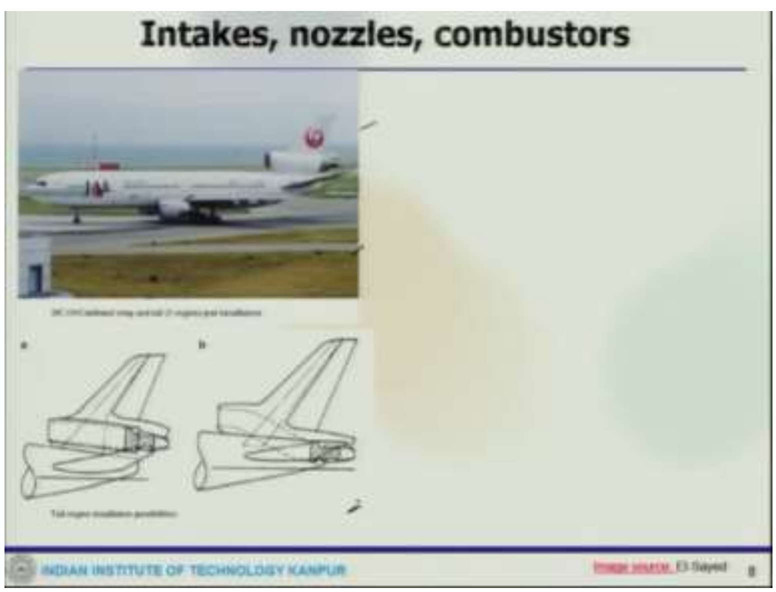

One can have a separate example like this kind of installations; this is called the combined wing and tail. So these are having sort of three engines, so tail installation represents a center engine installation, only one turbofan engine is installed in all available tail combination with either wing or fuselage arrangement. So there are four different arrangements which could be possible bifurcated inlet, long inlet, long tail pipe, S-bended.

So this also has some advantage, this kind of engine. It is mounted very far aft, so a ruptured turbine blade or disk will not impact the basic steel structure, high thrust reverser without inferring control surface effectiveness, but obviously there are some disadvantages. Inlet loss is quite high, maintenance and repair is also very difficult, then like one of the S-bend kind of installation is like this, what it shows?

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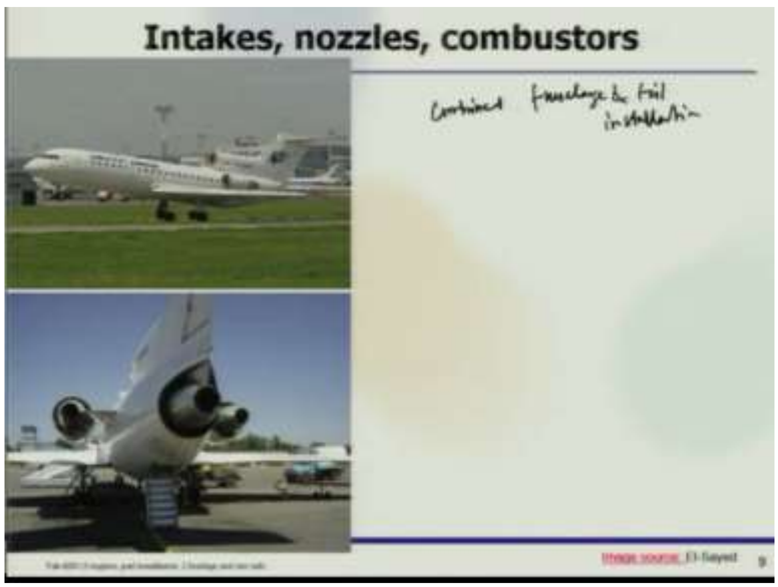

Then we can have like this is a combined fuselage and tail installation. So this is again used for Boeing 727, TU-154; these kind of installations are used.

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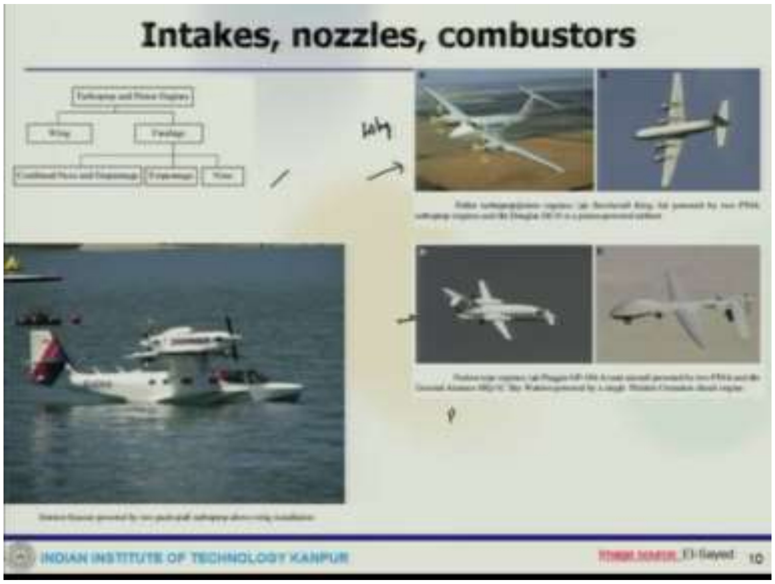

Now we can go to other one which is a turboprop installation where there could be wing installation or fuselage, combined noise impairments or noise, so wing installation. We can have like this kind of thing which are wing installation, these are wing installation, then also pusher type. This is pusher type that kind of installation is there. Now this is another example where you have this is a Dornier's Seastar, a wing flying boat with two engines mounted on a single nacelle. So this is another.

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Now we can look at some of the fuselage kind of installation here. Now an empennage installation is here. This is an example of it. So you can see different kind of installations.

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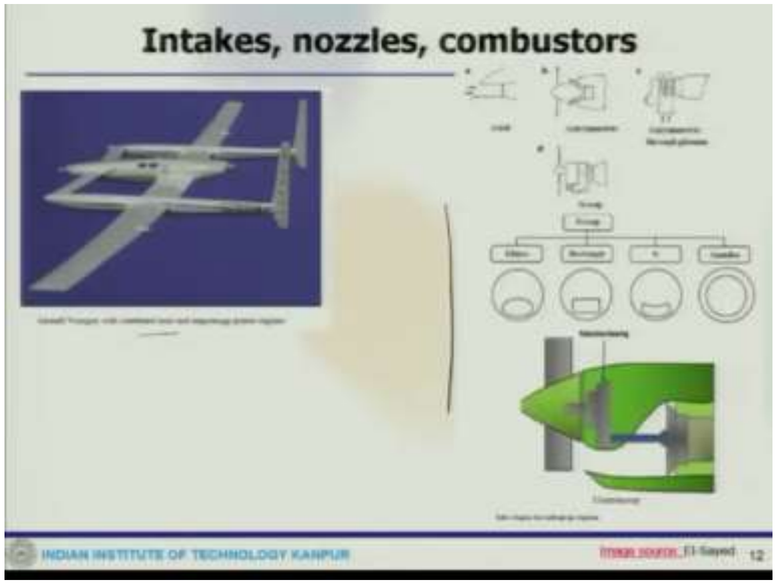

And finally when you see the combined noise and empennage piston engine, this is how it looks like. Now from subsonic or supersonic, we can go to like supersonic aircraft and supersonic aircraft are also like. So another thing is that intake of turboprop engine may have different shapes, depending on the size and location of the reduction gearbox coupled to the propeller. Inlet may be axial, axi-symmetric. So these are the different things.

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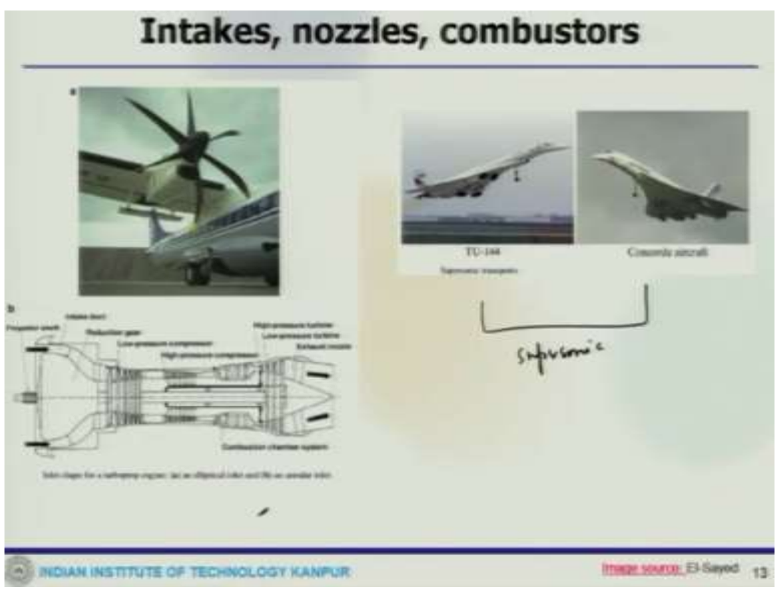

And then also it shows the elliptical inlet and annular inlet like that. Now here we go to an example of supersonic aircraft where you have intake of like this is in TU-144 and Concorde. Then we can look at some of the applications of military aircraft, which are either used.

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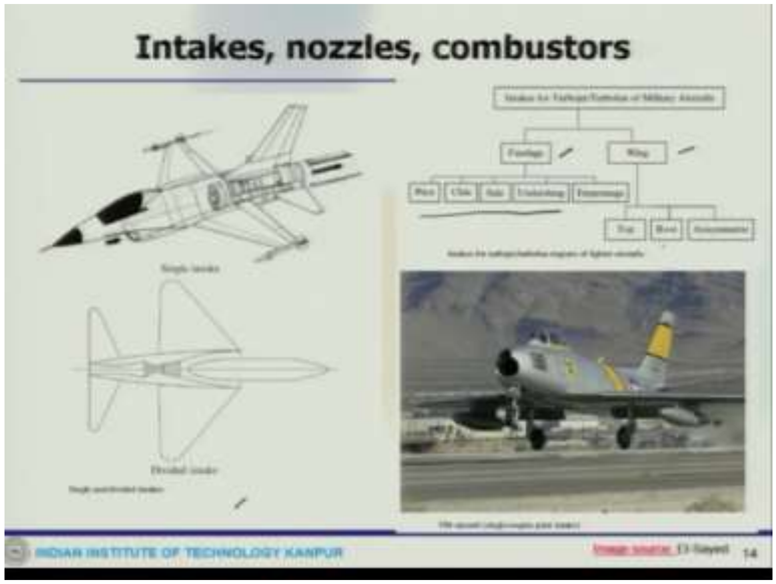

These are military aircraft either used by turbojet or turbofan, most fighters have one or at the most two engine situated inside the fuselage. So for military aircraft either you can have fuselage or wing, then pitot, chin, these are on the top, root, axi-symmetric. So, this is an F-86 engine which is a nose inlet employed on the F-86 US fighter.

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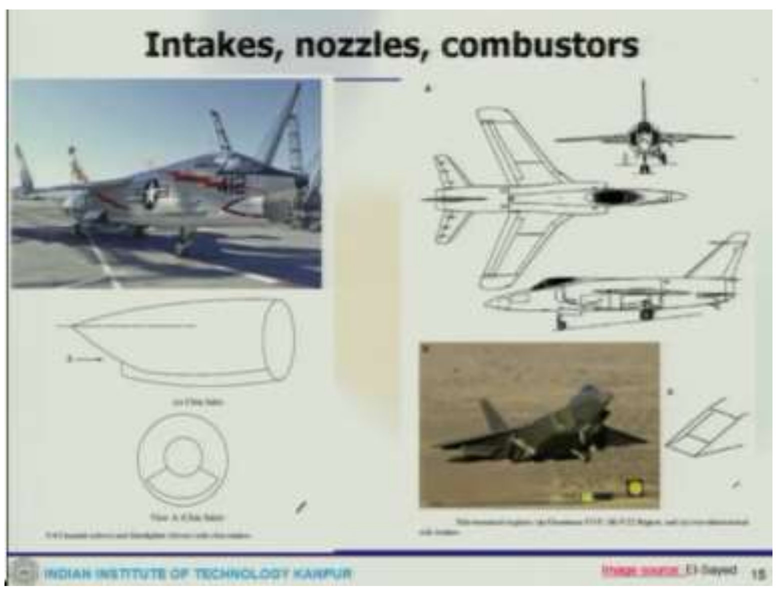

Where the chin inlet can be seen in this one. So this is a chin inlet, what you can see how the chin inlet looks like, then side mounted inlets. These are side mounted inlets for Grumman F11, F-22 raptor. So this how they look like. So these are different state of inlet.

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Then one can look at also the wing installation. So wing installations will give you an idea. So now this one this F-16 has under fuselage intake. So this is a slightly different intake and then we have this Thunderbolt 2 which has also empennage kind of inlet. Now moving forward if you look at the wing installation, this is a one kind of wing installation. So this is Vulcan B-2 bomber with 4 engines installed at wing root. This is B-2 Spirit Stealth bomber with 4 engines. So these are also winged installation and then you can say unique wing installation is found in SR-71, where it is powered by 2 turbojet engines having variable geometry, axi-symmetric inlet.

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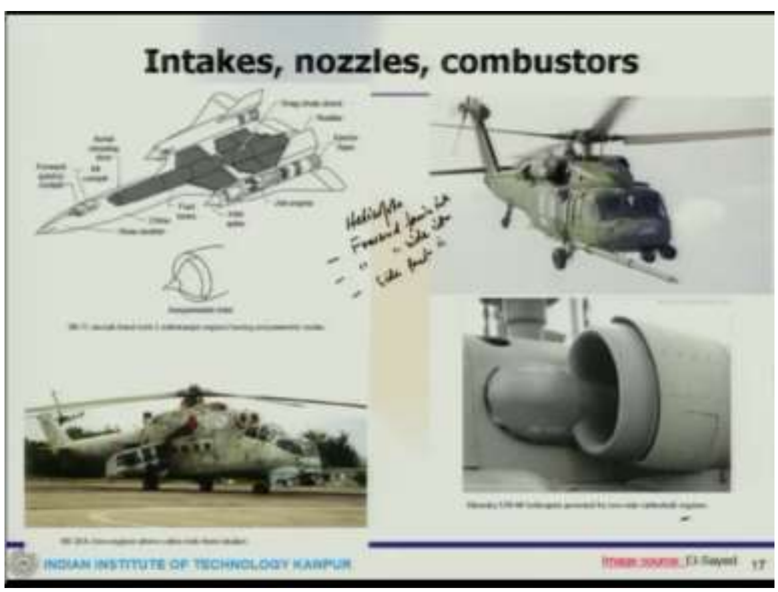

Now also helicopters will have two different kinds of intakes; one is forward-facing intake. So helicopter can have forward-facing intake. This can have forward facing side intake, then it can have side facing intake. So this is what forward facing pitot intake with source, then this one here it shows the forward facing side intake.

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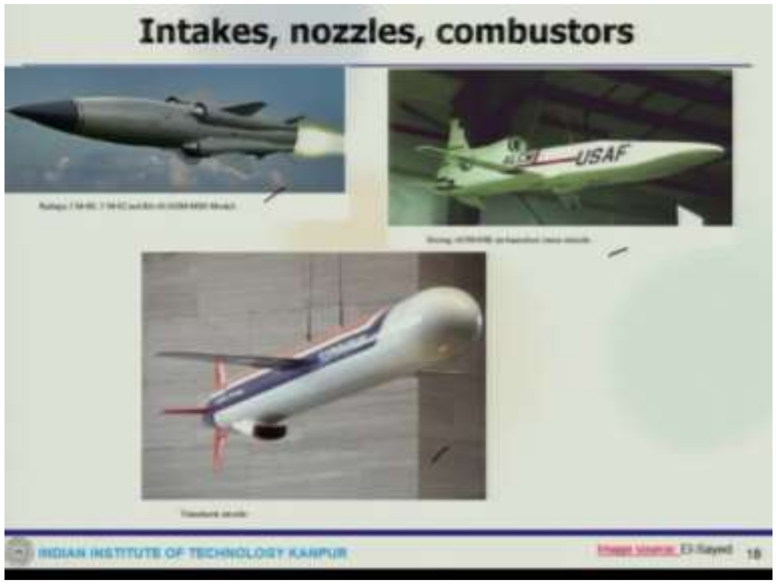

Now moving ahead, we can look at also some of the rocket. So there are ramjet engines. So this is ramjet engines, then there could be turbojet engines, so this is a turbojet engines.

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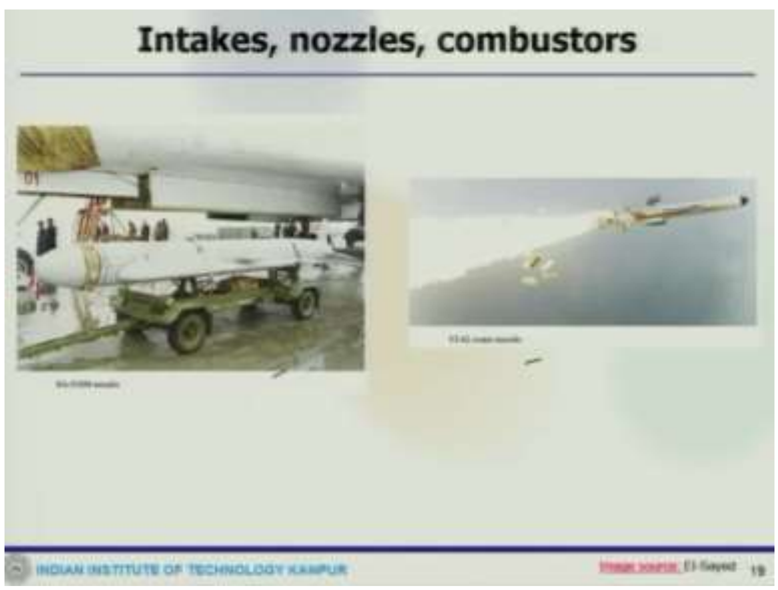

And so also there could be two spool. Now these are in the missile also they can have similar to this. So this has some two spool turbofan engines TVD50. So there are different kind of engines which are possible.

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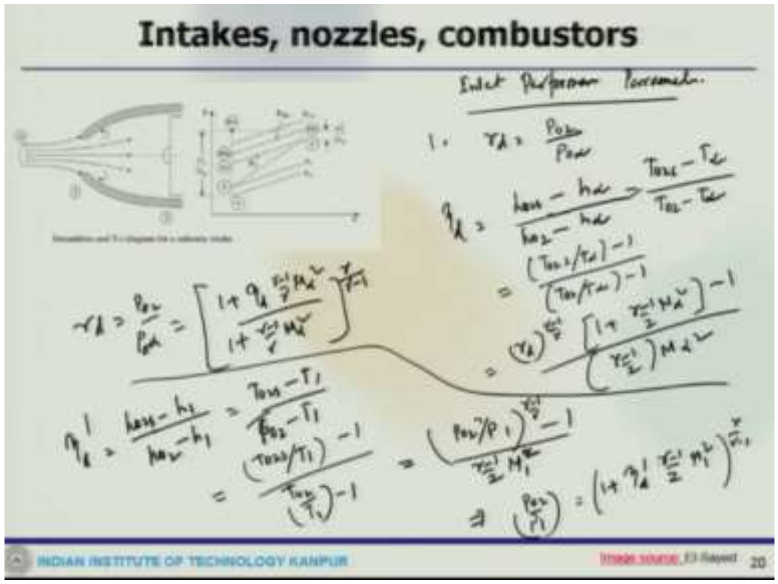

And now if you look at the inlet performance parameters, what happens inlet performance and the total pressure recovery

$$r_d = \frac{p_{02}}{p_{0\infty}}$$

and so the isentropic efficiency of the intake η_d which could be define as

$$\eta_d = \frac{h_{02s} - h_\infty}{h_{02} - h_\infty} = \frac{T_{02s} - T_\infty}{T_{02} - T_\infty} = \frac{\frac{T_{02s}}{T_\infty} - 1}{\frac{T_{02}}{T_\infty} - 1}$$

So this could be defined as

$$\eta_d = \frac{(r_d)^{\frac{\gamma-1}{\gamma}}\left[1 + \frac{\gamma-1}{2}M_\infty^2\right] - 1}{\left(\frac{\gamma-1}{2}\right)M_\infty^2}$$

Now the stagnation pressure ratio which is

$$r_d = \frac{p_{02}}{p_{0\infty}} = \left[\frac{1 + \eta_d \frac{\gamma-1}{\gamma} M_\infty^2}{1 + \frac{\gamma-1}{\gamma} M_\infty^2}\right]^{\frac{\gamma}{\gamma-1}}$$

So, however, upstream of the intake is isentropic, so all losses are encountered inside intake or from state 1 to 2.

So in some cases the efficiency is different in the internal part diffuser. So $\eta_d{}'$ which is

$$\eta_d' = \frac{h_{02s} - h_1}{h_{02} - h_1} = \frac{T_{02s} - T_1}{T_{02} - T_1} = \frac{\frac{T_{02s}}{T_1} - 1}{\frac{T_{02}}{T_1} - 1}$$

So this gives us back that

$$= \frac{\left(\frac{p_{02}}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{\gamma - 1}{2} M_1^2}$$

so which means

$$\frac{p_{02}}{p_1} = \left(1 + \eta_d' \frac{\gamma - 1}{2} M_1^2\right)^{\frac{\gamma}{\gamma-1}}$$

Also there could be air distortion at the intake outlet. So that also often encountered when the real flow is associated with some degree.

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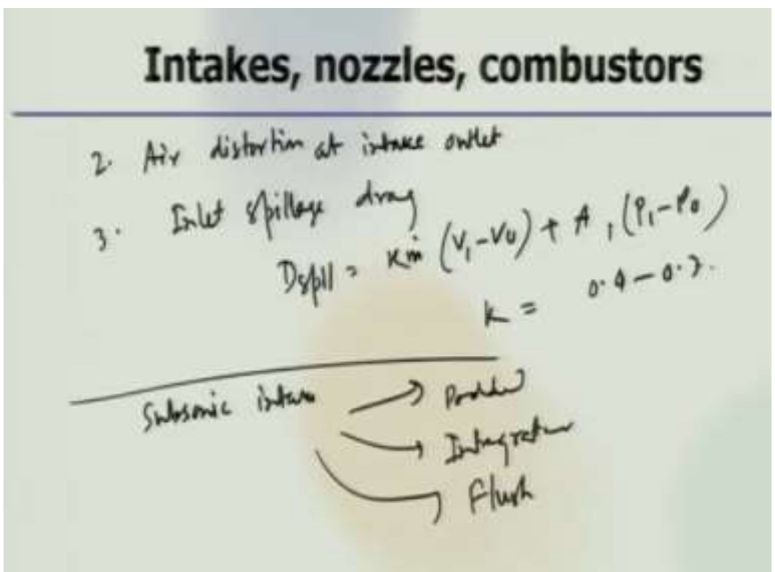

So that means air distortion at intake outlet, then there could be inlet spillage drag. This is the drag occurs when the engine cannot handle all the flow that approaches the inlet. So the theoretical spillage drag would be

$$D_{spill} = K\dot{m}(V_1 - V_0) + A_1(p_1 - p_0)$$

where k ranges from 0.4 to 0.7, which is a constant determined by experiments. Then one can have subsonic intakes. So these could be podded, this could be integrated or it could be flush. So these are different kind of intakes which is possible.

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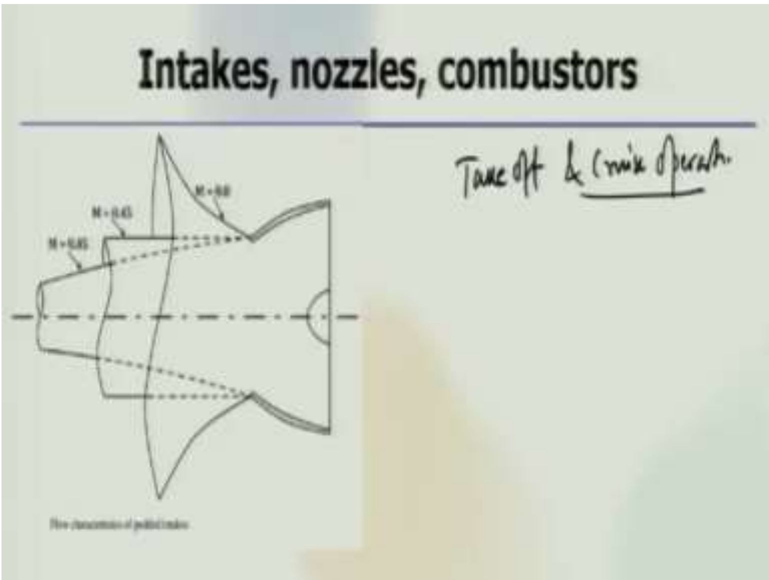

Now this you can see, there is characteristics of a podded intake for different flow conditions, because the inlet does not have thermodynamic work and the total temperature through the intake is constant. So then, there could be also takeoff and cruise operation. So takeoff and cruise operation, so there could be like depending on the fly speed the mass flow demanded by the engine, the engine may have to operate a wide range of incident conditions.

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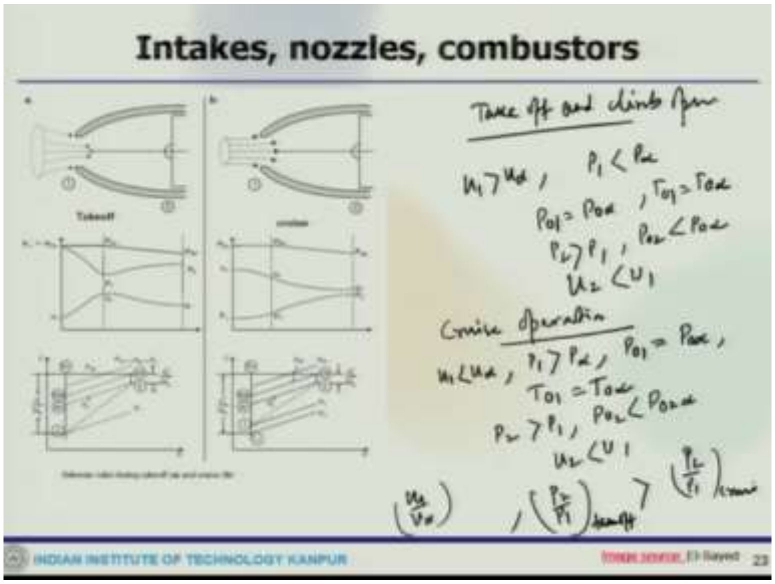

So you can see what happens during takeoff, this is how the intake will behave here and this is what is going to happen when there is a cruise. So takeoff and climb operation, during low speed high thrust, so the engine acts as a sink to the floor assist to this. So during that when

$$u_1 > u_\infty$$
$$p_1 < p_\infty$$
$$p_{01} = p_{0\infty}$$
$$T_{01} = T_{0\infty}$$
$$p_2 > p_1$$
$$p_{02} < p_{0\infty}$$
$$u_2 < u_1$$

So these are the conditions which are satisfied during that time. Now when we go to cruise operation, that time the condition is that

$$u_1 < u_\infty$$
$$p_1 > p_\infty$$
$$p_{01} = p_{0\infty}$$
$$T_{01} = T_{0\infty}$$
$$p_2 > p_1$$
$$p_{02} < p_{0\infty}$$
$$u_2 < u_1$$

So for cruise condition to avoid separation or to have less severe loading on the boundary layer, it is recommended to have low velocity ratio, like $\frac{u_1}{u_\infty}$ and consequently with less internal pressure lies like

$$\left(\frac{p_2}{p_1}\right)_{takeoff} > \left(\frac{p_2}{p_1}\right)_{cruise}$$

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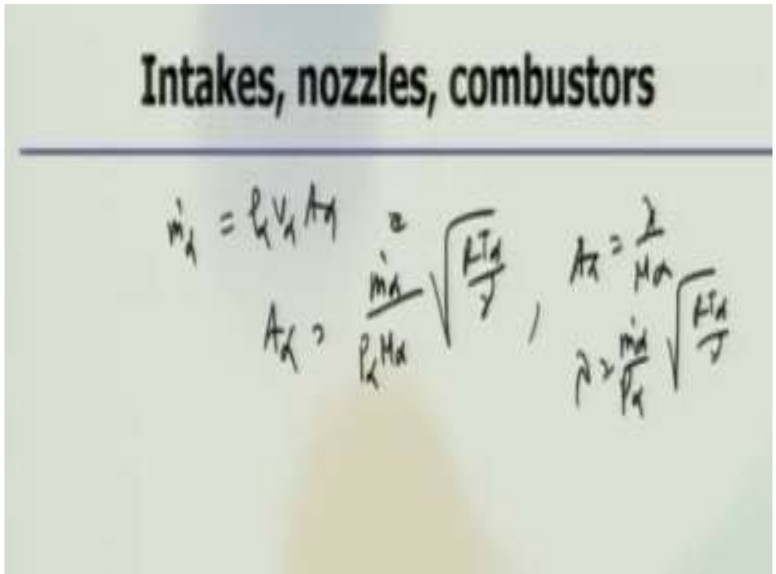

So now, we can capture an area of a turbofan case study like since from mass flow rate we have like we can see these things like

$$\dot{m}_\infty = \rho_\infty V_\infty A_\infty$$

which is now we can from here we get

$$A_\infty = \frac{\dot{m}_\infty}{p_\infty M_\infty}\sqrt{\frac{RT_\infty}{\gamma}}$$

and

$$A_\infty = \frac{\lambda}{M_\infty}$$

$$\lambda = \frac{\dot{m}_\infty}{p_\infty}\sqrt{\frac{RT_\infty}{\gamma}}$$

so this is from a turbofan case study and so we can get a ratio.

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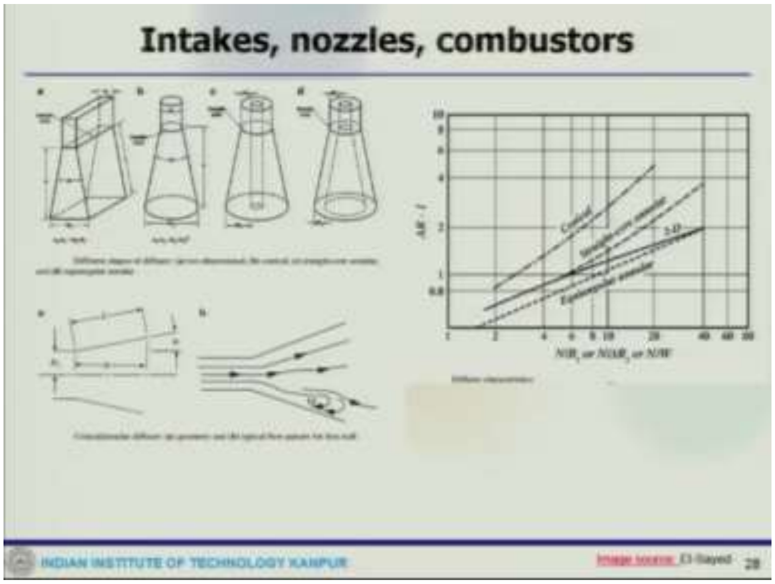

Now similarly, so what we have already seen that the different area angle can be also, I mean, area ratio and all this can be find out from the different configuration. So just to have a look at different kind of geometry like you can have different kind of diffuser 2-dimensional conical, straight cone and how the diffuser characteristics will perform and this is a conical geometry and typical flow pattern around that kind of diffuser. This is quite important to have a look that how these things actually behave. So then we can move to a supersonic intake.

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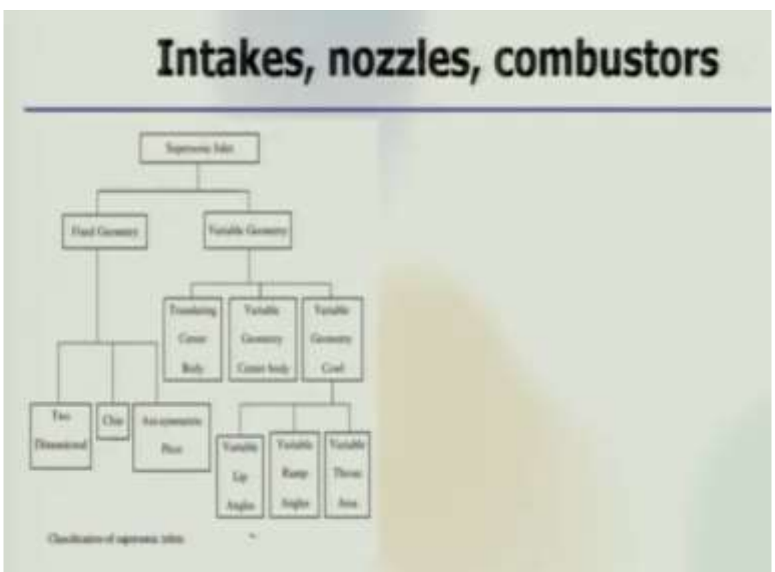

Where also supersonic intake would be 2 different types; that is fixed geometry, variable geometry and all these like two-dimensional axi-symmetric, fixed geometry also could be two-dimensional axi-symmetric or chin type translating center body and all these.

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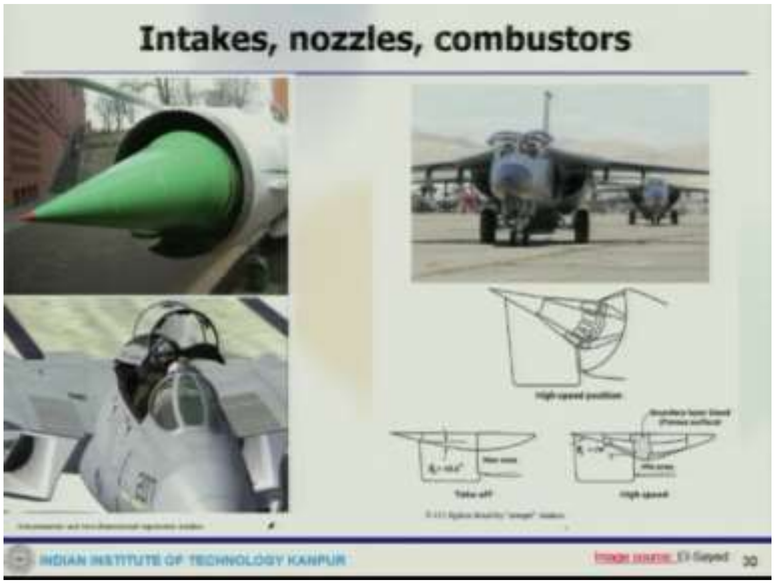

So this is an example of axi-symmetric two-dimensional geometry supersonic intake. This is a F11 fighter fitted with M take intake. So you can see supersonic fighter also; they have a different kind of intake, which are used.

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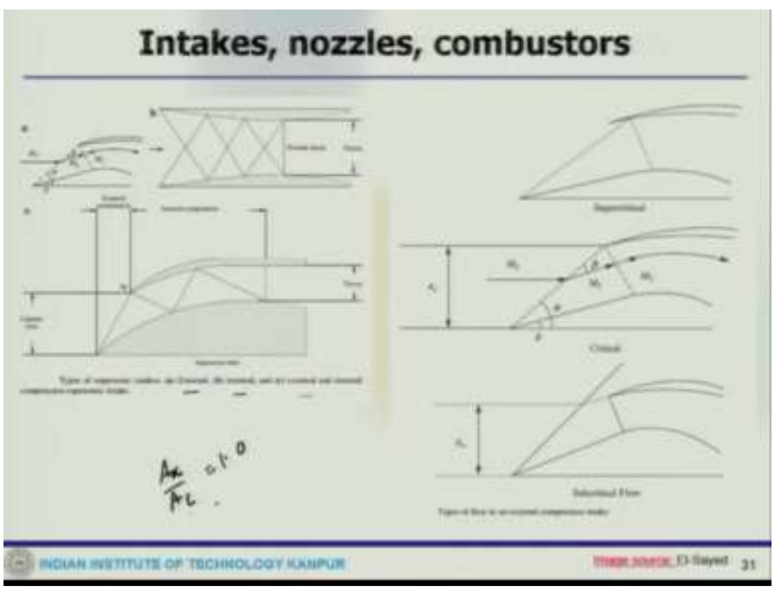

Again there could be another classification of the supersonic intake based on the shockwave pattern. So there could be external which is like this; there could be internal which is like this or external-internal combination. So this is another example of a classical external compression intake, where the shockwave pattern is shown and where one can say that

$$\frac{A_\infty}{A_c} = 1$$

So this condition Ac is for the critical flow condition. So this is what one can find out.

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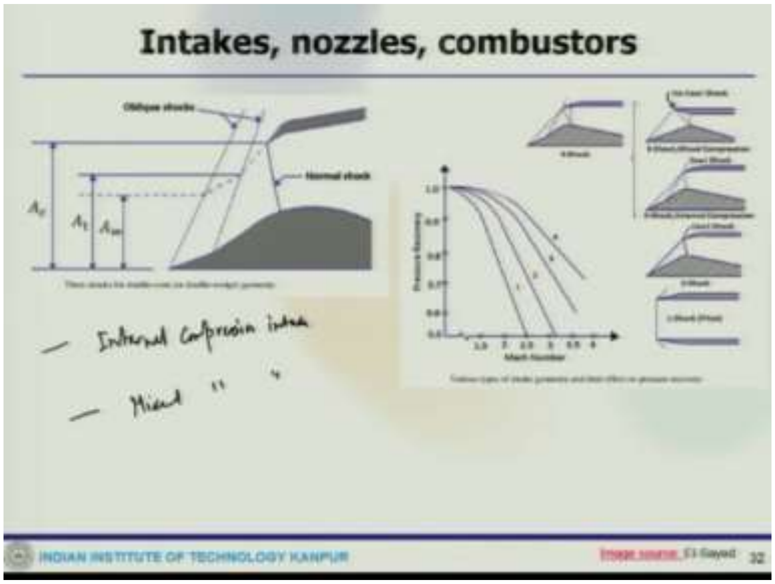

This is another intake pattern. So this is what A_c, A_1 and A_∞. So you can see oblique shock, normal shocks and all these are there and this is to make some remarks here that is the number of oblique shock increase the pressure recovery also factor increases from here up to Mach 2 equal deflections can be there. So this is another type of that, then so one can have internal compression intake. That is another or can have mixed compression intake.

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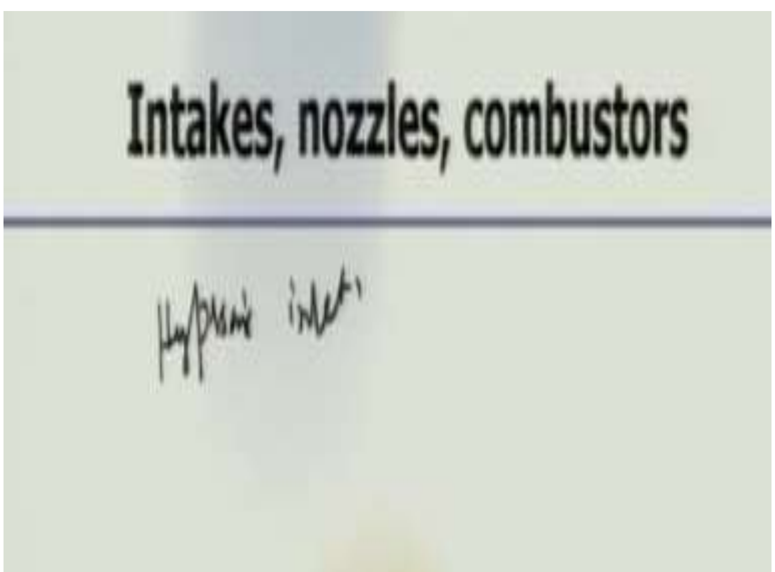

So these are also different kind of or the other one is kind of you can go to hypersonic inlets where all around the turboramjet or around these things that we have already discussed in details in the previous this thing. So this is all about the intake that we wanted to discuss upon, because we have already seen this analysis and all these also some of the different configuration and all this we have seen in the introductory lecture. So we will stop here and the next session, we will talk about the combustor.