Indian Institute of Technology Madras
Presents

NPTEL
National Programme on Technology Enhanced Learning

Aerospace Propulsion
Rocket Nozzles – Thrust Vectoring

Lecture - 23

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In the last class we had talked about how the plug nozzle would have a better performance off design performance let us look at it in this graph.

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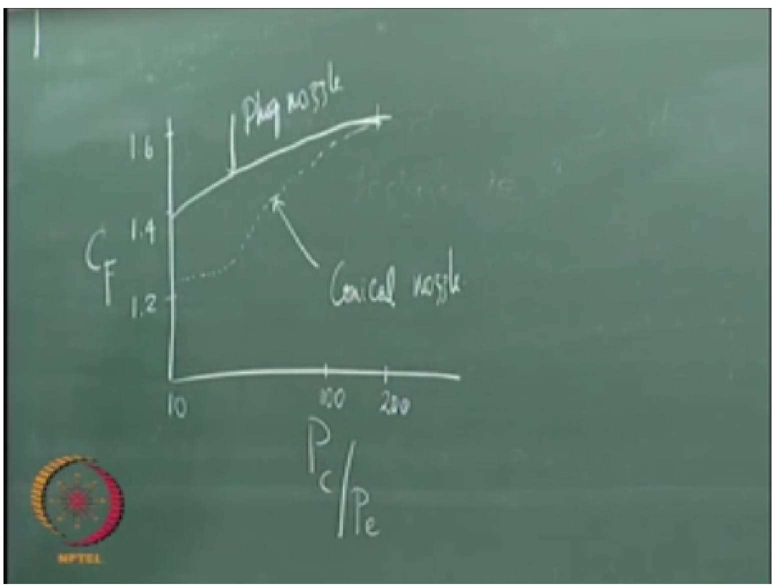

If we have P_C / P on the x-axis and C_F on the y-axis this is a log scale, so if you have a nozzle design for some high-altitude conditions and we are here a conventional nozzle or a conical nozzle will go like this whereas a plug nozzle will have a superior performance throughout this is okay, so the conical nozzle has a much inferior altitude at conditions other than the design conditions it is performance is not as good as a plug nozzle or a narrow spike nozzle, so next we move on to the other topic that is thrust vectoring right thrust vectoring is something that is used by all missiles as well as launch vehicle.

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If you look at the tactical missiles that is these are small rockets and if you look at what the level of thrust that they produce the accelerations that they have initially is of the order of ng so they very quickly go to a very high velocity, so which is why you do not need any control in the booth space they usually have something known as a boost phase wherein the thrust is very, very large and it goes to very high accelerations due to gravity the acceleration achieved are very high and after which they will have a sustained phase which will essentially keep it at that particular Mach number okay.

So for such rockets or tactical missiles aerodynamics is a very good aerodynamics offers very good way to control the motion of this as in, if you want it to wear around to a target and other things you can have fins and you can make it make it go towards the target very easily, but if you look at launch vehicles and strategic missiles that is long-range missiles when they take off their accelerations are very, very small typically of the order of 1point 6 g to 2 g they are not very large.

So as they are going up they are going up very slowly and crosswinds can take them in a direction that is not intended, if you have strong crosswinds now once we cool you can put off the launch by a few hours you can say till the weather gets into some kind of reasonable conditions you are not going to launch it and you will wait for that time to launch it but missiles you cannot afford to do that because you need to be ready every time yeah even in launch vehicles you would still want some kind of control in this period of launch where and the velocities are very small.

Up to it the time that it reaches a Mach number of around 0.5 aerodynamic control will not be very, very effective right, so it is unlike aircrafts where unlike aircrafts will have a very large surface area right the wingspan is very large, so it can produce substantial lift here you do not want it to have so much drag associated with any control surfaces you wanted to be minimal so you will have very small things, so a under these conditions you would need something known as prospect ring that is can you change the direction of the thrust itself so as to take the vehicle in the direction that you want it to go.

In addition if you have looked at launch vehicles let us say PSLV or something like that you will find that it has a main core and on the side it has small strap points right PSLV has 6 strap-on motors, now the nozzle of all these boosters are in such a way that their tented away that is the thrust that it produces is at some angle to the vertical axis right, so if this is the axis and the thrust produced is not parallel to it but at some angle right so if all of these thrust vectors meet at some common point on the axis.

Then it is perfectly balanced otherwise there is some imbalance and you need to have a counterforce to overcome this it you need to have a control force capable of overcoming this otherwise the vehicle could we are in a direction that is not intended, so for all these things you need this thrust vectoring okay now thrust vectoring can do all this that is it can allow the vehicle to rule yaw and pitch in this class we will concentrate on what are the ways in which we can vector this thrust.

What are the means that are available and what is it that is practiced and what can also be done okay, now typically thrust vectoring there are three modes that are usually followed one is.

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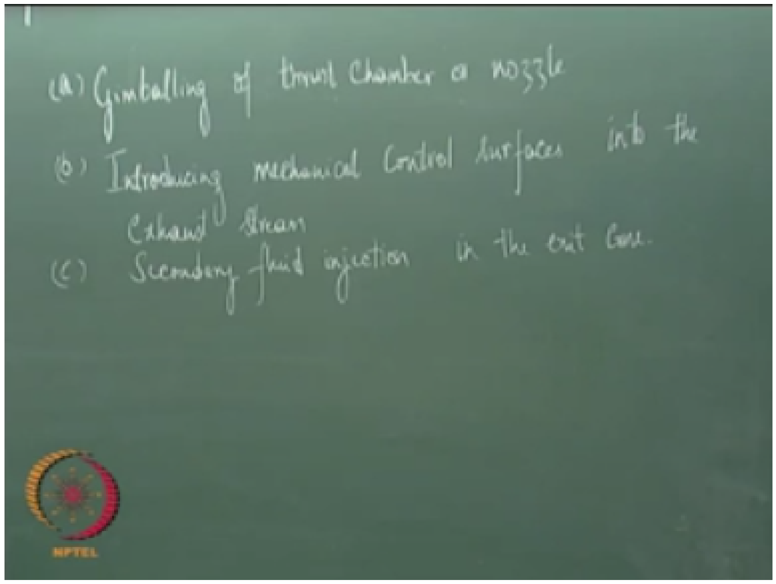

Jim balling of trust chamber or nozzle or introducing mechanical control surfaces or second wave fluid injection in the exit coup we look at each of them in a little more detail in this class now firstly Jim balling the thrust chamber or the nozzle, if you look at a liquid engine liquid engines typically the propellants are not stored in the engine or in the chamber where it produces thrust that is the fuel and oxidizer mix in, but so it is stored in a separate chamber so the engine is as itself will be very small.

So you can look at moving the engine in two different planes to get the control force that you require okay that is possible in a liquid engine.

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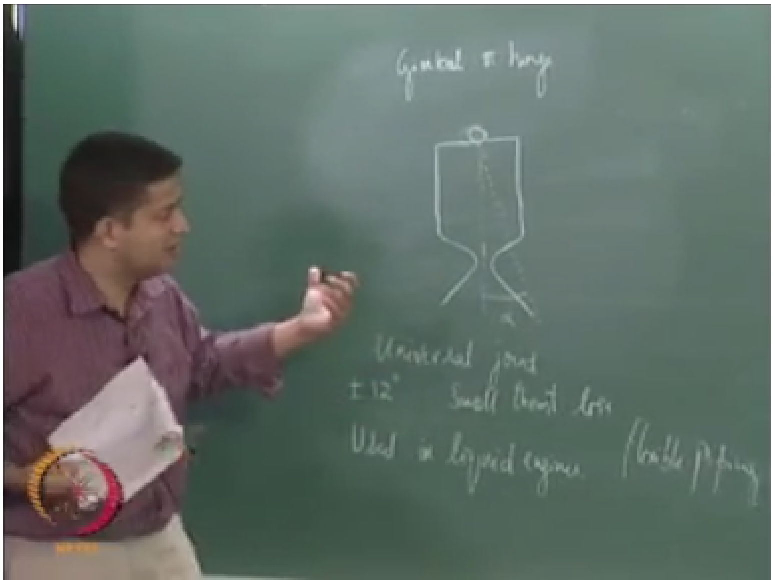

That is if the engine were hinged on this you could move it around by an angle α in either direction and if you have something known as a universal joint Universal joined us nothing, but if you have two hinges right if you have two hinges like this using one of them you can move it in one plane using the other one you can move it in the other plane right, so using both of them you can move it and two different planes that is what is a universal joint, if you have the entire engine mounted on a universal joint.

Then you can move it in this plane by α and also in the plane perpendicular to the board by an angle α okay, so that is what a gym ball or a hinge will do as you can see if the engine is moon who overall engine is itself moved by an angle then the thrust produced will be the cause of this angle right, so it will be lesser than the actual thrust so you would not lose some amount of thrust by vectoring the thrust itself so you can using this move the entire vector the thrust by plus 0 12^0 and there will be a small thrust loss.

And this is typically used in only liquid engines that is because as I said earlier, if you look at solid engines the entire propellant is also inside the motor, so it would be very difficult to move the entire motor because the weight of the propellant is also there whereas in a liquid engine the propellant is stored elsewhere and only thing is you need to have flexible hosing otherwise it will not allow this kind of movement okay.

So you need and you need also large actuators to move this and the critical thing is, if you look at this the entire thrust of the engine is transferred through this hinge or the gym ball, so this needs to be very carefully designed because this is a very critical parameter I mean very critical element because the entire thrust is transferred through this element to the rest of the vehicle okay so this needs to be carefully designed instead of Jim balling the entire engine the other option is can we just move the nozzle itself and that is called as a flexible nozzle.

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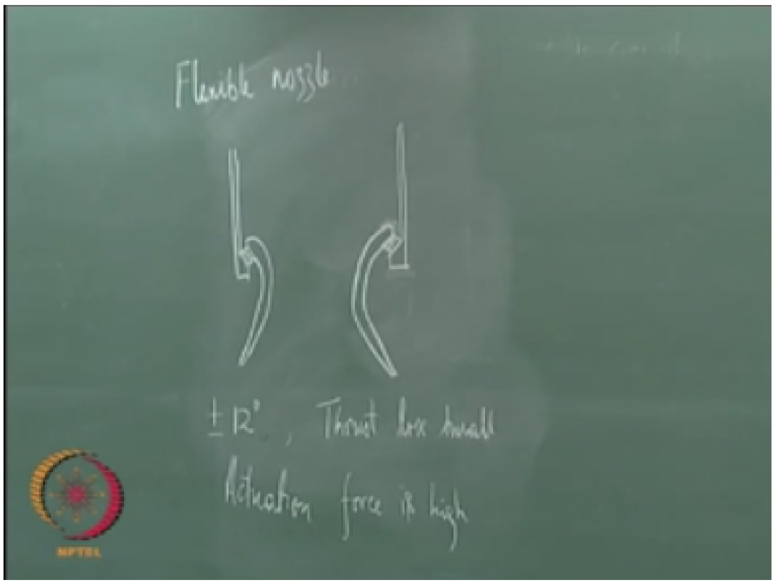

So if you have an actuator and move this nozzle alone right then you can get the same desired effect of vectoring the thrust only thing is this joint needs to be flexible here and allow for movement okay this can also give + 1 – 1 and again there will be a small thrust loss because you are anyway vectoring the thrust, so the cause of the thrust is the only one that is available in the axis along the axis this has also been used in both solids and liquids rockets here you can use it in solid rockets.

Primarily because you do not have to move the entire motor you are only moving the nozzle but still the actuation force required here is also quite significant you need the last of this variety is again, if you have something like a ball and a socket joint instead of this one you can move the nozzle.

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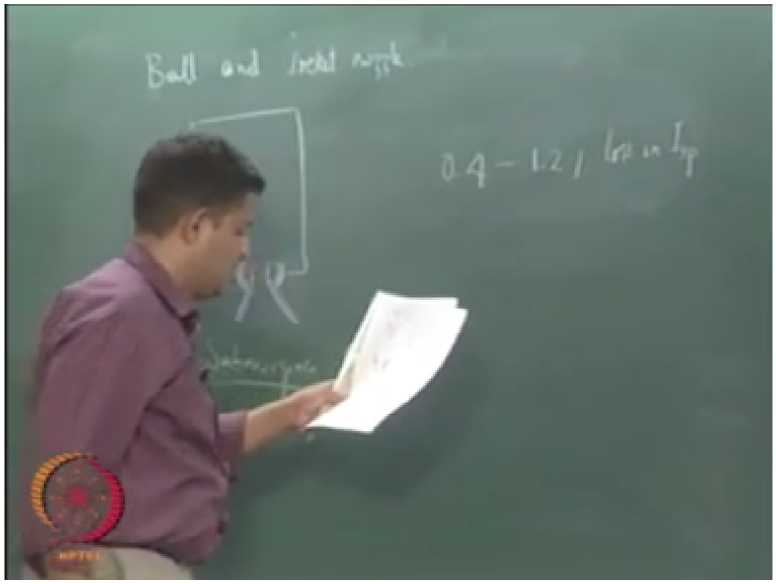

If you have it mounted on a bearing then you can move it and therefore get the required trust metric, now in both these methods the nozzle in some sense is submerged inside the motor and this leads to something known as submergence loss primarily, if you look at the gases coming out they need to you would also have propellant stored in this direction, if it is coming in this direction it is a lot easier otherwise the propeller the gas is coming from burning of the propellant in this region will have to turn through a large angle.

And that will lead to some losses because the flow will now have to turn through a large angle to get to the nozzle and that is given by something like it varies between 0.4 to 1.2 % loss in ISP and if you remember the discussions that we had in the morning that is if this propellant were aluminized propellant right, then we discussed that the particles noon or us condensed particles do not expand and they cause loss right this gets coupled with that and depending on the percentage of aluminum present in the propellant.

And the amount that the nozzle is submerged the loss could be higher I mean this it is within this range it could be higher, if it has more submerged lesser if it is less submerged the next set of control that we can get is from mechanical control surfaces here.

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If you are using mechanical control surfaces what you will have is something getting into the exit flow and therefore you are going to obstruct the flow and cause the require prospect jetovator are something like this, if you have a rocket motor this at its normal position it is something like this and if you want to have a side force you could change its position to something like this, so this does not protrude into the flow in its normal position but when you change its position on one side you get overexpansion and on the other side you get a little bit of enter expansion this causes a side force okay.

So you are going to get a small amount of thrust vectoring if you are using this you will get something like + 1 – 7^0 of thrust victory and compared to the previous ones this is a lot better in that sense that firstly it does not require a very large actuator actuation power right, because you are only looking to actuate a small surface and therefore the power required is smaller here these are used in solid rockets, yeah this small portion is dotted line it is it is in line with the nozzle when it is not doing anything right.

You can then rotate it and on one side it will it will be flush with the nozzle, so it will act as on one side it will over expand and on the other side it Lander expand and therefore give you the required side force then there are something known as jet tabs.

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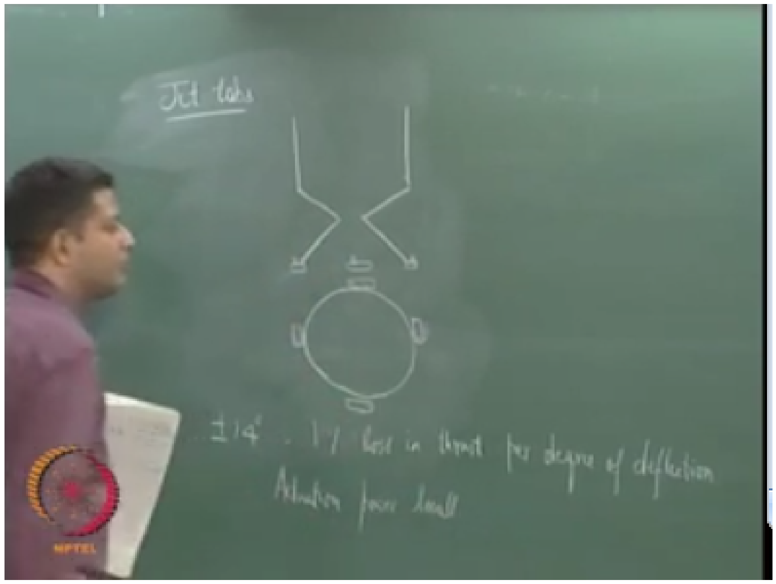

Now if we were looking at it from the bottom it would look like this now you could move this into the flow as per requirement okay and depending on the amount this up stretch the flow you will get the thrust force proportional to that okay, so as such this the both these do not obstruct the flow in their normal position, so they did not add to any loss in their normal operation but when they are used they will lead to a small loss with this you can get + - 14^0 of change in the thrust.

And whenever this is in use it leads to something like 1% loss and thrust per degree of deflection and the actuation power here is also very small because you are only trying to actuate a small tab, so the actuation power required is smaller here the last in the mechanical control surfaces is something known as a jet rain.

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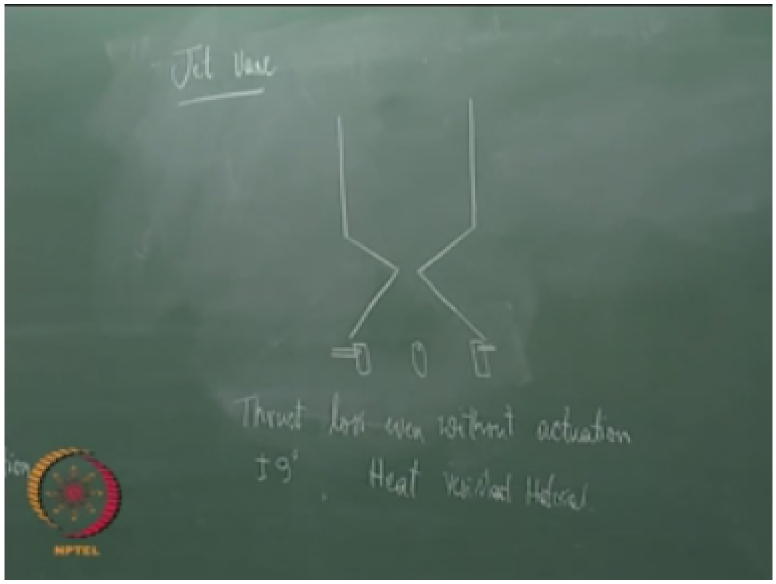

These jet wins are in the exhaust gas flow so because they are present in the exhaust gas flow itself even without actuation they are going to lead to some kind of thrust loss okay, so they are going to have you are going to have some rust loss you can get thrust-vectoring of the order of + - 9^0 and the thrust loss will be more when it is actuated okay it will it is there even without actuation in this case there will be more when it is actuated, so this needs a pretty good heat-resistant material.

Because it is always in the exhaust flow right what is usually done in the case of jet vanes is you might need this for a small period of time during takeoff or during some critical operation after which you can throw them away okay, so these are used in some examples wherein you are launching something from a ship or launching a missile from a ship or something like that then it has to turn by a large angle, so you can use this and then throw this event for the rest of the flight this is not useful okay so it is used for a very small period of time now the last thing that is used actually in rockets is the liquid engine.

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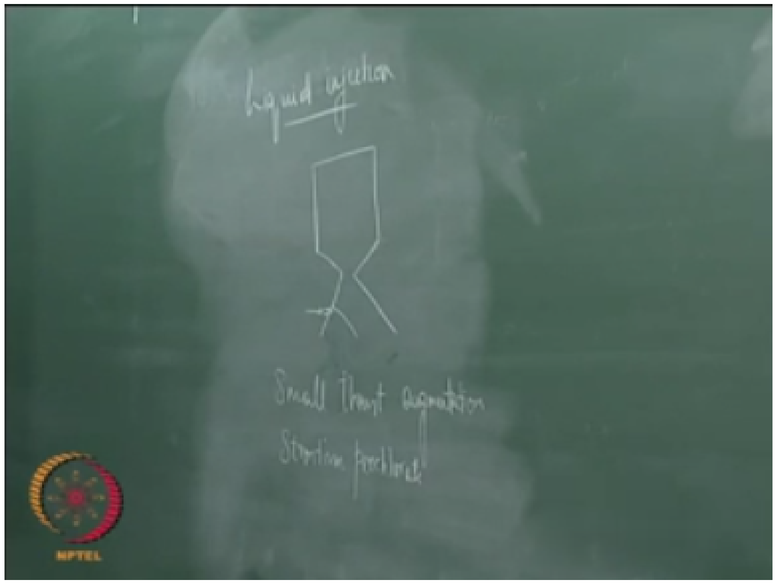

Remember in an earlier class we said if you have an oblique shock the flow separates and it will introduce a side force right in this method of controlling or thrust-vectoring we actually make use of that and we inject a liquid at some known points in the divergent portion that is let us say if we inject the liquid at this portion because of the liquid coming out here the an oblique shock develops up upstream of this liquid injection point and because of this you will get a side force right because in this portion it actually acts as a nozzle being cut off and after some length and therefore it get gets you the required side force okay.

SI TVC is used in ESL ways stage one motor for respective control in this case because of the liquid injection there is a small amount of thrust augmentation that is happening the liquid that is used is strontium perchlorate, now the reason for using such a liquid is if you look at the momentum of the jet that is coming through if you are injecting this debt this jet needs to have a higher momentum than the jet, so ρJ VJ^2 square must be comparable to ρg Vg^2 now if you notice here the density of the gas is very small and but the velocities are very large and that is squared right.

What else here the liquid velocities are not going to be so large, so you need to make it up with a higher density liquid which is right this strontium perchlorate is used people have also thought about using a fraction of the exhaust gases themselves taking a certain bleed from the combustion chamber and using it, but the trouble with that is you have to have leak proof valves that operate not only at high temperature but also at high pressure which is not very easy otherwise if there is a leak there will be always a side force.

So you do not want that and therefore this kind of taking a certain bleed from the combustion chamber has not been pursued, so therefore you have to have a large tank containing this stronger perchlorate primarily because if it needs to be injected at some velocity the pressure here of the jet must be greater than the pressure here, so this tank needs to be pressurized okay and then the liquid has to be expelled under pressure so that makes it a little more bulky but as I said.

If you want to use gas injection then hot gas handling is not very easy in liquid engines in some of the liquid engines you usually have something known as a gas generator which is used to run the turbine which in turn runs the pumps, this gas generator also has an exhaust which can be used in auxiliary nozzles provide the kind of thrust-vectoring that we want, so you will have small motors for that.

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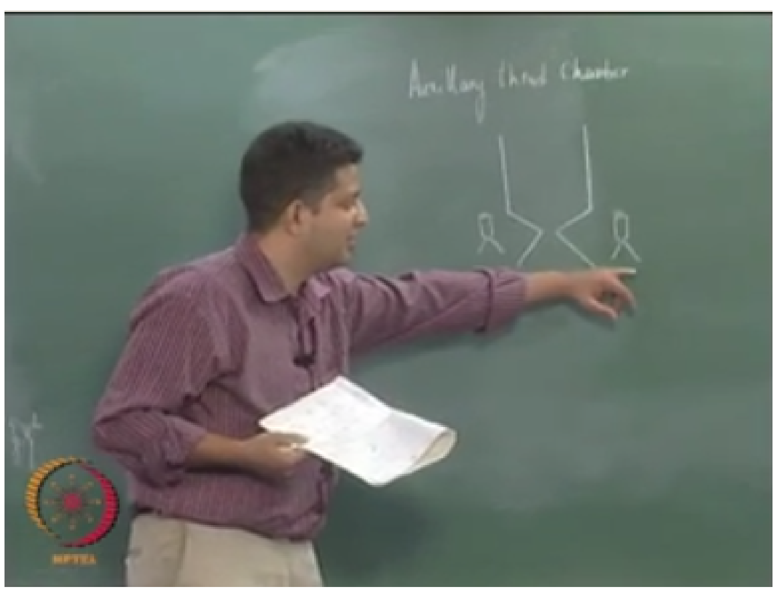

If this is the main engine you could have small engines that can be moved you could have these small thrust chambers which you can control and move, it move the entire thrust seamer that will give you the required sight force that is required, but in this case the thrust vectoring that is possible is very small not very large so the only other thing that people have kind of thought of using but not yet looked at this in this case instead of using a liquid it is a one has a liquid rocket motor a small liquid rocket motor and inject the exhaust gasses here that could also give you the required side force.

Primarily because you will have a very high jet velocity okay and if you want to switch off and switch on this it is not very difficult, because you are only going to operate the liquids right switching on and switching off a liquid rocket motor is not a problem but this is something that has not been pursued and probably could be pursued sometime later there is also another method wherein if you have for rocket motors and the exhaust coming out through canted nozzles right something like this.

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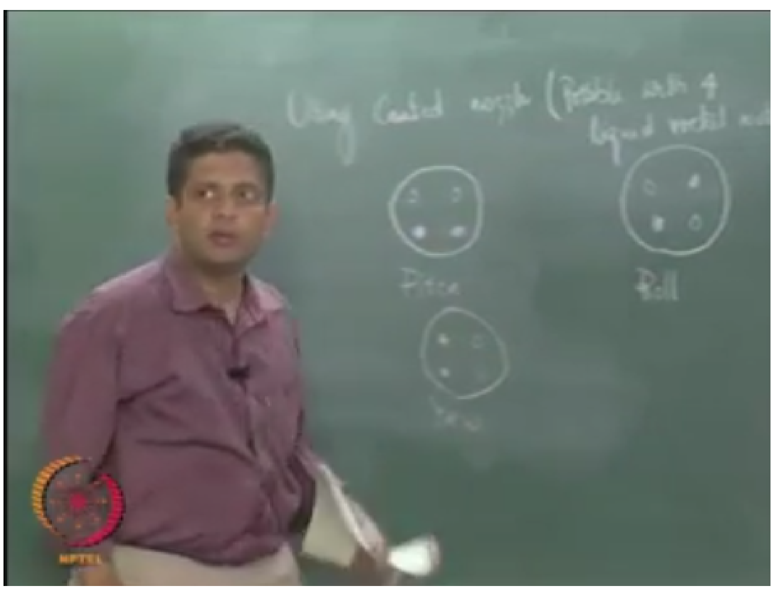

Let us say you had four rocket motors liquid rocket motors that are providing you the thrust then you could have a situation wherein, if you look at it from the bottom let us say these are the exhaust ports of these four motors you could increase the thrust and decrease the thrust in two of them to get your required control force that is let us say, if you want to pitch up and pitch downright so you could actually increase the thrust of this to pitch up and reduce the thrust in this so that it will this will cause a this will make the pitch which if you are looking into the board this will cause pitch up pitch down okay.

If you are looking into the board this will cause the vehicle to pitch down and similarly you can have this is for pitch or yaw increase the thrust in these two or the other two to get the required I emotion and you could also have rule using two of them in this fashion okay, if you increase the thrust in these two then you can have this is only possible, if you have a liquid rocket motor and if you have four of them if you have this is canted nozzle so the thrust vectors will not be parallel I mean perpendicular to the board it is at an angle.

So you will have that role till now we have looked at this rocket propulsion course in this fashion that is we have not looked at what is the thing that is there in the thrust chamber right we have looked at nozzle we have tried to derive equations to get the specific impulse of the nozzle, if you not bothered ourselves about what is the kind of engine that is there liquid solid or hybrid now let us look at in the next class we will start looking at the different kinds of engines that is solid liquid and hybrid motors okay thank you.

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