Rocket Propulsion

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Lecture No. # 33

Pumps and Turbines: Propellant Feed System at Zero "g" Conditions

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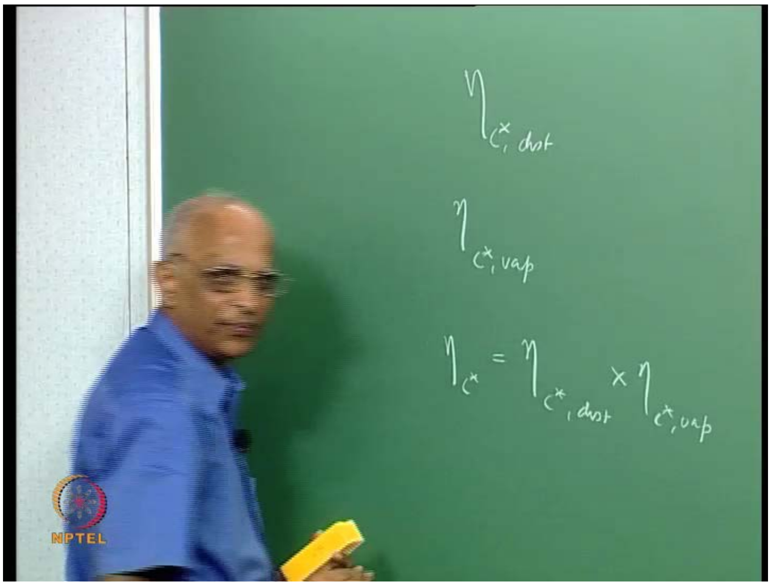

Well, good morning. Then we continue with what we were doing in the last class namely we looked at the efficiency of c star due to distribution. Then we calculated the time taken for a droplet to evaporate, we calculated the value of the evaporation constant lambda and we said well c star due to evaporation also I can calculate. And we say that the total value of c star due to these two effects is equal to c star due to the distribution and multiplied by c star due to vaporization. And this is all about it. You get the efficiencies. I want to spend a couple of minutes on this vaporization.

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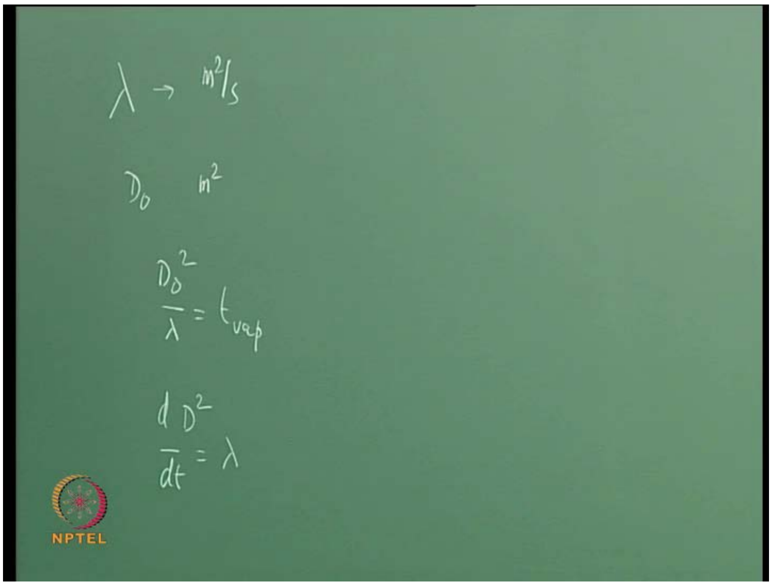

See we told ourselves well, lambda is a constant it depends only on the properties of the fuel and therefore, lambda for a given say diesel is so much like kerosene is around 0.2 millimeter square per second.

If I have a hydrogen droplet in hot medium it is something like almost four millimeter square per second. I can get the value of lambda. I can therefore, say the time taken for a droplet in terms of d naught square divided by lambda. I know the time; that means, d naught square this has units of meter square per by second d naught square has units of meter square. Therefore, I get d naught square by lambda gives me the value of vaporization time right and the question of lambda that is the evaporation rate constant. Why do I call it as a constant? We find anyway d d square by d t which is equal to lambda which I call as evaporation rate constant, does not depend on any parameter, does not depend even on the diameter. It is just a function of the diffusion coefficient, density of the droplet and density of the medium and therefore, lambda tends to be a constant.

Therefore, you know if you go to any lab which deals with combustion they do experiments, they take a droplet find out the time taken for vaporization. But, then there is a complexity this complexity comes whenever I have a droplet it is in a medium. That droplet somewhat you know when the medium is different. It tends to sort of absorb that particular gaseous medium on the surface and therefore, lambda is not really a constant at different pressures. At low pressures well it is a constant. At high pressures I find that we did some experiments. In fact, one of your seniors by name Balaji he did some experiments. I would not say experiments he did a series of computations on equilibrium at high pressures of liquid surfaces, calculated the value of lambda and lambda at high pressure tends to decrease. In fact, his work was published in physics of fluids and that is what we do research work on in combustion evaporation rate mixing and stuff like that. We found that lambda decreases at high pressures, but, again it picks up at very high pressures and we also find that at high pressures, a droplet may become equal to a gas that in other words; if I were to plot something like a phase diagram may be I have a T and v diagram, I have the solid line, I have this line which is a liquid line.

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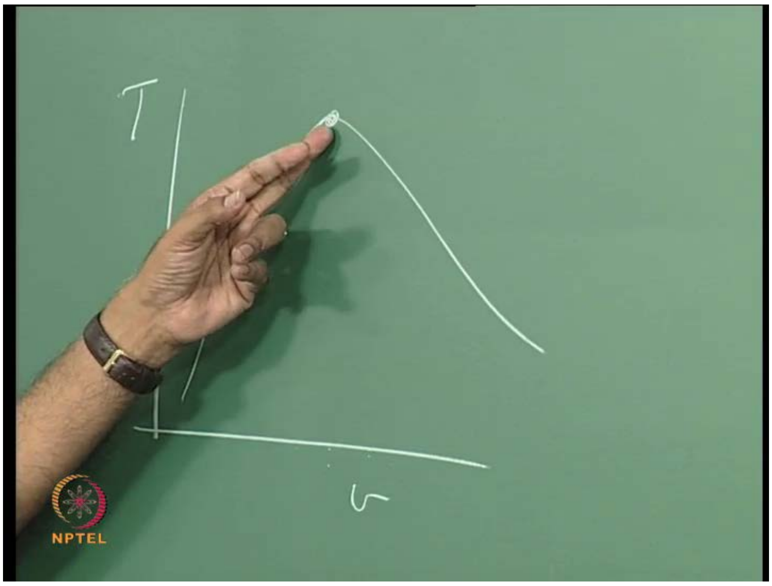

I have the vaporization line. This is my critical point. When I approach the critical point and this critical point is not very high for kerosene in oxygen it could be as low as 50, 50 bar, but, I operate my chamber pressure at very high pressures. At that time what happens is may be oxygen gets dissolved on the surfaces, the critical pressure increases in this binary medium and still the droplet would still be in the subcritical case. And therefore, this question of lambda is something which is important in which lot of papers are written and therefore, I think you all should have a feel for it. I think this is all I wanted to say. I will not go into these details in a regular class but rather let us now come to the second point namely what is it we have done so far? Let us let us take a quick summary.

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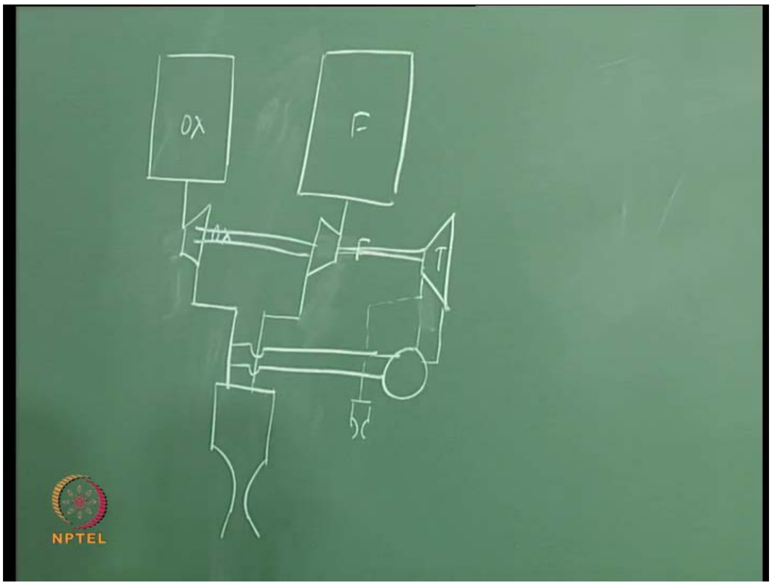

We started with tank ages. We said liquid propellants are pushed into the chamber. I could have either a regulated gas pressure mode, I could have a pump feed mode, I could have something like a blow down mode and all that. Ultimately what is it I did was I brought the fuel and oxidizer into the chamber. We looked at the efficiencies, we looked at the chamber, we already looked at the nozzles.

But what we have really not looked at is some of these pumps and turbines in a gas generator cycle we said. I increase the pressure and then I pass it over here. Similarly, over here what is it I do? I put a pump over here and then I pump the liquid over here, the second one may be this could be oxidizer liquid, this could be fuel liquid, this could be oxidizer pump, this this could be fuel pump and then what is it we did we bled? Some amount of oxygen or oxidizer some amount of fuel burnt it in a gas generator and then drove the two pumps. That means, I put it into a turbine, I expanded the gases in the turbine. That means, I reduce the pressure in the turbine. I generated power I drove this over here and when I took the exhaust gases and put it back into the chamber. I called it as stage combustion and when I allowed the thing to go out to an auxiliary nozzle I said it is a gas generator cycle.

Therefore, may be I should spend some little time on these pumps and turbines. Normally, the turbines what we use are of the impulse type impulse type means velocity. I just convert the enthalpy into high high high velocity gases or rather.

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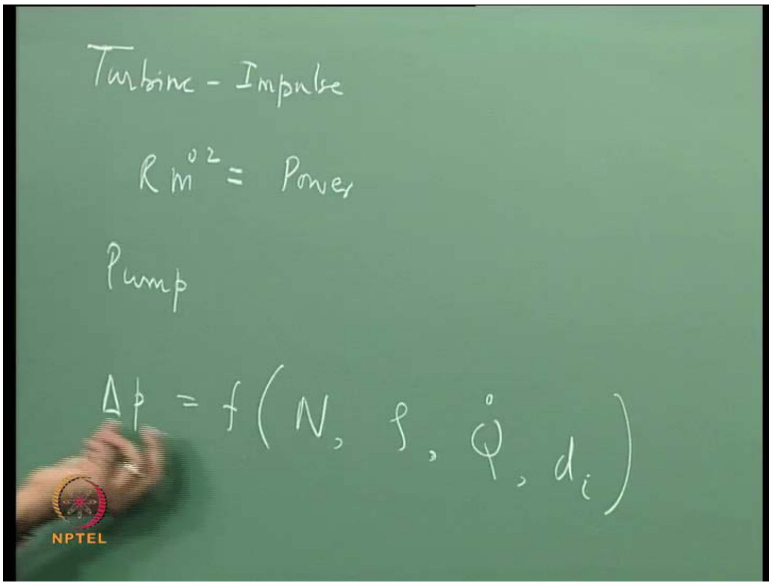

I have something like enthalpy of the gases at the exit of the gas generator that is at inlet to the turbine I have at the outlet of the turbine the enthalpy and this is converted into something like velocity. The velocity impinges on the blades, rotates the blades and that is what drives the pumps. The pumps on the other hand; that means, we say turbine is generally of impulse type and how do we say this? We say well, it goes as the resistance into something like a mass flow rate r into m dot square is what gives me the particular power to run a particular turbine. This I just put as resistance, I will be revisit this value a little later.

Then I have the two pumps pumps if they are small if they are for a small engine it could be a centrifugal one wherein I have small flow, but, I need high pressure. It could be a series of axial flow pumps or it could be combination of centrifugal and it could be a combination of radial and axial and all that therefore, several possibilities exists for a pump and if you have to go into details of pumps and oxidizers; it becomes an exercise in turbo machines and I will not go to it go through it. But, I also want to do some justice to pumps and turbines therefore, we find what is a pump required to do? A pump must generate some pressure and what are the parameters which are there in a pump? May be the speed of the pump? So, many n r p m and generally pumps rotate at very high speed so of the order of 20000 to 60000.

In fact, we have a new engine known as Vinci which is almost like one lack r p m is the speed and why do we need high r p m? My dimensions must be small therefore, my speed must be large such that I am able to get a high pressure. Therefore, one of the factors is n r p m. This speed of the pump depends on the density, depends on something like a q that is the mass flow rate through the particular pumps, was the, is the factor. May be it also will depend you know speed. I said must depend on the dimension may be a nominal dimension like, let us say diameter of the impeller or some mean diameter of the system. Therefore, we say that the head developed by a pump must be a function of a set of parameters. In other words to be able to quantify the pressure rise in a pump, I need these parameters and now I find that the number of parameters which effect the performance of pumps are delta p, the speed, the density, the flow rate and this this is quite representative. In other words I am talking in terms of five parameters which are required to characterize a particular pump.

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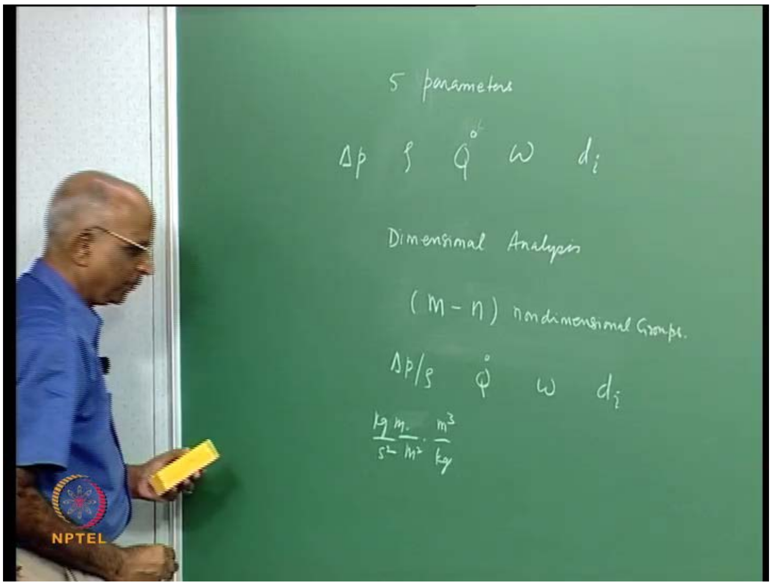

And what are the five parameters I am talking of? I am talking of may be delta p across the pump, may be the density, may be the flow rate, may be speed instead of writing in terms of n r p m, I rather put it in terms of radians per second omega which is same as n. That means, two pi n is equal to omega and then the last parameter which I said is d i.

Now, I want to find out the influence of all these things on delta p and vice versa. How do I do a complicated problem in engineering which involves a number of parameters?

Dimensional excellent, we have to do something like a non dimensionalization or dimensional analysis. Therefore, let us do this you know at least we we say I have studied pumps through a dimensional analysis procedure. In other words I am looking at the Buckingham pi theorem and telling myself I have five parameters of for the problem. And Buckingham pi theorem tells me if I have a problem involving m parameters and having n primary dimensions to it, I can from m minus n non dimensional groups. right This is Buckingham pi theorem.

Therefore what are the primary dimensions I am talking of? Well, when I look at this problem delta p and rho. Well delta p and rho is a combination. Then I am looking at may be q dot, may be I am looking at omega, I am looking at d i. Let us put the quantities here delta p by rho, let us put the dimensions out Newton per meter square into kilogram per meter cube. But, Newton is equal to kilogram meter per second square. Therefore, this gives me unit as meter meter, meter square over here; that means, equal to meter square by second square here and therefore, the unit let us let us put down the primary dimensions now.

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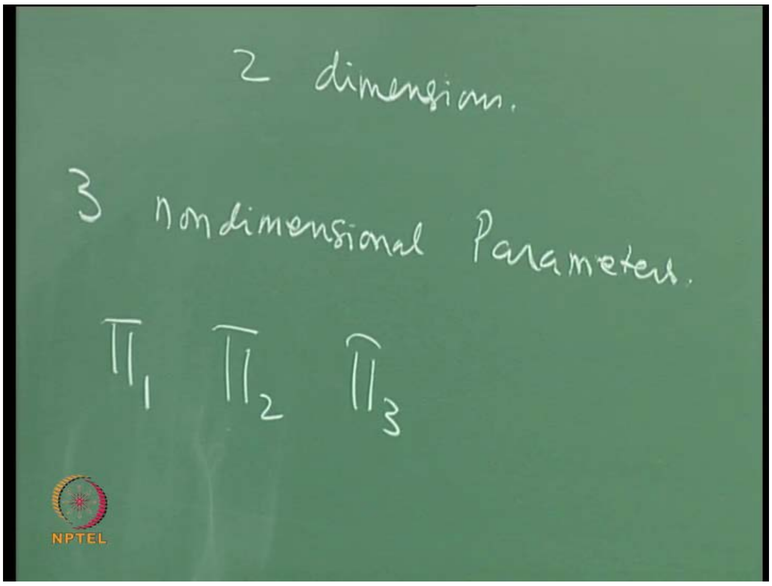

The primary dimensions for this problem are delta p by rho has unit of l square by T square length by time square. Q dot has dimensions of yes meter cube per second that is equal to l cube by t omega exactly yes you are one by t and we have d i which is equal to l. See I was very particular to this dimensional analysis because in any subject we must know how it applies and we must be able to draw the conclusion and here also we have a pump which involves some parameters. Therefore, how many fundamental dimensions do you have? l and t alone. That means, two fundamental dimensions and the number of parameters I have are five.

Therefore, I should be able to get three non dimensional parameters. Therefore, I say for the case of pumps and turbines put together or a or let us say a tur[bine]- turbo pump I want to develop pi 1 one non dimension, pi 2, pi 3. Well, let us let us let us derive these pi 1 pi 3 pi 3 and then try to analyze and let us see their how how we can describe turbo pump operation and how to go about making a turbo pump. Let us say we know we know the other things. Why not we do this?

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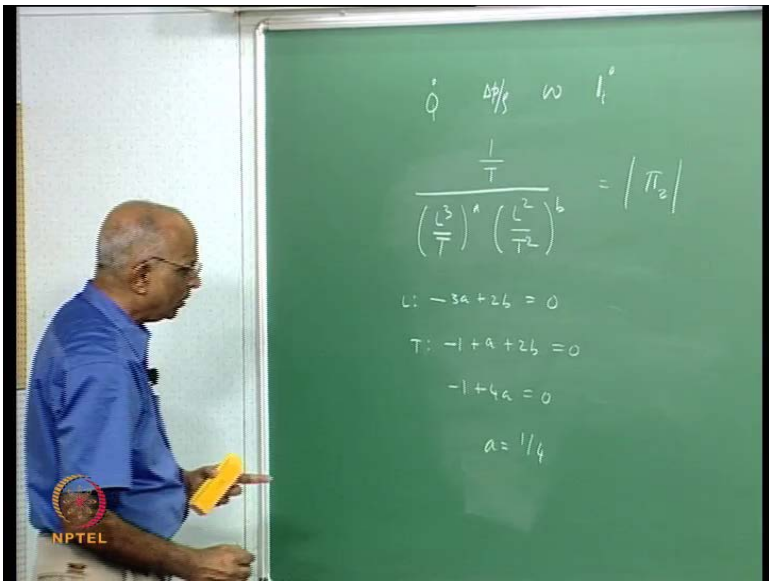

Well I go back and look at the problem. My five probe parameters are delta p, q dot, then I have omega and d i. You know even without doing a non dimensional parameter, I can say delta p by we we also had rho here delta p by rho.

I know delta p by rho v square; rho v square has units of pressure and therefore, I can write delta p by rho v square or rather one non dimensional parameter could readily be delta p by rho into omega square by d i square. Just by observation why is that? I know rho v square has units of pressure kilogram per meter square. Then again meter square by second square this gives me new[ton]- Newton per meter square therefore, by observation let let us do one by observation, let us do one by detailed analysis. Let us say well, delta p by rho can be put in terms of a non dimensional parameter delta p by rho omega square d I square which is my first non dimensional term. Let us do the second non dimensionalization with for q dot.

I have q dot 1, then I say well delta p by rho should should also cause variation in q dot. Well, I have omega I have to some extent already taken d i in this. Let me now put d i as equal to 0. let us Let me not consider d i. I put it as equal to 0 not being influenced or rather I am looking for a non non dimenstionalizing the value of mass flow rate in terms of let us say delta p by rho to the power a into omega to the power b which I want to write as pi 2 because I am going to separately look at d i little later. If I were to look at this what what would I get? Should I really take this over here or should I take something over here?

So, why why should omega come over here? Let us let us keep this or rather let me consider again instead of putting q dot; if I am interested in let us say omega over here and then omega I put in terms of let us say q dot to the power a and let us put the other term delta p to the power rho to the power b; this could also be a non dimensional parameter.

In other words, I would like some non dimensional zing to be done for the speed of the system as a function of flow rate and this; whether I can derive a non dimensional term here; that means, I consider pi 2 to be here rather than this value and if I have to now erase it out and say my pi 2 is going to be here; what should be my value of a and b? How do I do this? I say omega has units of one over t then q we just now told is units of l cube by t, meter cube per second to the power a, delta p by rho we had l square by t square to the power b. This should give me a non dimensional parameter. Let us say pi 3 over here it is non dimensional. Now, what should be my choice of a and b in this for it to be non dimensional? Let us solve it we find. If I solve for l I get minus three a plus two b is equal to 0 because I have to find out the value because I have I want the net one to be non dimensional not depending on l and t. If I write the equation for t, i get minus one then plus a minus plus 2 b. I bring t on top here t to the power a and t to the power 2 b minus 1 is equal to 0.

And for what is it I get? I get 2 b is equal to 3 a. If 2 b is equal to 3 a I get minus 1 plus four a is equal to 0 or rather I get a is equal to 1by 4. If a is equal to 1by 4; the value of b should be equal to what? yes Now, let us redo it. Come on l is equal to minus three a plus two b equal to 0.

Minus (( )).

You have omega 1 over t you have l q dot is equal to l cube by t to the power a q you had l square by t square to the power b. Therefore, I have 3 a, minus 3 a. It is at the denominator minus three a.

(( )).

Minus 2 b you are minus 2 b because all what I am trying to say is I swallowed a step. I have T to the power a into T to the power 2 b divided by T 2 into l 3 a l 2 b. Therefore, it is minus three a minus two b is equal to 0 and the next one is minus one plus a plus two b is equal to 0 and therefore, over here I should we we should have, we should redo this. Let us do it therefore, I get two b is equal to minus three a and therefore, I get minus one plus a minus three a is equal to 0 or rather a is equal to half.

If a is equal to half then the value of b is equal to 3 by 4minus 3 by 4 minus and minus; that means, I am getting is it all right? Let us do minus one plus a and two b is equal to two b is equal to minus three a. I have taken it on the other side minus three a. Therefore, a is equal to minus two a minus you here I am getting minus two a minus one is equal to 0. That means, minus one minus two a is equal to 0 or rather I get two a is equal to minus 1. Therefore, a is equal to minus half. If a is equal to minus half the value of b is equal to plus 3 by 4.

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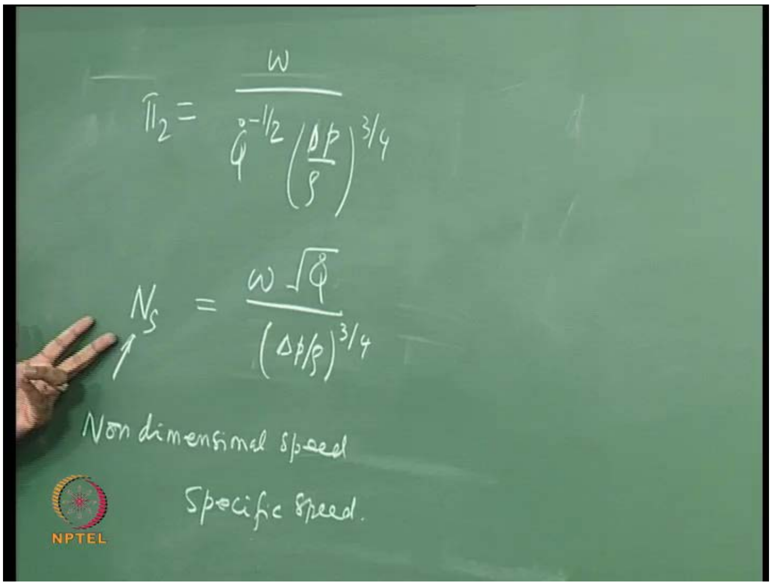

Therefore what will be my expression pi 2? Pi 2 is equal to I get the value of omega on top. This was my q q to the power a which is minus half and I have b b is equal to delta p by rho to the power plus 3 by 4 or rather this tells me that the value is equal to omega root q dot, this should have been q dot here divided by delta p by rho to the power three by four and this pi 2 is what we call as a non dimensional speed or a specific speed.

Therefore, I have got the second parameter. Therefore, let us put down the parameters together.

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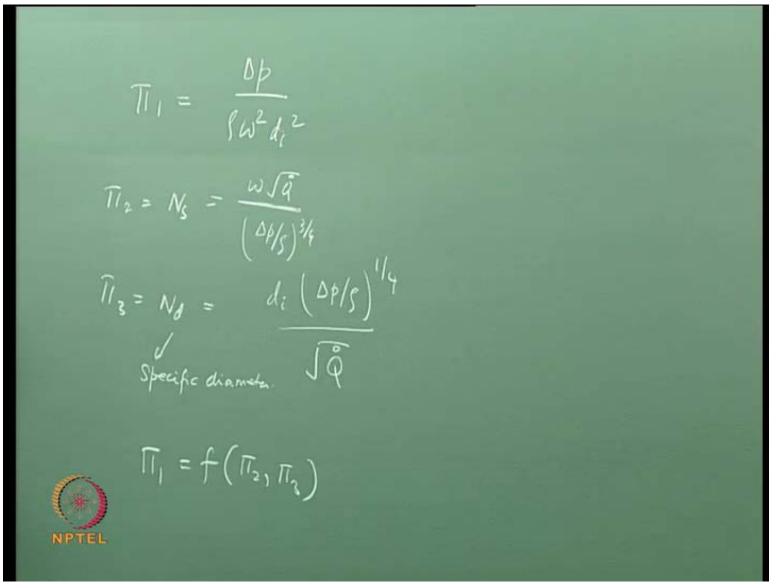

The first parameter I said pi 1 is equal to delta p by rho omega square d i square. The second parameter it says omega under root q divided by the value of delta p by rho to the power three by four which I now call as specific speed. I do the same analysis for finding out the non dimensional d i and therefore, I do this and what is it I get? I will not do it in class. May be take it as a homework problem. Therefore, I take the value of pi 3. Let us put it down here this is pi 1 this is pi 2 which we call as specific speed, the value of pi 3 we will call as specific diameter and that will come out to be equal to I just write it out the same thing we will follow and do it otherwise it will eat into our class time. We call it as, we we do the same exercise; all what I am saying is we will again write d i pi 3 is equal to d i divided by delta p to the rho by rho to the power a into q dot to the power b evaluate a and b for I get a term like this and the value what we will get is; t i into delta p by rho to the power 1 by 4 divided by under root q dot flow rate.

Well, these are the three non dimensional parameters. We call it as N d or specific diameter and the performance of the pump can be expressed as pi1 which is this parameter as a function of the specific speed and the specific diameter and this is how we non dimensionalize the parameter. But, why did we non dimensionalize it?

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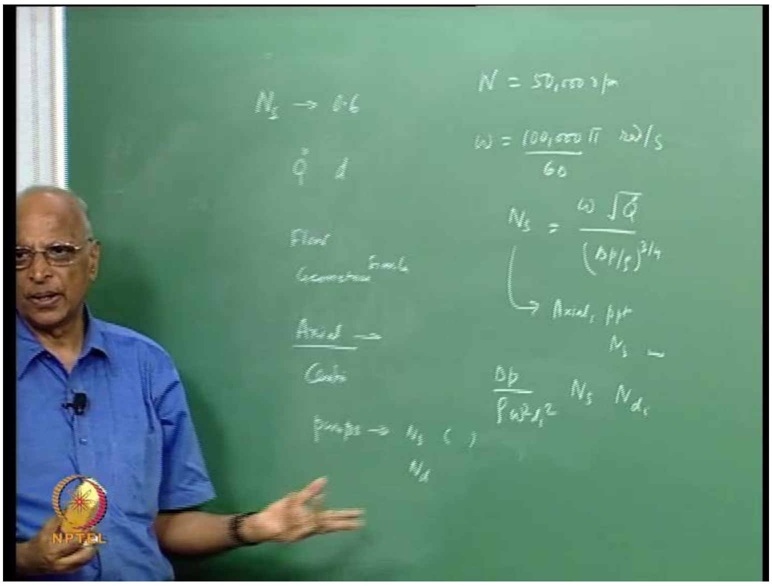

Let us take one of the non dimensional parameters and see what is the impact and why we are doing all this? When I say the specific speed N s is given by omega root q dot by delta p by rho to the power 3 by 4 and I call it as specific speed and if I say specific speed of a turbo machine is something like let us say let us say 0.6; what does it denote? Why is it so important?

This non dimensional parameter tells me for a given value of this diameter. If I were to scale up the my diameter, I have to scale up the value of q, I scale up the value of that dimension and all what I am saying is for a pump having the same value corresponding to the different sizes what I could have and different values of speed, the flow in the pump, the geometrical characteristics of the pump will be similar. In other words for the same dimensional number, that is the same speed if I say the non dimensional speed is so much then I can assume for different values of q different values of diameter for a given type. It could be axial, it could be handling a particular type of propellant or it could be centrifugal or it could be anything else or a combination of some of the things.

For a given axial flow machine handling a particular set of propellants if I keep on varying the quantities and if I vary the size of it, if it if I get across a given number over here the number is invariant; it shows that between the different type that is one category of let us say an axial pump if the size is varied if the size is varied automatically q and d will get varied and speed will vary q dot and d will get varied and, but, if the speed the specific speed is same the flow characteristics and the geometrical similarity will be there and therefore, you know in all the pumps, all the systems what we use the for a given let us say a cryogenic pump if it is axial flow will have N s between a small range of variables.

If I were to say the N d that is the the specific diameter it will have a small range of variables. Therefore, you know if I have to scale up a cryogenic pump still using the axial pump I will go ahead and design for this particular value of specific speed. Therefore, these non dimensional parameters are powerful because they allow us to determine the range of operation of a particular system like what we said was the speed of a pump may be fifty thousand r p m, may be therefore, omega is equal to let us say 100000 pi radians per, radians per minute or to convert it by radians per second I divide it by 60 I get so much radians per second and therefore, for this radians per second if I were to get the equivalent value of N s and how did I get the value of N s? I get omega I get for that particular machine or particular pump; I find out the flow rate, I find out the pressure head developed by it, I get the value of N s.

And now, if I were to design another pump which has to cater for a much larger flow rate and a different size of it, if I get the same value of N s well, the flow characteristics that is the that is the nature of flow in the system that is the hydraulics in the pump and also the geometrical characteristics will be similar. And therefore, for a given type of pump let us say axial pump, for a given type of propellant the N s will fall in a very small number may be 0.6 to 0.7 and therefore, these numbers are useful and also the performance can be written in terms of N s, in terms of N d I, in terms of the delta p by rho omega square into d i square and this is why the non dimensionalization is useful. But, we always whenever we plot the results of pumps and turbines, we always plot it as a function of specific speed anyway dimension is one number, in terms of delta p versus specific speed and that is how the performance of pumps are measured.

You know this brings us to the next part of our talk, you know we we looked at the pumps and turbines from non dimensionally non dimensionalizing point of view the question is what are the characteristics?

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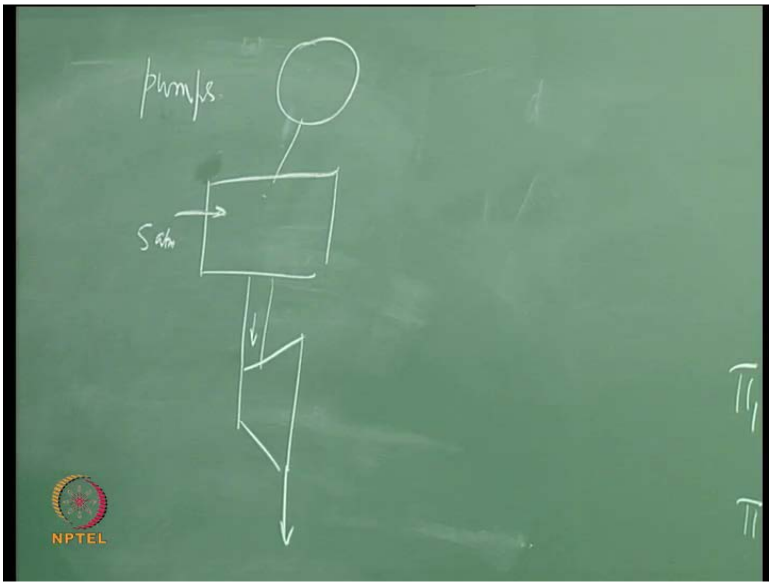

What are the problems with pumps? see we told ourselves I take the propellant from a tank. I take it into a pump. Well, I cannot have a high pressure in the pump in the tank may be the pressure here is let us say five atmospheres which is the upper limit. Now, I feed the propellant into the pump over here and I take the outlet from here this is inlet this is outlet.

That is a maximum pressure at which I can supply because I have to carry a gas bottle here. If I have to increase my pressure I have to increase the gas which is not possible. Therefore, my pressure at the inlet is cannot be high now if at the pump is to rotate at very high speed the velocity of the blades will be high; if the velocity of the blade is high then the static pressure will be low. If the static pressure falls below the vapor pressure bubbles of the vapor are formed and bubbles of vapor formed will harm the blade. It will immediately go. We are rotating at high speed these are things which go and hit the blade and the blade gets damaged.

Therefore, the pump is subject to cavitations and in any pump it is necessary for us to reduce the cavitations. To eliminate the possibilities of cavitations how do we eliminate it?

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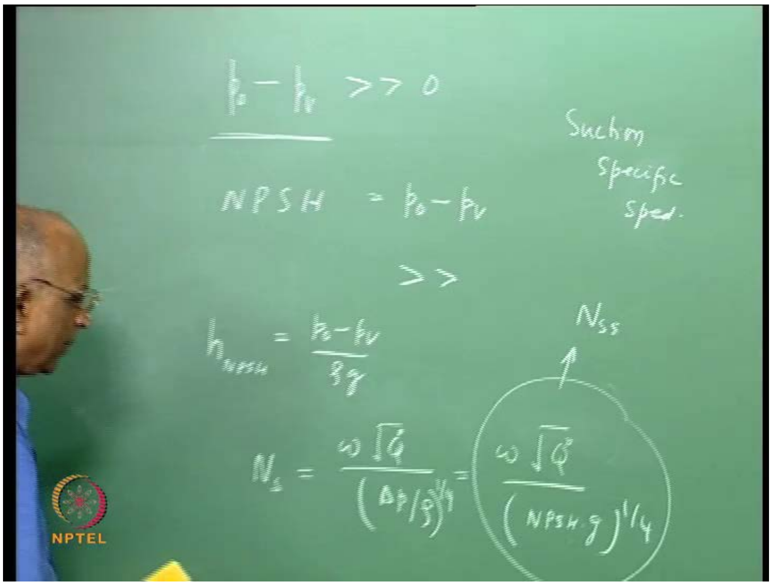

My supply pressure or the stagnation pressure at supply which I call as p naught and this p naught we are talking of a case when it the maximum could be five atmosphere minus the vapor pressure should be a large number right. But, this number depends on the speed of the pump. If omega is larger then my p v is same. What happens is the static pressure reduces to this value and therefore, my cavitation would start and therefore, you know this number becomes an extremely important number and we say the net positive suction head that is the net positive suction head which is given by p naught by minus p v must be a large number for any pump.

Is it clear? Why we say? I would I would like the net positive suction head that is the p naught minus the vapor pressure which we call as net positive suction head is p naught minus p v or rather I can write this net positive suction head as equal to in terms of rho and g as equal to p naught minus p v by rho g is the head net positive suction head. And if I were to take this head, which I know for cavitations I need a reasonable number and if I were to substitute in the value of the non dimensional parameter pi 2 which we call as specific speed and what was specific speed equal to? It was equal to omega root q dot divided by delta p by rho. I substitute delta p by rho whatever I am getting at the pump inlet as equal to something like omega into q dot divided by net positive suction head into the value of g to the power this was here three by 4 4 I am sorry I gobbled it up.

This value is what is referred to as N s s. That is we say the specific suction speed for preventing cavitations or we say this head must be this value must be a a number, must be such that cavitations does not occur and we say this is equal to non dimensional number with respect to cavitations. We call it instead of writing it as N s which was the specific speed, we say as suction N s s. Now, all what I am trying to say is cavitations is an important parameter. We would like the net positive suction head to be large and therefore, this N s s gives you an idea of what we what what we need to do to make this a large number or rather the specific speed must come down under the suction conditions.

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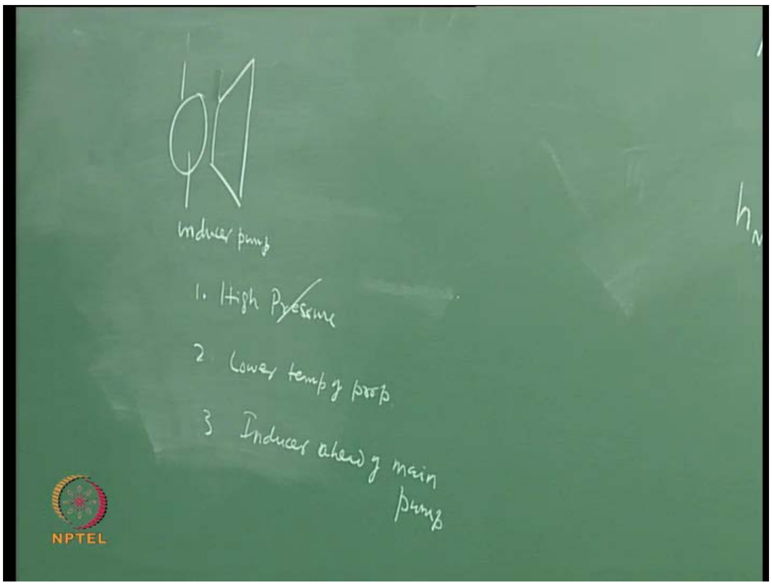

We tell ourselves well I would like the value of p naught minus the p vapor pressure to be a large number. How can you make this? Either the tank pressure must be increased or else if I can sub cool my liquid, if I cool my liquid the vapor pressure comes down. I can still get a larger number or the third thing is before the pump that means, I have a pump like this. I supply it before the pump, I put another pump which I call as an inducer pump such that when the main pump is rotating at very high speed, I get a higher value of p naught. That means, I can improve the the net positive suction head by the following three. Either provide high pressure tankages which is not the correct solution, which is not not possible; second is lower the temperature of the propellants in which case I reduce the value of p v or I put something like an inducer ahead of the main pump.

Therefore, people who who work with liquid propellant rockets will talk of an inducer ahead of a pump and this is the reason why it is done. I think this is all about the turbines and pumps we reduce the we reduce the problem to one of non-dimentionalization. We talked in terms of a specific diameter, we talked in terms of a specific speed and said there will be similarity when the non dimensional parameters are the same and we will be able to quantify the performance and normally the performance is always expressed in terms of this non dimensional parameters.

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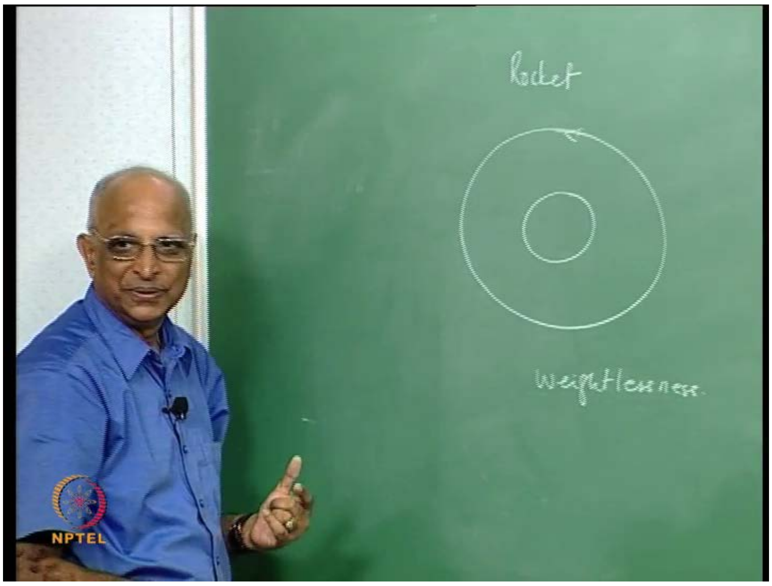

I think with this background of turbines and pumps let us come to the last topic and I have been telling you earlier whenever we have something like a rocket which is going up and one of the functions of rockets is maybe you have the earth, the satellite must go around the earth in some orbit and we said orbits are something like a freely falling bodies. We also told ourselves all freely falling bodies have a problem in that they are a case of in a state of weightlessness. right Is it clear?

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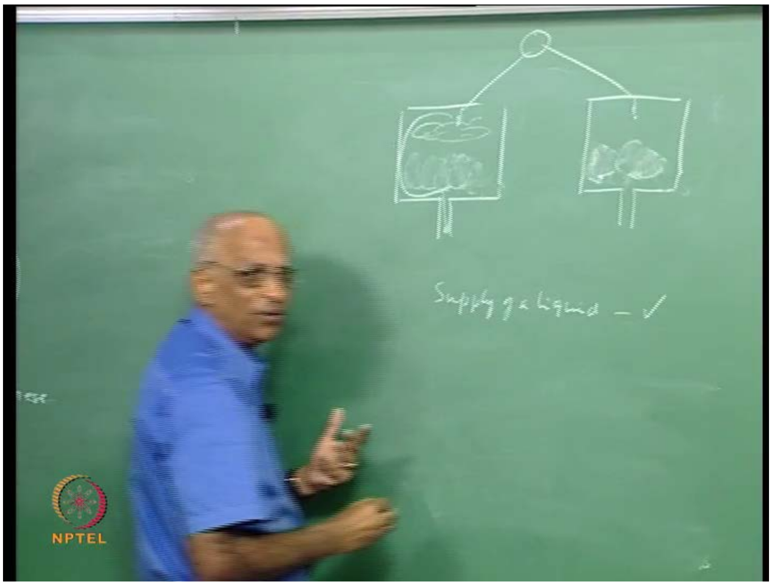

We we talked about it then. Now, the question comes I have a propellant tank may be a liquid fuel tank, an oxidizer fuel tank well the liquid is at bottom of the tank. I have a drain port through which I am drawing the liquid.

If the rocket as it is going with the satellite or when the rocket is moving up it is just coasting such that it is again in a state of weightlessness, it is not powered. Then if the liquid is in a state of weightlessness it is not going to be at the bottom here it could be anywhere here. It could be distributed anywhere and if it is going to be distributed anywhere my at even if I put a gas over here, I push the gas through gas, I push the liquid gas will come out through this rather than the liquid. Therefore, supply of a liquid under the conditions of let us say weightlessness is something to be taken care of and how do I do it? I thought let us just take some pictures on the net.

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I downloaded some of them because tends to be something which is important you know this shows one astronaut in one of the space shuttle services.

You know he is trying to eat something, but, you know the body what he wants to eat is just freely floating. He he cannot really unless he releases his hand and comes back to it. It is not going to fall because it is in a state of weightlessness.

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You know how do you drink water in space? This is again an astronaut. He is in the s t s, the the space shuttle system wherein he has a water here and he wants to drink water.

There is no way the water can come to him. He has to literally catch the water drop, bring it to his mouth and drink otherwise he just cannot drink.

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And this is the problem we have of weightlessness. You know, I thought all of us being in combustion. This is how a candle flame looks like on ground. But, if the same candle I light when it is in a state of 0 g that is weightlessness I get a beautiful picture like this.

That means you know there is no buoyancy because buoyancy depends on gravity. Since, there is no buoyancy the flame is beautifully a hemisphere over here and this is the state and therefore let us now come back to our problem of whether I can I can be how do I supply propellants when I am in a state of weightlessness and that is something which we have to do.

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This shows water droplets on on some leaves in the international space station. These plants were grown there and when you try to water them, you know see water bubbles this is the water drop on a leaf. water This water drop does not have any mass here I am sorry it does not have weight. It has a certain mass, but, weight is zero. Therefore, you know you see the leaf which is storing such a large quantity of water because it is weightless. It it is, it just does not have a weight by which it can fall down.

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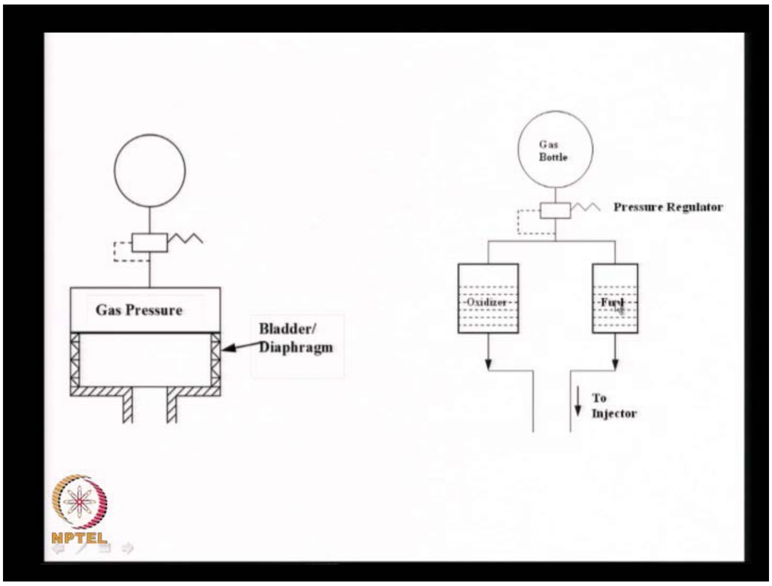

And therefore, we come back to our problem. We have a gas bottle, we have the oxidizer fuel and the fuel over here. Both are in the liquid state. When the flight is in a state of weightlessness, well oxidizer could accommodate in any way and I will not be able to supply it and therefore, one of the measures which was done in the early part of the rocket technology was, I would have something like a diaphragm. What is a diaphragm? Well, let us let us sketch it out.

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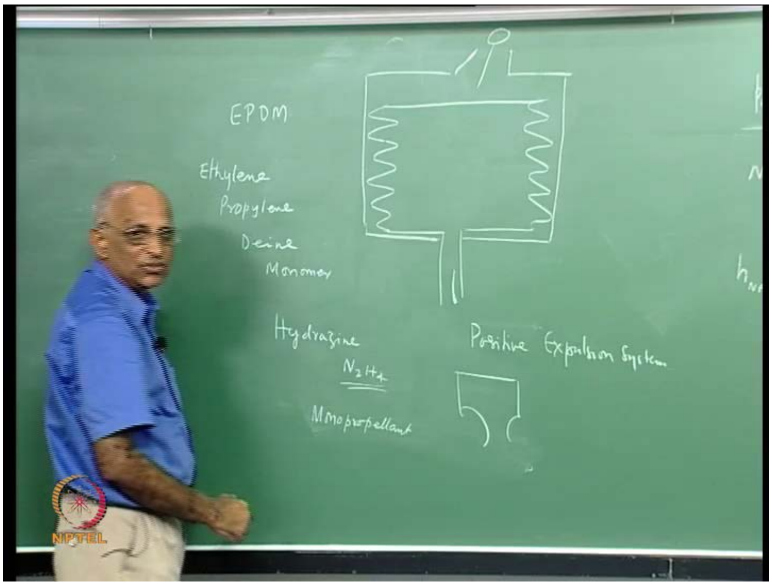

You know, you have something like an elastic material, like the foot ball bladder. Something made of rubber. You know something like the we have this harmonium in which we compress thing that is the diaphragm and this is something which gets squeezed. I put this in a tank, propellant tank over here and enclose the propellant completely within. Now, I pressurize it with a gas and this fellow compresses the diaphragm and the diaphragm as it compresses, it keeps flowing. That means, I contain the liquid positively. That means, this is known as a positive expulsion system.

That means, I cannot leave the liquid free. I have the tank age, but, within the tank age I must put a diaphragm and in the diaphragm, I store fully the liquid. There is no gas at all. I make sure there is no vapor at all and I positively push it through and the fuel gets expelled into either a pump or directly into the, such chamber. That means, both my tanks will consist of a diaphragm which is a positive expulsion system. Now, diaphragm must be a very flexible material. One of the material used is E P D m rubber is more or less universally used. What is this E P D m? It is a rubber type. It is known as ethylene, propylene, deine, monomer.

Why this rubber is chosen is most of the upper stages or let us say the the rocket stages which are used in spacecraft use the fuel hydrazine or m m h and m m h is again monomethyl hydrazine; that is hydrazine based fuels. And this particular diaphragm material should not get dissolved in this particular case because if it gets dissolved even a trace quantities get into this, it may affect the performance later. We will study this may be in the next class wherein I will deal with monopropellant phosphorous, a single propellant can I use it for a a a a rocket.

What happens is this will go and poison this and this uses a catalyst. The catalyst will degrade and therefore, the general tendency is to use E P D m rubber for the positive expulsion system. But, you see the positive expulsion system has its own problems. You are having something like this rubber material, diaphragm material and it occupies a volume with the result the useable space is not fully used. That means, the entire tank space is not be cannot be filled with the liquid. I am I am losing something.

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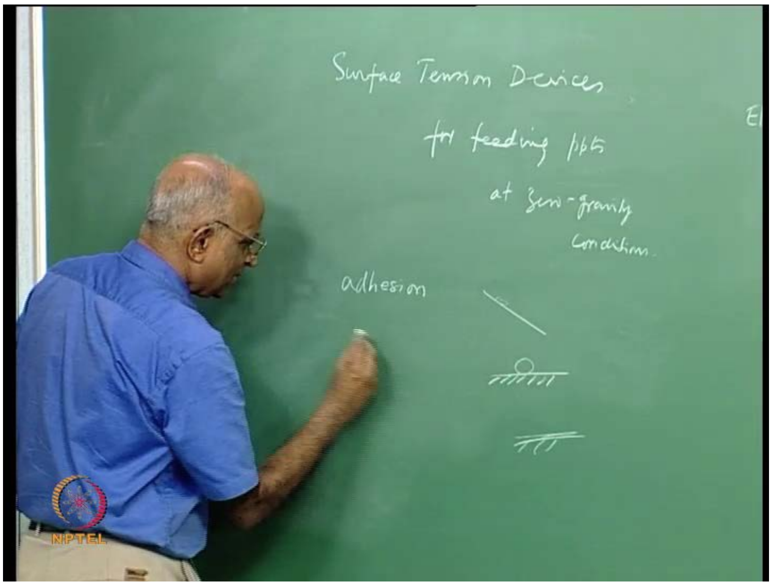

Therefore, the current trend and or what do I must say is the more more recent generation by more recent I mean for the last 15 years or so; if not more you know the thing is to use surface tension devices for feeding propellants, liquid propellants for feeding. Let us say propellants at 0 gravity conditions.

All of us know what surface tension is a surface when wetted things stick to it. Why does something have to stick to the surface? Well, you talk in term of adhesion. I have a surface of a metal. I put a mercury drop the mercury drop stays as a drop it does not smear on the surface. If I put water on a surface it smears. That means, I say surface adhesion takes place. In this case something like cohesion takes place. We do not want cohesion, but, want the liquid to spread. It is not only the properties of the liquid, but, the properties of the surface of the material are equally important like for instance, water spreads in on a in a glass tumbler or in a vessel in a glass vessel, but, the same water does not spread on a lotus leaf. That means, we are looking at surfaces and how do I make use of surface tension to be able to overcome this problem.

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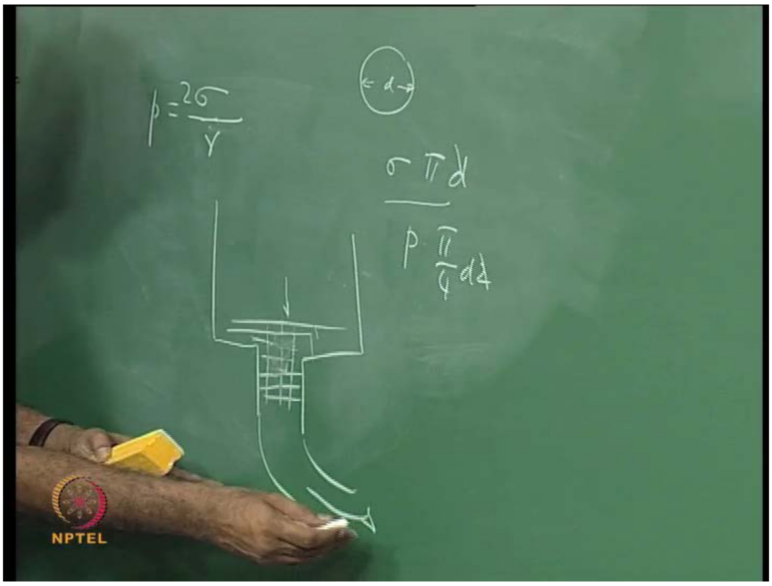

Well, I can think of the following. let Let us do a small exercise supposing I make let us say a sieve; that means, a series of things crosswire like this. Let us say I make spherical holes over here, I dip it in water. The thing is retained over here. How is it retained? Let us say I have may be a now I sketch it. I have a series of holes here and now I pour water the water just sticks to the surface. Now, I push air over here. May be there is a value of pressure drop across this before which air cannot even enter it. That means, I must overcome the surface tension pressure and if were to write surface tension as units of Newton per meter and what does it do? It wets the surface. Let us take I take an individual value, the diameter is d the surface tension pressure is sigma. Let us say Newton per meter into d is the value.

Now, I sort of push air into it. The force of pressure on this is equal to let us say the force of air which is being pushed in is equal to let us say p into pi by 4r d square. This is the perimeter. Therefore, this should have been sigma into pi d over here and therefore, this particular diameter can hold a pressure equal to something like let us say d and d gets canceled, p comes on top over here. Therefore, something like sigma over p is equal to divided by 2 sigma by d, 2 sigma by r because or rather four sigma by d or 4 sigma by d or 2 sigma by r. And therefore, this is the pressure. Therefore, if I can make some of this compartments here of a particular diameter and then if I have a tank like this and if I can contain in the tank a series of meshes here and you know in these meshes liquid is always whether it is gravity or not surface tension does not depend on gravity because it is just a pressure force at a excuse me at a surface.

And therefore, you know what happens is and I make sure that the gas pressure will not permeate through I choose the the diameter of this hole such that, then in that case this is always wet. Whenever I want to supply a propellant, the propellant is available. When I supply the propellant immediately a thrust gets generated and the propellant which is there comes over here and these are known as surface tension devices for supplying fuels at 0 gravity.

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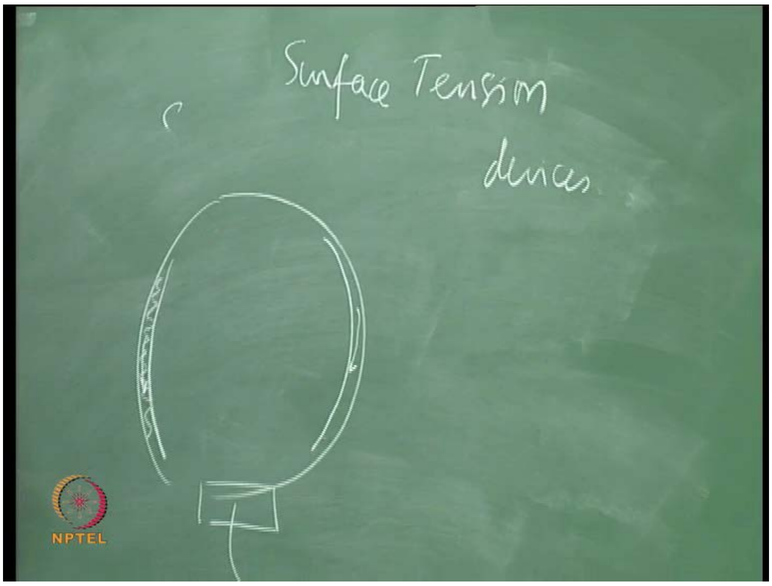

Let us take a look at some of them. You know see this was what was done, but, then I have a tank I can also use these things for a dynamic pumping. Let us say I have a take like this I put some devices like veins which are on the surfaces. I enclose, I am able to contain this. I shape the veins such that the pressure here is lower than the pressure here. In other words the flow of propellant takes place and I collect it in a surface tension device here and I can supply it and these are known as veins. let Let us take a look of them as has been used in some of the spacecrafts.

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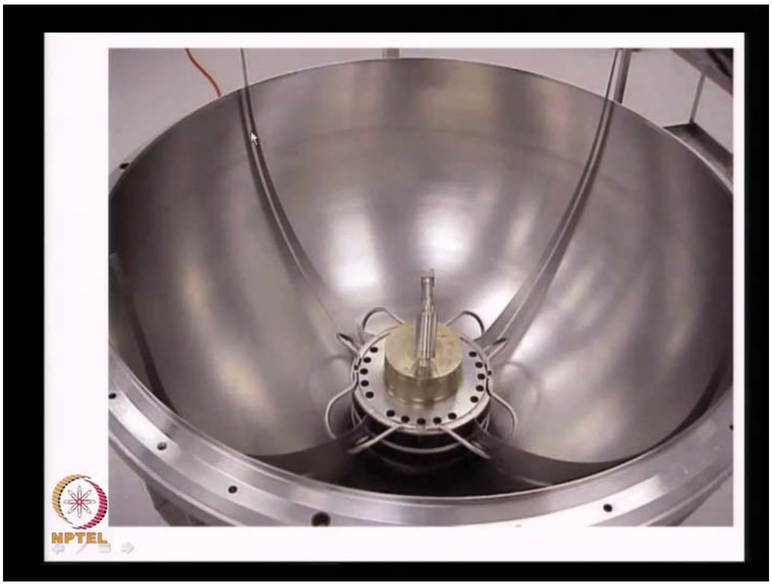

Well, this is what I said. This is my area wherein I contain these these screens or openings such that the fluid is retained there. These are veins through which may be fluid comes over here. This is another view of it, may be I have the veins over here. This is the vein what I am talking of, this is the gap what I am talking of, this is where the sieve is there which collects the propellant and feeds it into the chamber.

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These devices have high values of expulsion efficiencies. That is most of the propellant can be expelled unlike in the case of the positive expulsion system. This is all about surface tension devices I think we are more or less covered the liquid propellant rockets we considered the different elements, but, just to get into one small part of it, let let us what what is it we said?

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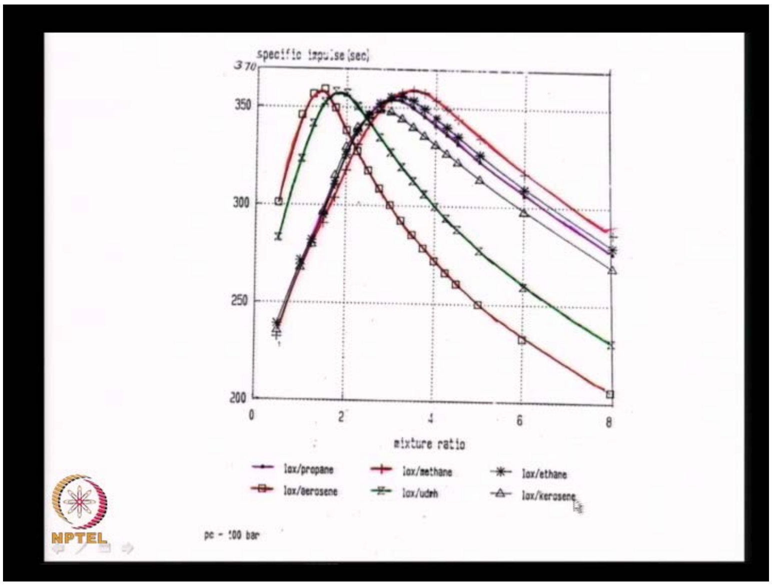

We talked in terms of specific impulse, we talked in terms of mixture ratio, we talked in terms of different propellants. The propellants which we did not consider there may be liquid propane, liquid methane and liquid ethane. When we compare the performance of liquid, oxygen and kerosene; we find kerosene has lower performance than these cryogenic fuels like liquid propane is normally a gas, liquid methane is a gas and therefore, you know people are trying to work on whether they should use some of these propellants in future machines.

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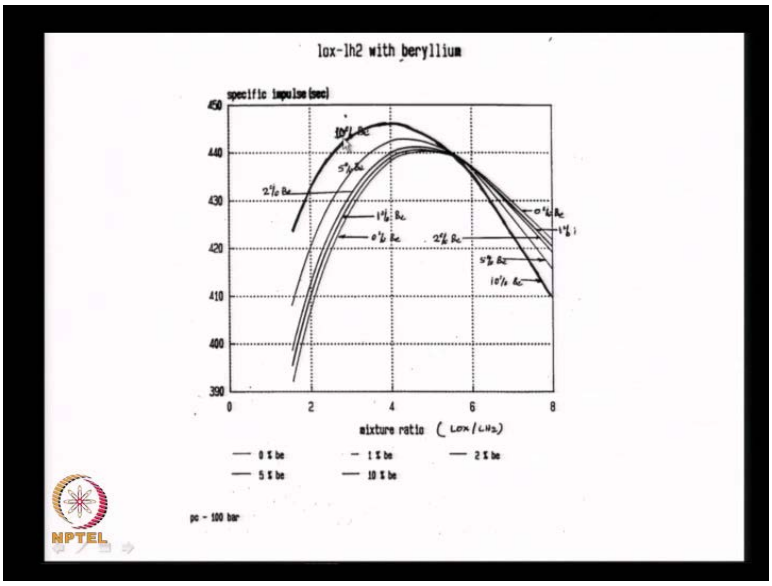

Let, But, it has still not become operational and the last slide which I wanted to say was then we consider a solid propellant; we added metal to solid propellant to improve specific impulse.

But if we try the same thing with liquids what happens is the molecular weight of the products goes up and putting metal in the propellant rather than improve the performance does not really give the advantage like you have solids. Therefore, metal in liquids does not seem to be a solution. The 0.1 is higher molecular weight of the exhaust, second is liquids requires or metals require some more time to burn and sometimes the the metal comes into an oxide, but, unless that oxide releases the heat, I do not get the energy and that is where I gave you that assignment wherein with dissociation let us calculate the products of combustion. It will it'll illustrate the different type of problems we have.

I think this is all about liquid propellants and I think we have covered more or less of it. In the next class, what I do is I will talk in terms of monopropellant rockets and hybrid rockets and then get into the problem of combustion instability there. Well thank you then. I think this is about it.