Rocket Propulsion

Prof. K. Ramamurthi

Department of Mechanical Engineering

Indian Institute of Technology, Madras

Lecture No. # 27

Review of Solid Propellant Rockets

Well good morning, then I think today what we will do is, we will finish our discussions on the solid propellant rockets. Now something amusing I thought, I should start with this.

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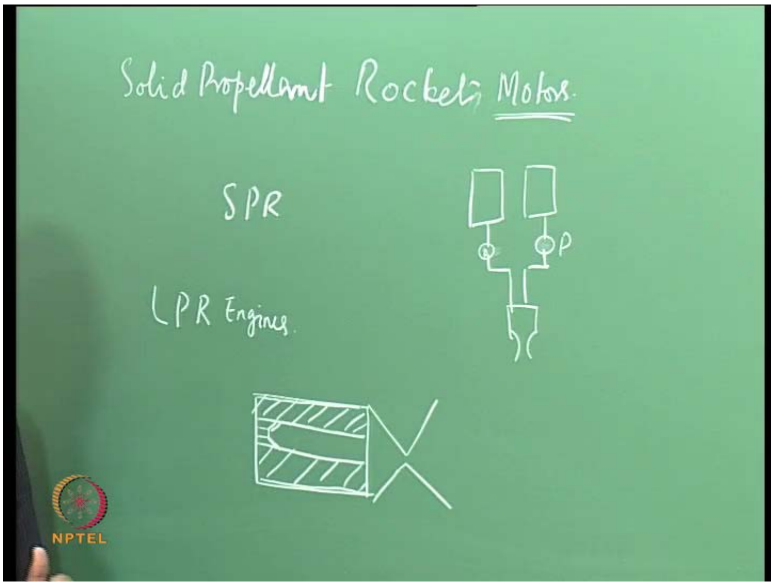

Solid propellants rocket, which are known as SPR are also known as solid propellant rocket motors. Whereas, when we talk of liquid propellant rockets, liquid propellant rockets are known as liquid propellant rocket engines. What do you think? You know in many textbooks you find this solid propellant rocket referred to as a motor whereas, liquid propellant rocket referred to as an engine. What do you think would be the reason for this? Any any guesses or something? Let us go back and look at the construction of a solid propellant rocket. Anyway we have a case in which we put some insulation we will revise it again towards the end of the class. Then I have a nozzle you know this is where the propellant is maybe some radial burning grain could be a star or something this is your propellant.

And what else did we do we did something on an igniter to be put here it gives a plain mandate when it ignites and it spreads this is what it consist of there is nothing else in the solid propellant rockets. If I talk in terms of a liquid propellant rocket engine, I should have tanks which carry the liquid, I have the lines it supplies it to the chamber. And to be able to pump the let us say the liquid fuel I need a pump here, I should need a pump here. Therefore, I have something like a moving parts something pump which moves whereas, and to drive the pump I need again a turbine I have moving parts in a liquid propellant rocket. Whereas, a solid propellant rocket has no moving parts it is just simple case and all that. Therefore, for some reason or the other a solid propellant rocket, because it has no moving part is referred to as a motor. In fact, the case is referred to as a motor case whereas, a liquid propellant rocket considering that it has moving parts is referred to as engine. This is the way I interpret it but in all books invariably. In fact, in your discussions when you go out and talk people will call it as a solid propellant rocket motor whereas, a liquid propellant is always referred to as an engine.

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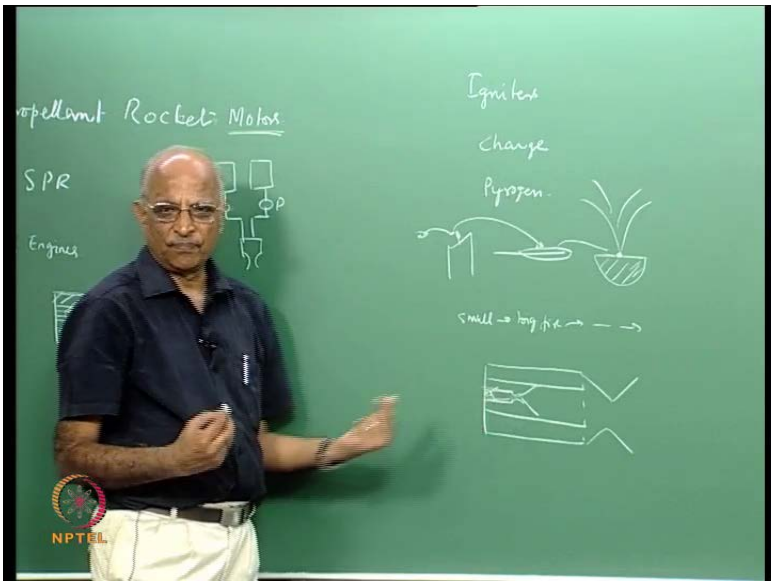

Now with this introduction let let's go back and see where we were last time we talked in terms of the igniters required. And let me just briefly go through what we covered in igniters again. See before igniters we were very clear how to design the burning surface area, how to be able to define the burning surface area, the configuration of the grain, the amount of thrust which is required I can now design my grain, and therefore, my my solid propellant rocket itself. When we came to igniter we said I put a charge which easily burns impinge a charge on the surface pressurize the cavity and then ignition takes off, but then we also told we have some types of igniters one was a pyrotechnic igniter in which I have a charge which is easily easily ignitable whereas, we also talked in terms of a pyrogen igniter where in we put a small rocket motor itself as the igniter.

What is the principle? Let us just say whenever I make a fire like for instance I want to light a candle let us say. I use a matchstick and light this candle. I cannot use this matchstick if I were to have let us say, a sparkler I do not generally use a matchstick, because it requires more sustain flame and therefore, I use a candle for lighting this sparkler. Now again I say I have something like a Bengal pot, it is something like a mud pot in which I put some pyrotechnic composition. I cover it over here it is something like this, I light it over here and here I get the sparkler. This is known as a Bengal pot, because this type of fire cracker originated in India in in in Bengal and therefore, to light it what I use is I put a sparkler I show the sparkler here and light this and it comes. What is it I see a small fire to make a little bigger fire to make at a bigger fire? And with this bigger fire I do this and so on.

That means, in practice we we we have to remember to be able to ignite anything a small fire always you make a big fire and so on. A still bigger fire, which is used to ignite a still bigger fire; and that is how things are if I have a furnace I do not put a a a an electrostatic spark. I create a pilot flame with the pilot flame I ignite it and so on. And so also in solid propellant rockets what we do is sometimes we use a small rocket motor over here. And that small rocket motor will again let let us put that down you know it is something which is important not only in this subject, but in all other subjects. I have a nozzle here let us say this is my case over here, I put a small rocket over here. That means, I will have something like a nozzle over here, I have another igniter for it over here, and this will contain a squib and another one which it ignites, and then for a small fire makes a bigger fire, maybe makes a still bigger fire which ignites your pyrogen and which still makes a bigger fire which generates your thing and.

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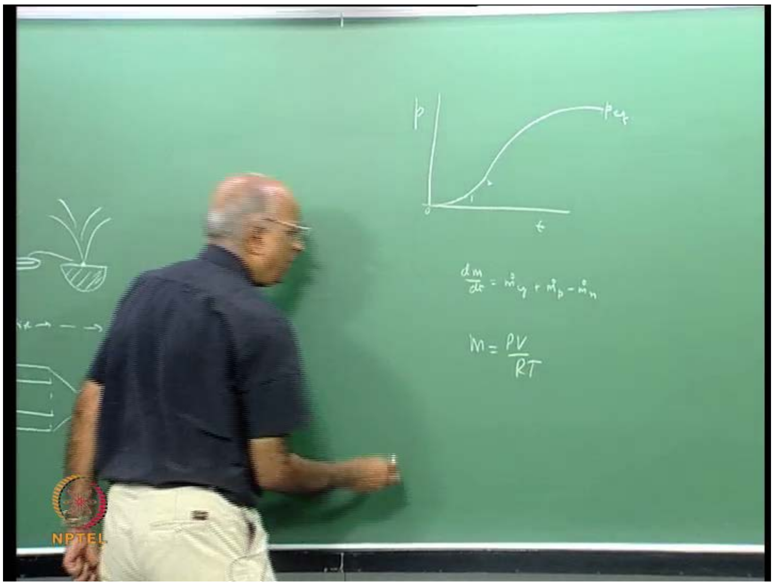

Therefore a pyrogen is a small rocket which ignites your main rocket. And what did we tell ourselves at that point in time. We said well if I have a large rocket and if I look at the pressure time trace I have something like it takes off it ignites here locally. What ignites initially it pressurizes the chamber to some small value. And also transfers heat over here and therefore, I have local ignition from let us say 0 to 1. And then the the flame spreads over the surface little bit to 2 and then when the overall flame has spread it reaches the equilibrium pressure which we say is p equilibrium.

We derived expressions we said you know this can easily be predicted, and how did we predict we said d m by d t that is the pressure which is developed that is the mass which is contained in this cavity. The rate of change of mass is equal to the rate at which the igniter, supplies the mass at that particular time, plus the contribution which coming which comes from the burning of the propellant and the spread of the propellant, minus the rate at which the flow takes place through the nozzle. And we were able to say m is equal to PV by RT. And we took the simple case where in d m by d t corresponds to the condition when the surface entire surface of the propellant has just got ignited that is 0.2 local ignition of a small surface followed by the entire surface getting ignited and we were able to get the equation to this curve and what was the equation

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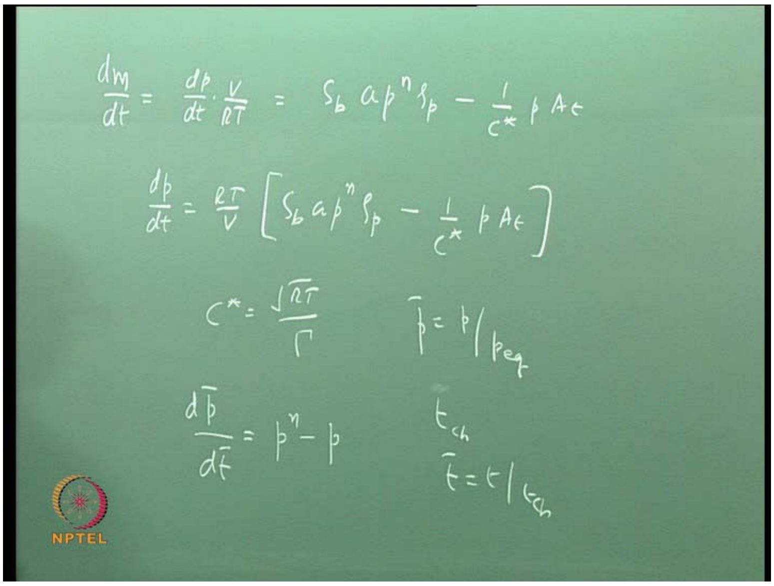

We told ourselves well I write d m by d t. And you see how simple is this m is equal to PV by RT that is d p by d t into volume is constant V by RT is equal to what is happening now the entire surface is burning s b, into r is equal to A p to the power n, into rho p that is the rate at which mass is getting generated, minus 1 over c star into p into A t. Therefore when we solve this equation we forgot d p by d t is equal to RT by V. And then we had this within the bracket, s b A p to the power n density of the propellant minus 1 over c star, into p into V t. And what did we do we said c star was equal to under root RT by capital gamma which was a function of the under root small gamma into 2 over gamma plus 1.

Therefore, RT we were able to write in terms of gamma square into c square and this particular equation we were able to get it in the form d non dimensionally. How did we get p bar? We said p bar is equal to pressure at any point in time let us say the pressure here is p. The equilibrium pressure is the final steady state value p by equilibrium p equilibrium is p bar. And we defined a characteristic time which came from V by A t we brought it out we got L star here, L star by c star we said as a unit of time we called it as characteristic time. And we said we will take a look at it when we study combustion instability and then we said t bar is equal to t by t characteristic. And therefore, we were able to get say t characteristic here by d t bar is equal to p to the power n minus p. Here on the side p should be p bar that means, it must be the non dimensional pressure.

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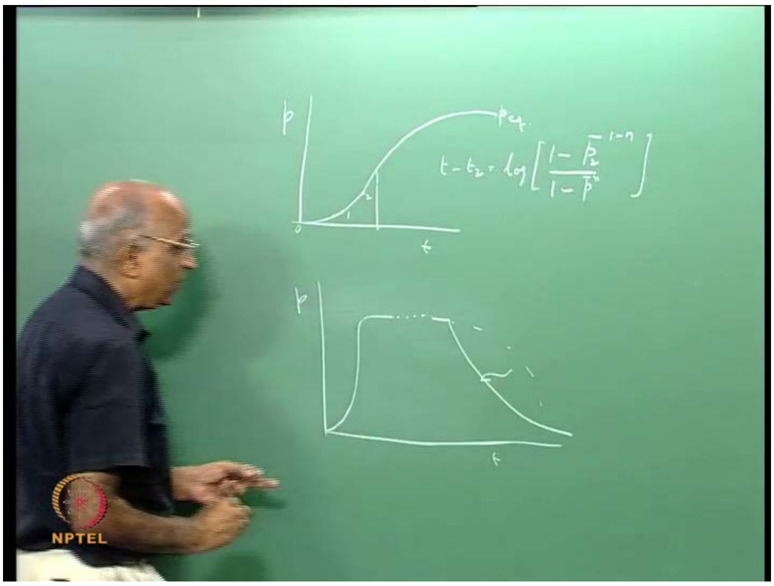

We integrated this expression and got it in the lon form that means pressure at any point or the time between let us say even 2 t 2 even 2 starting from even 2 at anytime we got it as logarithm of 1 minus p at 2 non dimensionlized to the power 1 minus n, to the power 1 minus p at anytime to the power 1 minus n is the expression for the time. Or rather we found it droops after some particular time. We followed the same logic to be able to find out what will be the variation of pressure. Let us say p over here, t over here we said well I have the ignition the motor ignites it keeps on burning and then all the propellant gets burnt. What will be the signature what I get over here? What will be the equation to this how will it behave does it go like this or does it go like this or the shape that we were interested. And the equation we got for this was very very similar, well all the propellant is getting consumed over here therefore, the equation for that particular one which we derived in the last class was d p by d t.

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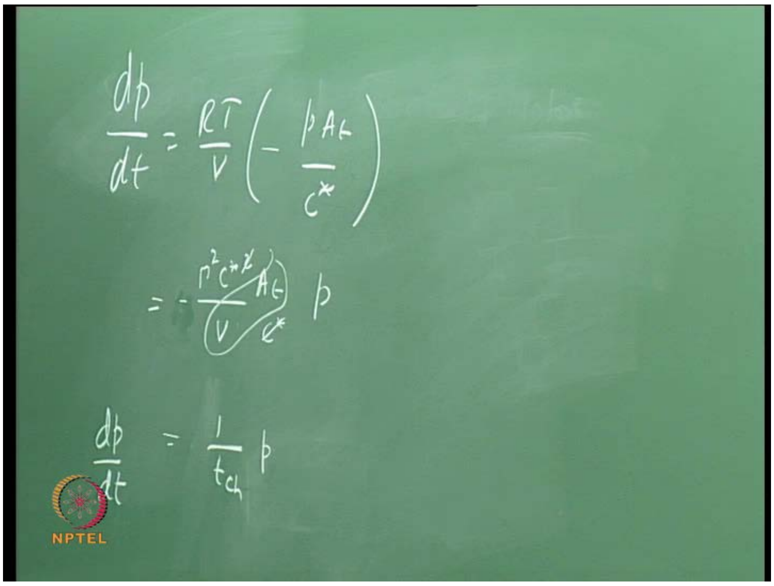

Again RT by V into the rate of depletion is minus p into A t by c star. Which is m dot n correct. And therefore, we did the same non dimensional r RT is equal to gamma square into c star square. And therefore, we got gamma square c, gamma square into c star squared divided by V we took A t outside, and we got the value of c star, again coming over here as p and therefore, this negative sign comes over here. And therefore now this becomes your L star that is volume by throat area, which is characteristic length. And now I have c star over here this is unit of velocity this becomes L star over here. And therefore, I could also write this particular equation in the form maybe 1 over L star divided by c star which is equal to your characteristic time, which is 1 over characteristic time, because length over velocity has a unit of time. And therefore, p over here we got this as equal to d p by d t. And then if I were to divide both the pressure here and pressure here by equilibrium pressure.

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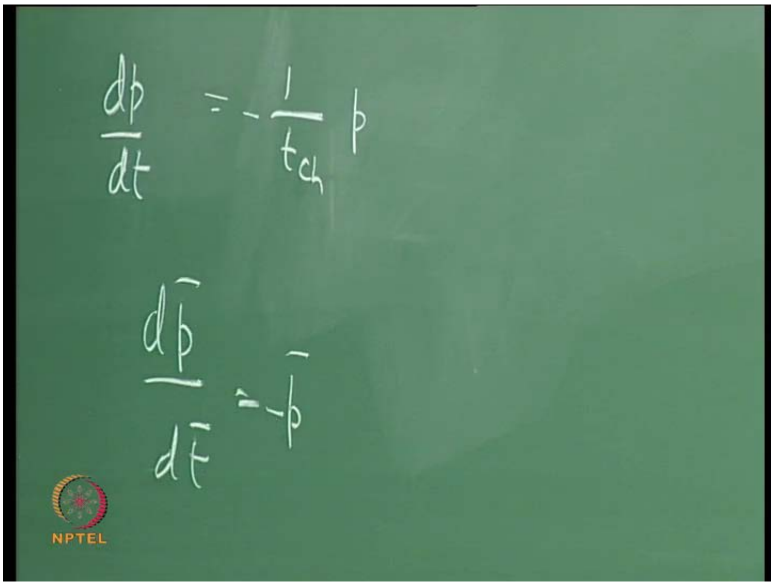

I can write it as d p bar and here I take this over here I get d t bar that is non dimensional time and non dimensional pressure is equal to p bar or rather this equation mind you there is a minus sign over here there is a minus sign over here.

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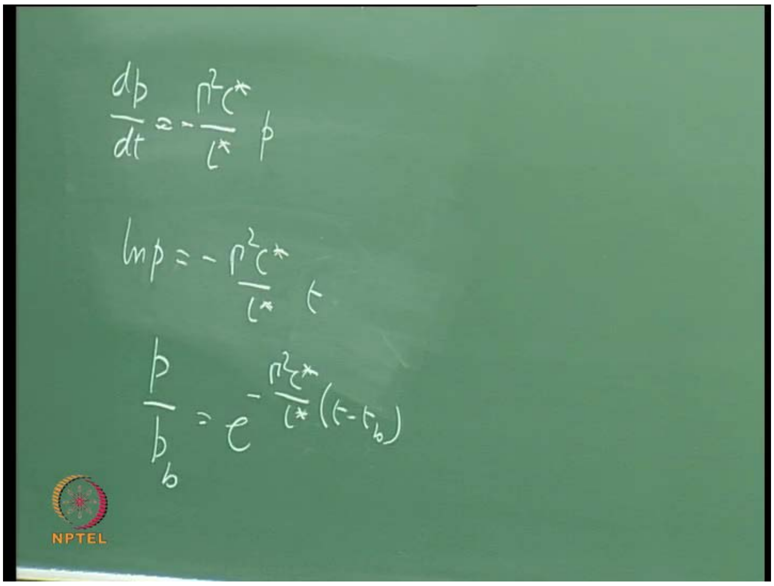

And this tells me that d t is equal to d p by p minus or rather the time taken for it lets say this is the time at which burning gets completed, t b burning gets completed over here. Therefore, I get t bar minus t b is equal to logarithm of the now I have to switch the value that means, my my final pressure will come at the bottom. And therefore, minus will come over here that is lon of lets write it out lon minus lon of the final value, minus lon of the value corresponding to the at anytime. I have the value of p bar that is I am non dimensional zing it I am writing this value the value corresponding to P B gives me the value of P B bar over here. And therefore, I get the expression as t bar minus this should have been t bar b is equal to lon of this becomes negative. Therefore, P B by the value of p over here. In in other words the the the decay is exponential and to reach 0 value is going to take a very longtime. And I did it dimensionally the other day and what did we do dimensionally. We could have directly integrated this value over here, and if you had taken this I would have got gamma square c star by L star I would rather let let us do that you know we must be able to do this in different ways. We could have got d p by d t is equal to gamma square c star by L star into p with a negative sign over here, gamma square c star V by A t is L star over here. And if I have had to integrate I get ln p is equal to minus gamma square c star by L star into t minus that means, here I should get p p divided by the value or p minus ln P B. This this if I have had to write without the limit I get t or rather I get p by P B that means, ln p minus ln P B is equal to e to the power minus gamma square c star by L star into t minus t b. That means, the pressure continuously decays with time.

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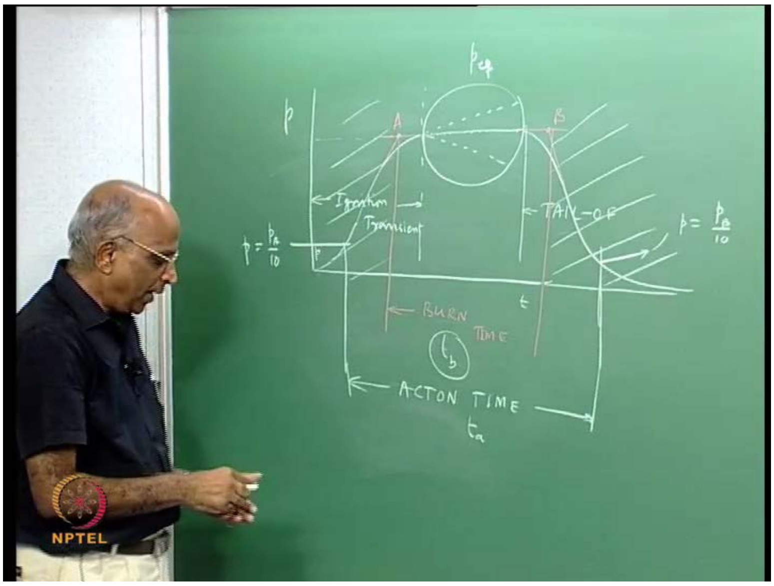

Therefore why why am I doing all this? And why are we doing all this? See there must be some reason the reason is, now what does it we have established? We say whenever a rocket motor ignites, the pressure changes with time, starts slowly builds up flame spread goes over here, then reaches if it is neutral it goes like this, if it is progressive, it goes like this, if it is regressive it goes like this, mind you this particular zone is equilibrium pressure; that means a steady state pressure. At the end of this what happens is well all the propellant gets consumed, it goes like this and comes back over here. This is the transient for ignition transient. This is a period of steady burning which will be much longer, and this is the time when it burns out or you have we called it as tail of. How do I use this you know I fire a motor I get these signatures? How do I find the time of burning of the curve goes like this out and it comes like this? How do I find the time of burning it becomes a little complicated and for that there are standard procedures how we do it.

I i plot let us say I consider the case of neutral burning one case what I do is, I plot a tangent to to this particular graph over here. I plot a tangent to this curve over here; I get a particular point over here. Similarly, over here I plot a tangent here I plot a tangent here

I get a curve point here. I say this is point a this is point b. And now see here also, me burning is taking place here also, me allotment you know I say the burnout is not sharp at this point it would have been somewhere here. This particular distance from a to b is called the burn time. And it is denoted by the word t b. See what is happening see burning has happened somewhere here, even though I say some little bit of propellant is still burning here. It is there therefore, this particular distance or the time period between a to b is what we call as a burn time. And this is how we characterize a solid propellant rocket motor. That means, we said that the burn time of this motor is so many seconds or so many minutes or so.

But then we must also realize during this period when before the burn time. It is still giving you some momentum it is still giving you some impulse and here also you get some impulse. Therefore, when I want to define a mission an mission is to get impulse with which the pellet goes up this also contributes, and this also contributes. In other words I take the maximum pressure ratio over here. I find the value of pressure over here, at this particular point as let us say the value corresponding to a divided by let us say 1 10th that is 10 percent of the value here.

Similarly, I get the value of P B here. I get 1 10th of the value here. That means, the pressure corresponding to this point is equal to pressure at this point is equal to pressure corresponding to the b divided by 10. And now here also I get the certain impulse here the impulse is going to be very small and this particular time between this to this is what we call as the time of action of the motor or action time. You can denote it by t a. In other words when I have had to plan a mission, I would like we want to launch a missile let us say. I get something over here something over here. I need this particular time, whereas to characterize the motor per say in a test or something well I am interested in the burn time. And always we see well the action time is greater than the burn time. Well this is all about solid propellant rockets.

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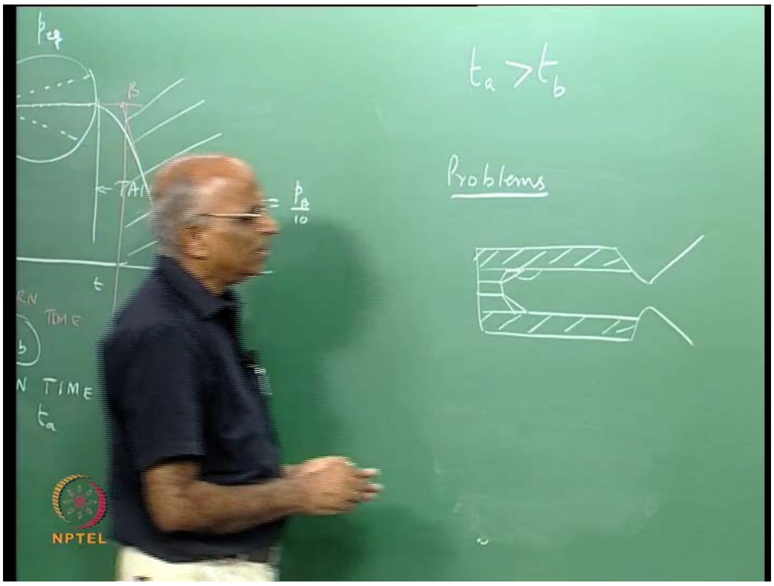

Now let us go back end examine 1 or 2 small problems we can have in solid propellant rockets. You know the why I am consider why I am considering this is whenever we make a rocket. Let us say let us say I have again I make a sketch of a motor. Let us say it is radial burning I put an igniter. And we told ourselves the other day most of the igniters are pyrogen igniters, because normally the rocket motors are quite substantial that is the solid propellant rocket motors are quite large for I have the propellant here.

Now I make an igniter. And how do we design an igniter we were very clear. It must pressurize this cavity to some value not very high value. Such that a flame can be near the surface and also give some energy and we said propellant requires some minimum energy for ignition. I get some plumes and it ignites a particular surface. This is all the requirement and there after the flame spread and pressurization takes place, and we had this particular curve local ignition flame spread and the pressurization, but very often when we do this test what we find is instead of the pressure going like this.

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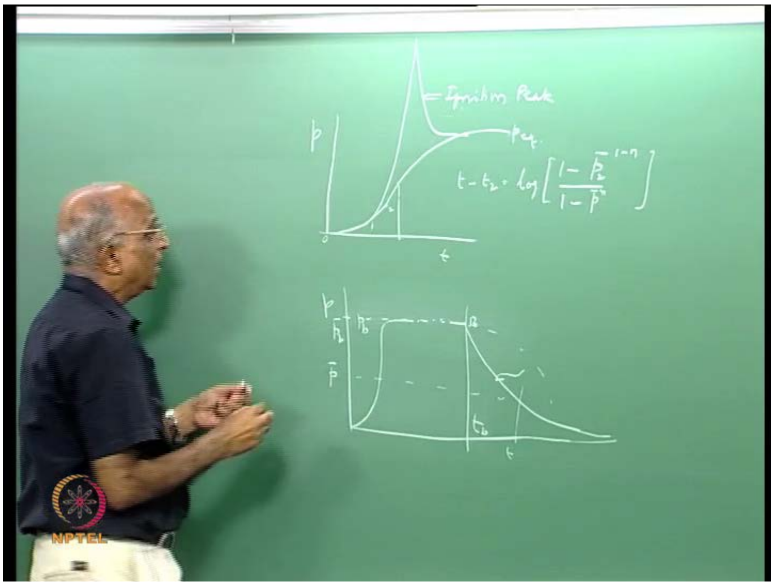

Very often something the pressure goes like this and comes down like this. In other words I get a peak pressure. That means, the I get something like an ignition peak in the process of ignition transient I get something like a peak, in the ignition and this is detrimental, because all of a sudden I get I get some thrust, which is not desirable why should such a such an event take place.

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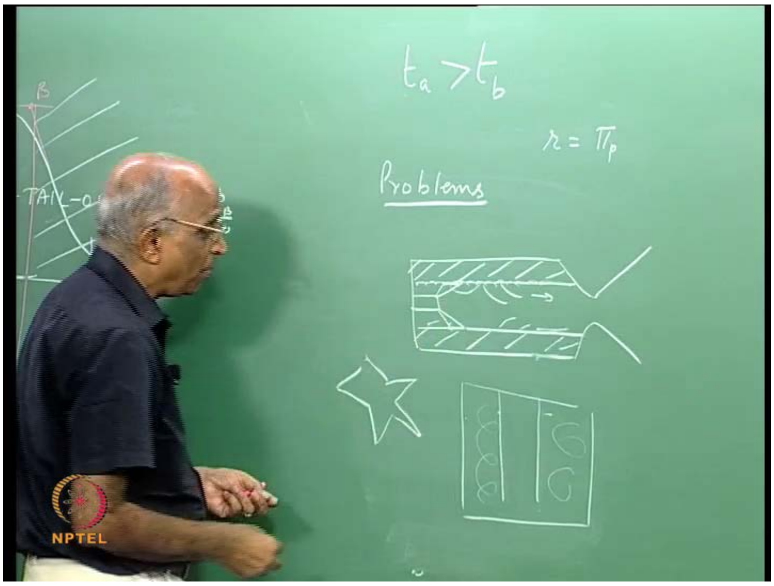

Let's take a look and why why what are the parameters. When we make this propellant how do we make a propellant. Well I take a case motor case like this a solid propellant rocket case. Inside it I put a mandrel if I want to make a cylindrical grain I put a cylindrical rod over here, pour the propellant over here, if I want to make a star grain well the shape of this mandrel which I use should be a star shape and then I i cure it and then I remove this mandrel therefore, I have this particular shape of the grain over here. And on removing some times to remove the grain is difficult and therefore, we use some agents which a like silicon oil or something which are essentially insulators to be able to easily remove it and I form the grain in this particular way.

Now if the surface of the grain is such that it is not easily ignitable. What happens you are transferring energy the grain gets heated and as it continues to get heated it is a it is a when it begins to burn it starts burning at a higher temperature, and since it starts burning at a higher temperature the value of r is now influenced by the temperature sensitivity factor. And therefore, since this you have a burning takes place at a high temperature it produces much more mass or it burns with a higher speed. And therefore, you have a higher amount of mass energy which is getting released and therefore, the pressure could go up. This is one reason the second reason could be maybe I have velocities, and it could lead to higher velocity higher burning rates towards the end and that is also possible.

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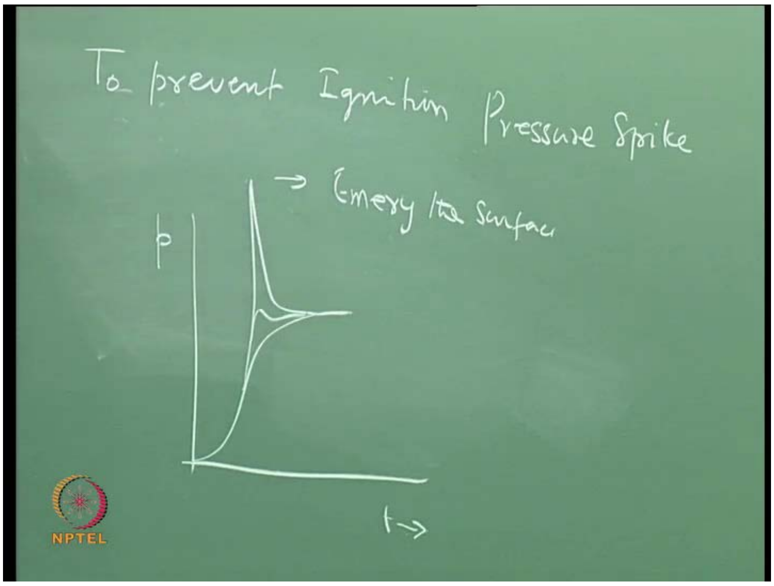

But, to be able to prevent this what this normally done is we take something like an emery paper and remove the surface defects, and ensure that the surface of the propellant is easily ignitable. Let let us put it down to prevent ignition spike ignition pressure spike. What we do is maybe we emery a surface. Take an emery paper may be make the surface make sure oxidizer and fuel are readily available, and it catches fire easily. If not may be you have to make sure, that the surface is such that some other reason like erosive burning which I will consider shortly does not lead to an h normally and have a pressure spike instead of the motor burning like this it must not happen I have a huge pressure spike. I can always tolerate something which is small, but this must not happen in practice it is something we have to guard against. Something which I missed out telling when we talked of igniters was very often when we ignite a motor the gasses are going out and some of these motors have to ignite in vacuum.

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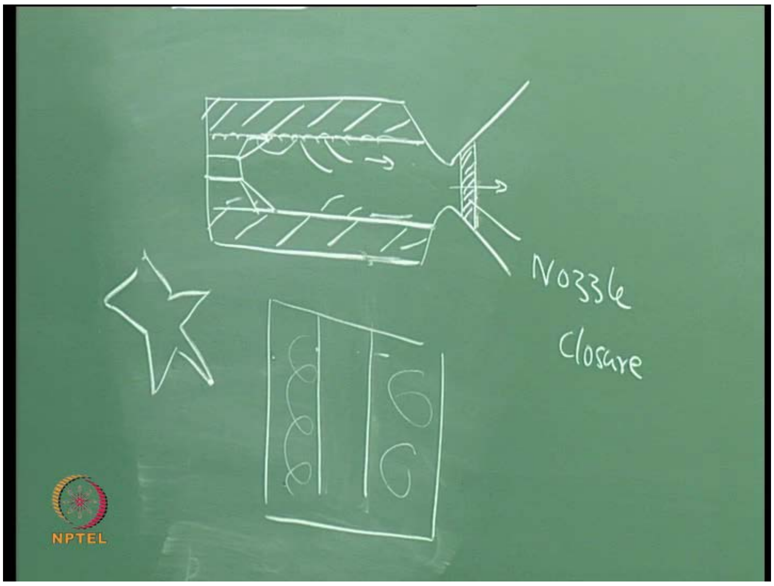

And therefore, we put something like a closure here, we initially close the thing like this and when pressure builds up this goes off and once the motor is ignited this gets thrown out and make sure let us make sure that this is around 5 bar to 6 bar such that some minimal pressure get's created. This is known as a nozzle closure well these are all about solid propellant rockets we have considered the burn rates we have considered how to go about making a a grain of a particular configuration to get a particular thrust. And then we looked at igniter we looked at the action time the burn time. And therefore, maybe we should put things together at this point in time before we close our discussions on the solid propellant rocket.

Let let let us see what what we could think of we talked in terms of burn rate r. How did we define the burn rate or how did we determine the burn rate well we said I can make a propellant a small strand may be something like may be a diameter. Let us say one centimeter or so I could put it in a chamber I pressurize the chamber to whatever pressure I am interested in. Then I i ignite the surface may be I measured the burn rate when it propagates through a particular distance. I control the pressure in this chamber at this particular chamber in which such strands are burnt is known as Crawford bomb. it is something like a bomb type of a calorimeter in which I burn the propellant, but all what I do is I put a fuse wire here, I put a fuse wire here, I give a timer the timer tells me it starts over here stops over here this length is L l divided by the time is the burn rate r when the chamber is pressurize to some level.

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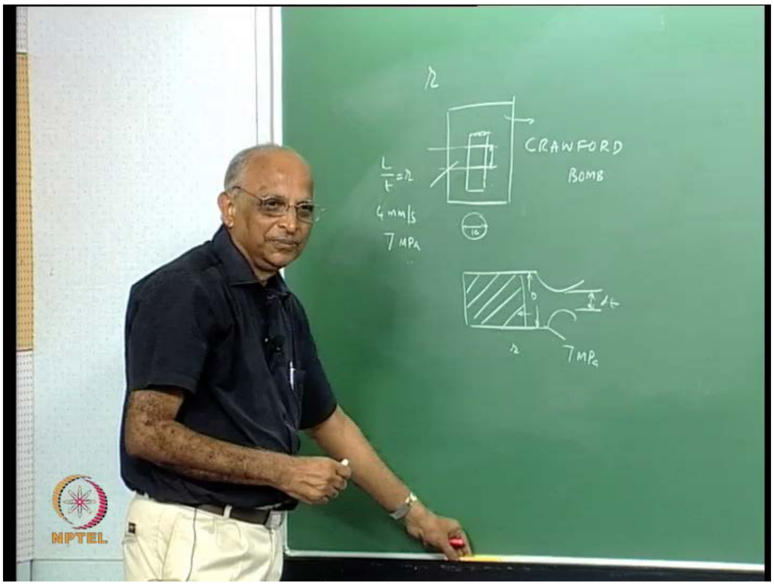

Now I use the this burn rate in a rocket motor and well the racket motor let us say the same end configuration is like this and in the rocket motor what I have may be the diameter is d the throat diameter is d t. I want to find out the burn rate I measure over here it gives me let us say 4 millimeters per second at a pressure of let us say 5 or let us say standard pressure 7 m P A here the chamber pressure is 7 m P A. The question is will I get the same value of r or should I get a different value. What is your take on this how would you feel should it be the same I measure in a strand I take it over here, I put a same pressure ambient I measure a burn rate of 4 millimeters per second at the same pressure as is over here. And I want to measure the burn rate in the motor, because I use this to be able to design this will it be the same or should it be different if it is different why should it be different any guess on this. How would you look at this problem to be able to answer this; we again go back and write what is the equation, we derived for burn rate.

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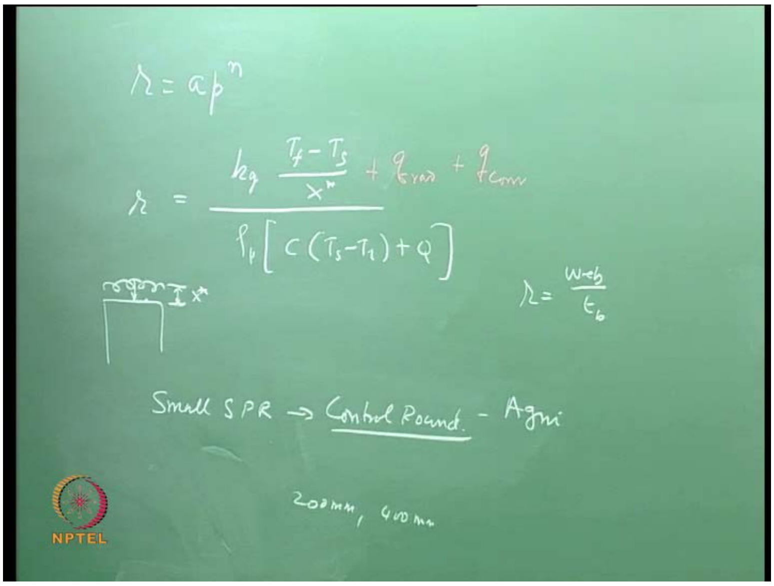

We got the equation r is equal to A p n how did we get this equation we said. Well I have the surface the flame is standing of at a distance x bar from the surface, please keep our discussions very clear. And how did I we get this we said r is equal to the heat which is given over here, thermal conductivity of the gas above the surface, into the temperature of the flame minus temperature at the surface, divided by x star is the heat which is conducted divided by rho p into specific heat into surface temperature minus the initial temperature plus the exothermity of the surface we derived this based on the simple model over here.

Now can we look at this, for the experiment over here, and the experiment over here? And say would it be different in the two cases or should it be the same this is a perennial problem we have with solid propellant rockets. Now what is happening here the ambient is all cold gas even though it is at the same pressure. Here the ambient is hot gas therefore, I will have heat radiation coming on the surface. In other words when I test a motor I will have something like q radiation coming on the propellant surface, I could also have in a radial burning grain q due to convection coming on the surface. And therefore, the burn rate in a motor should be higher than in when it is tested over here. And therefore, to determine the burn rate what is done is you have to test it in a small solid propellant rocket and these rockets are what are known as control blocks or control round, because I cannot really use this standard apparatus to determine the burn rate. I have to use this, because it is more representative and what do I do the what do I do with this? May be when I am developing a propellant different formulations I try I fix the formulation here, but the final burn rate is always derived with a small solid propellant rocket itself. Which is known as a control round in India we call control round as a agni rounds, but mind you the name should be control round let us not confuse it with agni missile may be we will talk about it later.

Small rockets may be diameter around 200 m m length around 400 m m block, cylindrical burning is what we call as a and that is how we determine or how do we determine burn rate. Burn rate is equal to web web thickness divided by the web burn time. And that is how we do we we go ahead and do it, but now the problem is still still worst I come to this case of let us say. I consider two cases well we said the solid propellant rocket or space shuttle is a very large motor, diameter is around 3.8 meters diameter the length is around 40 meters this is one motor.

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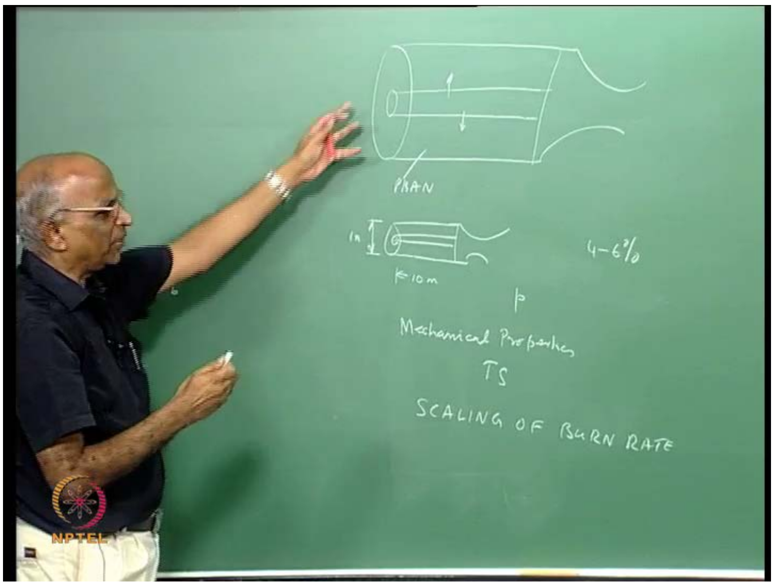

Let us say it is also let us say some some star shape, but we just say a simple radial burning out side let us say I have another motor using here we said p ban propellant. the same p ban propellant in a small motor not a control round, but so let us say in a motor let us say 10 meters long, may be diameter of 1 meter similar, grain will the burn rate in this and this at the same pressure be the same or different. Again I look at the radiation radiation depends on the mean beam length. Therefore, I expect the burn rate in a larger motor to be different, but it is not necessarily true there are other factors like mechanical properties of the propellant. Why I say mechanical properties mechanical properties could be hardness could be tensile strength, could be the ductility of the propellant. And during burning I could have some deformation taking place all those things is going to affect my thickness over here.

And therefore, scaling of burning rate with size of the motor or size of the rocket is always of interest. And we should have some say, but I I observe that when you have some medium size motor and you go to larger size, the increase in burn rate is something like 4 to 6 percent generally. And after particular size it does not really affect it significantly, but we have to verify it through models. And what are the models we use again we go back to our basics, write the equation find out what is the role of convection and radiation and solve the problem simple.

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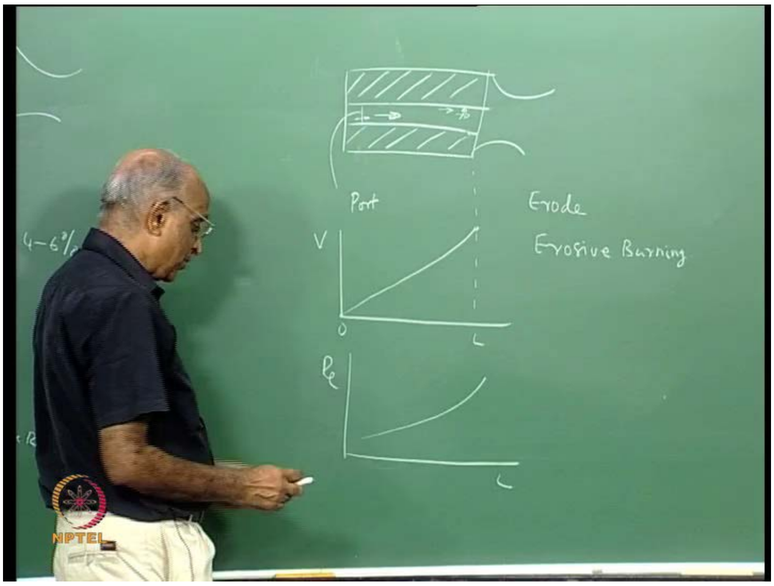

This brings me to the last point namely if we were to have something like a long propellant grain. Like let us say I have a internal burning grain, let us say radial the the initial cavity diameter which is also defined as port of a rocket motor, that is the cavity that is the port cavity is of small diameter. And it burns at the surface let us say this is the propellant grain, gas is coming out let us plot the value of velocity of the gasses which is moving here, mean velocity of the gasses, as a function of length starting from the head, end towards the nozzle end.

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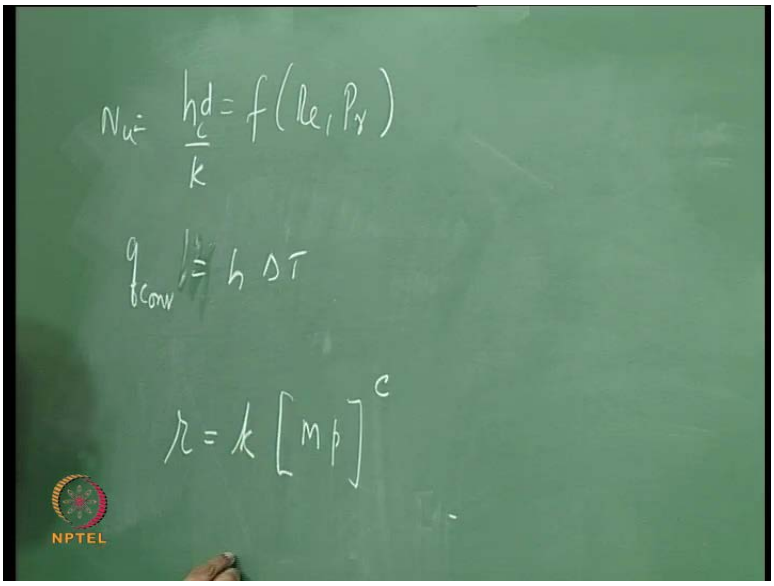

Here there is hardly any velocity, but more and more gasses are flowing therefore, the velocity is increasing over here. Velocity is maximum at the nozzle end. Now what does velocity does to a surface which is burning. Well it can erode the surface like in the in the in a river. Let us say a river is flowing and what does current of velocity do it drags the sand from the river. So, also I could have something like erosion let us write it down it could erode the propellant surface, in other words I could have something like an erosive burning. Mind you propellant was heterogeneous composite it is sort of eroding the surface or erosive burning, but more than erosive burning I find velocity here is higher therefore, my Nussle's number or my Reynolds number at at the point let us let us put it down let us now write it, I have Reynolds number as a function of length well my Reynolds number is increasing. If my Reynolds number is increasing well my Nussle's number or heat transfer is going to go up.

Therefore I am also going to get increased convective heat transfer. In other words I can talk in terms of erosive burning arising from convective heat transfer, and when we do such a modeling again it is simple you calculate the new value of heat of convection, is equal to function of Reynolds number into prandtl number. And this we write in terms of nusselt's number nusselt's number is equal to h d by k. And therefore, I can always find out the nusselt's number once I know heat transfer I can find out what is that q convection, is equal to h into delta t and therefore, I can find out the increase in rate and when I do that I find the burning rate can be put in terms of a constant into something like a mark number into the pressure to the power c.

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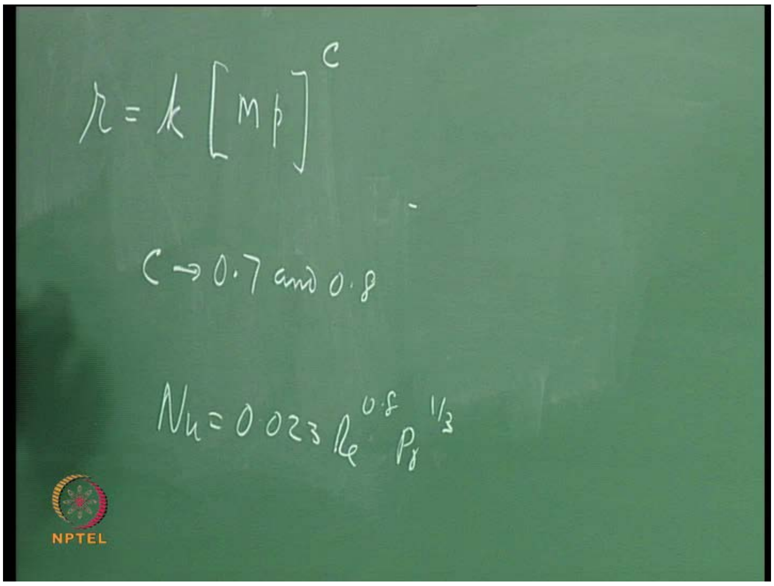

The value of the exponent c is typically between 0.7 and 0.8 which is something like saying. If you look at the standard correlations for nusselt's number you get nusselt's number in a turbulent flow is equal to 0.023 into Reynolds number 0.8 prandtl number to the power 1 by 3 that means, it it does show that convection plays a role. In addition to pressure I have mark number effects and this is what gives me the erosion effect.

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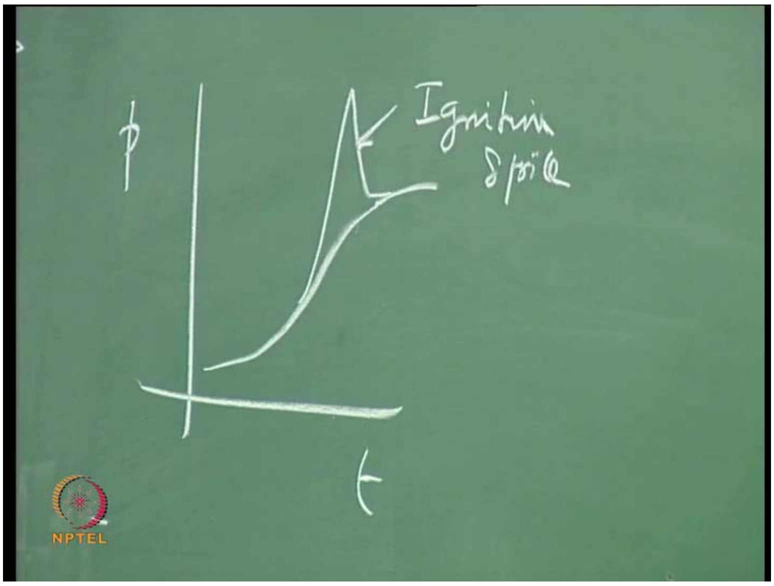

And this erosion effect, because it increases the burn rate can also lead to instead of the ignition going like this, at this time the port volume is small I could write you have a ignition spike that is pressure versus time I have an ignition spike over here. Well we can keep on talking of these different things which alter the basics with which we studied something which I thought I should bring out was. You know we told ourselves you will remember, that the solid propellant rockets could be either extremely small extremely large.

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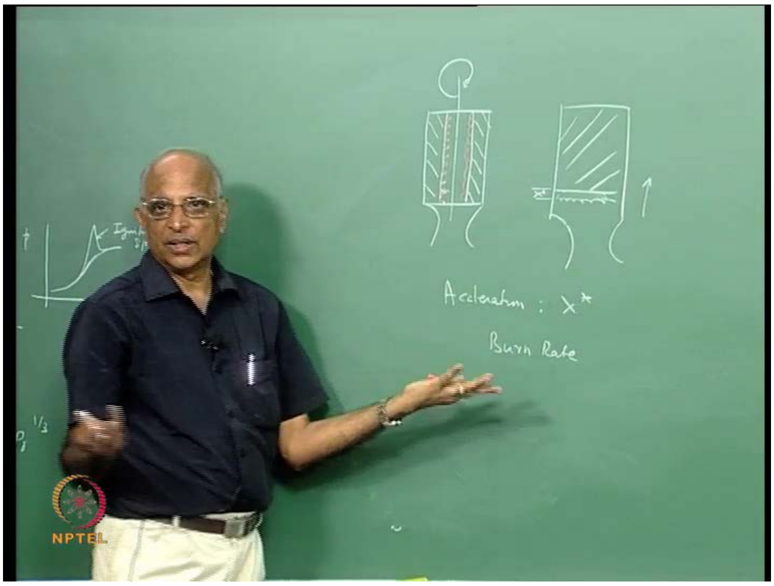

Supposing let us say I i I am launching a particular solid propellant rocket it has a nozzle. And to be able to stabilize it sometimes the thing is spun it rotates, or rather I have let us say an end burning grain, something like this it is burning over here, it is being launched like this, this is a case where in I am spinning a radial burning grain over here. And why do you spin to make it stable like just like we have a top which spins, which is more stable I sort of spin this this is linearly accelerating.

Now what is happening is the burning surface is over here. Therefore, in the frame of reference of this rotation, I have aluminum and all which is burning over here it gets pushed towards the surface. Therefore, I get the effect of local acceleration and the effect of acceleration is to be able to either push it away or push it towards the surface. And therefore, I can say well acceleration will affect my x star x star is the flame standoff and therefore, it will also affect my burn rate and you can have a simple model how do I effect find the effect of acceleration.

All I have to find out is what does how the acceleration affects my stand of distance from this. If I can find it out through a simple model well I can do it and what we do I know the math’s here, I know the centrifugal force here I know the acceleration over here, I know the mass of aluminum particle’s which are burning and therefore, I can do this problem. And this is how may be research continues in the area of solid propellant rockets. Well this is all what I thought I should say, but let let us quickly revise through and then address one or two of the very major issues which were faced in solid propellant rockets namely the control of thrust. I think I will do that for that I come back over here, just let us quickly revise in two or three slides what we have been talking of.

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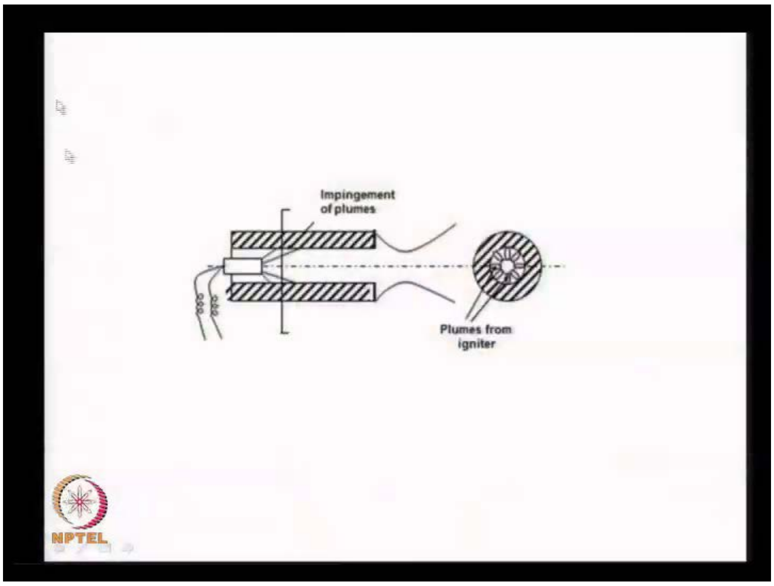

This is an igniter may be a pyrotechnic igniter. It produces these plumes impinges on this surface ignites this surface also pressurizes this cavity that means, these are the individual plumes which are igniting this surface here. The flame spreads and then the gases move out through the nozzle and this is how ignition takes place.

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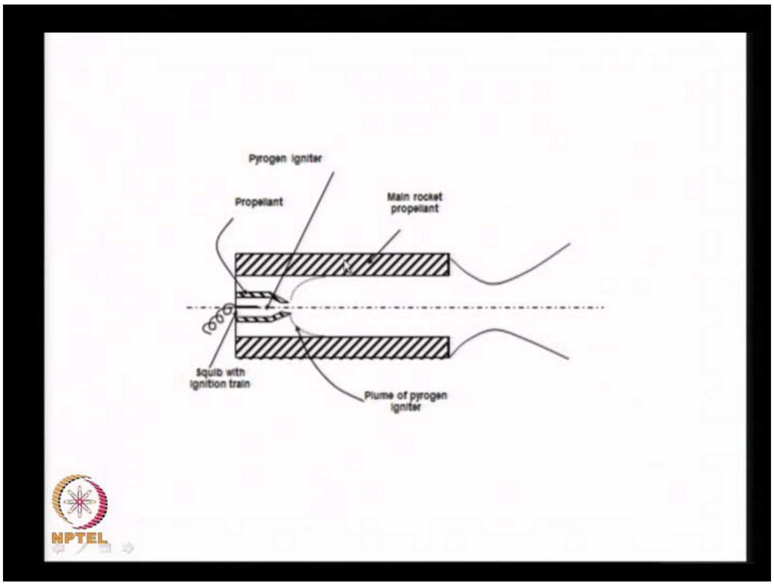

Let us go to the next one. This is a pyrogen a small solid propellant rocket. This has a pyrotechnic igniter here, squib over here burns here, then it burns here, ignites this surface and flame moves forward. That means a pyrogen igniter is a small solid propellant rocket it has a regular propellant, we will take a look at one of the propellant's for this and this is the main propellant which it ignites.

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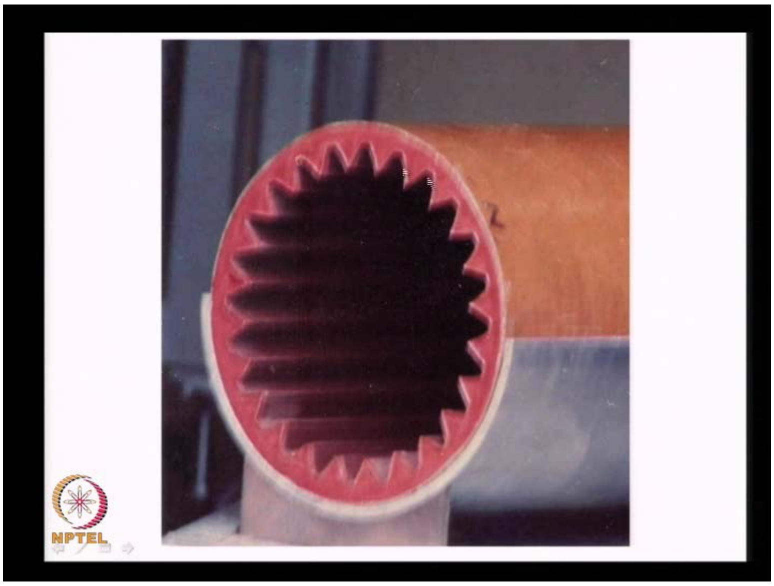

See this is our pyrogen propellant grain looks. We will see it is just one thing like a solid propellant rocket only you do not need. So, much of propellant therefore, I find I give a multi point star the red is what is the propellant. I have all these things I ignite the surface this generates hot gases and that is what ignites my main motor.

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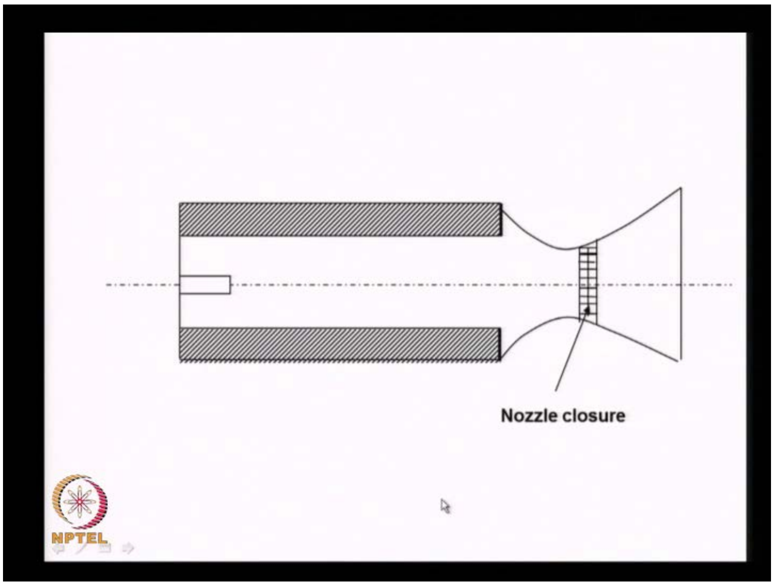

You we said gases must be hot gases must be contained within this port volume or cavity. I use a nozzle closure the moment pressure builds up well this is sent out. And therefore, flow through the nozzle get's started till then I sort of make sure that the ignition takes place in a chamber which is sort of enclosed on all sides this is known as the nozzle closure. It is just something like a small surface which is some ablative surface which is bonded over here, by glue and the moment it it develops some thrust it is pushed out. We use some such nozzle closures in liquid propellant rocket engines also we will cover it at that point in time.

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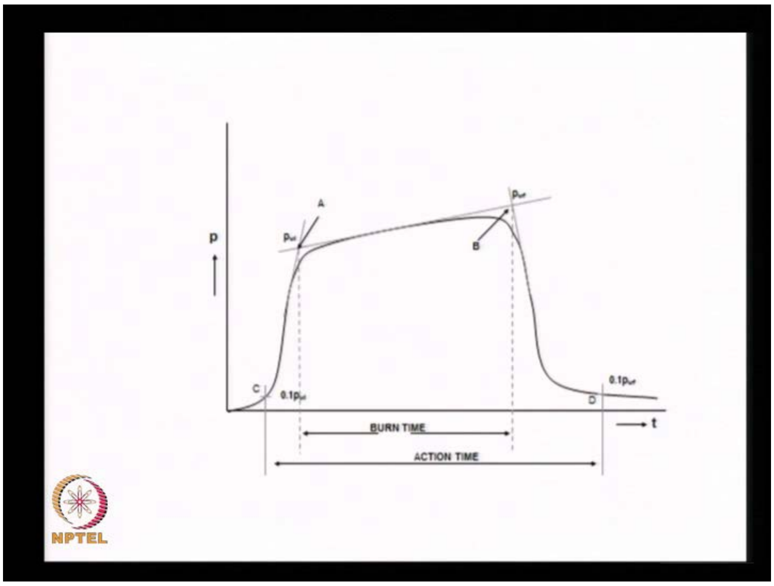

We talked in terms of burn time. Two tangents this is shown for progressive case a tangent here a to b is what is the burn time, and may be one- tenth of the pressure one-tenth of this pressure over here, is what is the action time. Well these are all about the solid propellant rockets.

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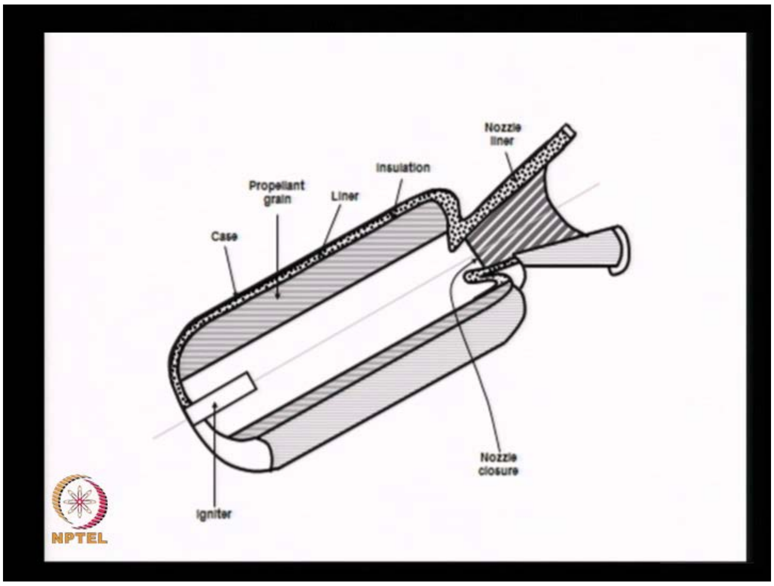

Now having done all this let us put everything together in a single diagram. What are the components of a solid propellant rocket? Well propellant basic it is contained in an insulation, or a liner then after this insulation have another liner, make sure that it is compatible with this insulation such that heat does not when when motor burns the heat does not sort of allow the motor case or the case which is a metal to burn off. Therefore, I have a propellant, I have a case, I have insulation and liner is also a form of insulation. And then I have this as a nozzle the nozzle could be sunk into the propellant on, and it could be made to flex we have seen that when we talked of in terms of nozzles. We have a nozzle closure over here; I have an igniter which could be a pyrogen igniter or a pyrotechnic igniter. Well this is all what a solid propellant rocket is. And we said it called a motor because there are no moving parts in a solid propellant rocket. Having done all this I thought let us review two practical problems which have been encountered, during the history of development of different rockets. And I just choose two of them, because all of us have heard about this and let us clarify what really happened.

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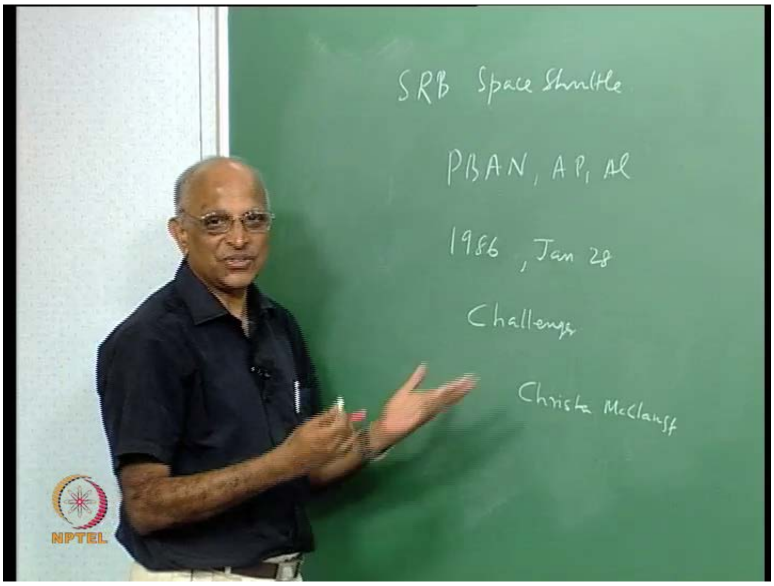

One is we talk in terms of solid rocket boosters for space shuttle. Our interest in this is we told ourselves a solid rocket booster for this space shuttle, in U S A was by far the world is the world's largest solid propellant rocket. It uses p ban polybutyl polybutadiene acrylic acid acrylonitrile as a propellant, this is the fuel binder of course, it contains A p, large amount of aluminum as in all solid propellant rockets. And what was the problem. In one of the shuttle launches this happened in 1986. I think January month may be 28th or so there was one particular flight known as the challenger, in which it misbehaved. And the entire crew 7 crew got got burnt out there, they all died and also not only the crew it was the first time that they took a civilian into space, they took a school teacher what what was the problem.

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Let us try to understand you know, because we have studied a quite a bit and we must be able to and understand what what what really went wrong. Well this shows the space shuttle you know what does the space shuttle consists of. It consists of a central engine which is a hydrogen oxygen cryogenic engine, there are 3 of them here they burn simultaneously. And behind the driving for this this is the space plane, and behind the space plane you have a huge liquid hydrogen tank, and at the bottom of it you have the liquid oxygen tank, this is the huge liquid hydrogen tank you need a huge tank, because liquid hydrogen is not very dense. You have two solid rocket boosters and first what is done is these 3 liquid engines fire, they are they make sure that adequate thrust is developed, because you can always switch on and switch off a liquid propellant rocket. And once it has developed a developed the particular thrust the two solid rocket boosters are fired. Mind you this what we said is around 3.8 diameters and around 40 meters in height and this begins to fire and in this particular launch it happened on a cold day.

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The temperature at the ambient was around minus 1 degree previous night; it was around in the morning around 8 clock or so. The previous night the temperatures went down as low as minus 15 degree centigrade. And this shows you know it was a perfect launch it takes off beautifully, but then after sometime let’s come back to the earlier slide after some time may be around 0.6 seconds after ignition of the solid rocket booster. You know around this region in the on the right side engine little bit of gas was found to escape now let let see the problem. Whenever we have this huge boosters what happens?

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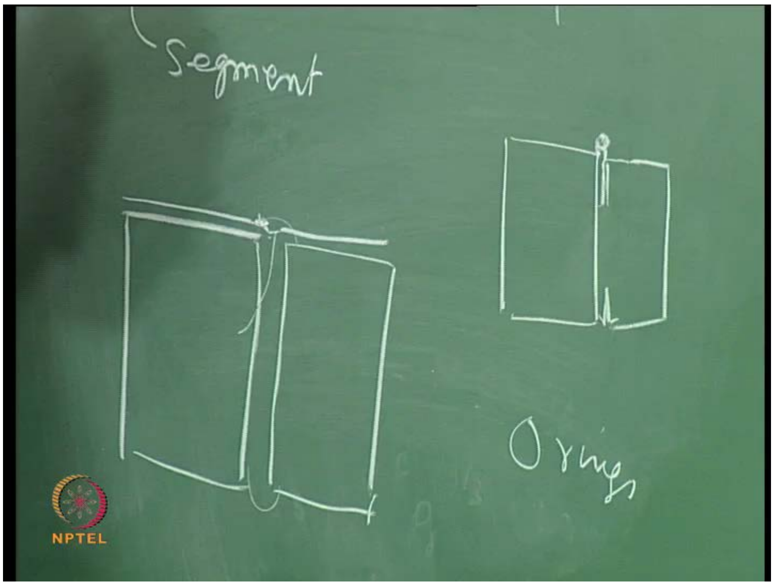

Let let us write how do we make the construction it is very difficult to to have entire motor or entire grain to be cast together we make it into blocks. And then assemble them together each block is known as a segment. And now therefore, you make small segments the solid propellant segments in the case of space shuttle consists of something like I think 6 segments. And what is done at the factory where in these things are made itself some of them are done, but 3 of the 6 segments are assembled in the factory such that it is still transportable, and then in the launch side may be the others are assembled together. How do you assemble it you you have the case over here, you have the case over here, you need to make sure that these two are put together or joined together such that the no leakage is possible.

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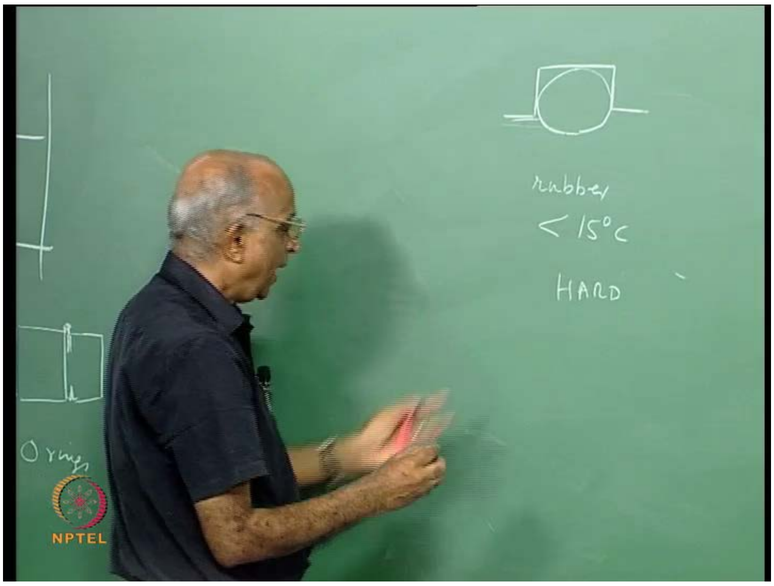

Between this in other words one segment may be I will put something over here insulation, then I have to put the other segment over here, this has to be joined together maybe I should be able join it in some form over here. And how is it joined we put o rings. In other words let let us try to make a a sketch of how the o rings function. See how do you assemble an o ring in any problem? I have a o ring groove, I put the o ring over here, and when I when I have to assemble this the o ring being flexible it it makes this junction to be air tight or leak tight. And therefore, 2 o rings are used and these o rings are of rubber. The rubber o rings which were meant for this have not been tested for temperatures less than 15 degree centigrade. The previous night was cold this particular launch was on hold for some time. And therefore, what happened the o ring which is resilient at ambient temperature becomes rigid and hard, and when it becomes hard it does not it allows the gas to flow by.

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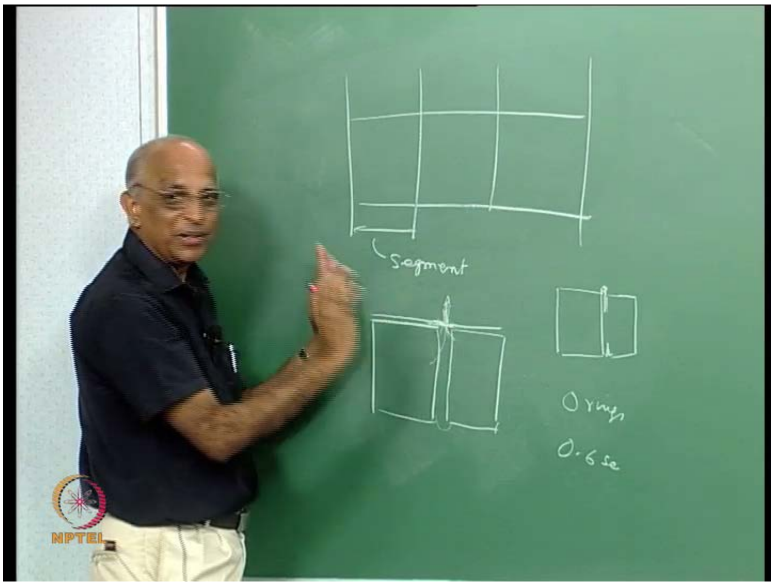

And therefore, at the segment joint what is available some little bit of gas begins to flow back. And the moment it is ignited within 0.6 seconds. You know people saw or based on failure analysis was done; they found some gases were beginning to escape. These gases are escaping, but you know our propellant is highly aluminum. Therefore, what does aluminum oxide do, it goes and blocks it well the motor is still safe it keeps on going further and further.

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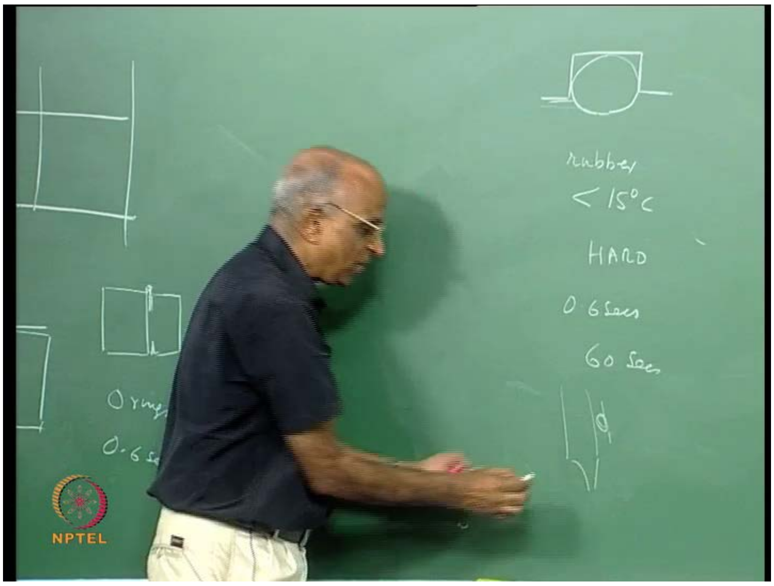

From 0 0.6 seconds at which the o rings have failed up to something like 60 seconds 62 seconds well the flight was perfect, it keeps on going because the aluminum oxide there is a hole aluminum oxide blocks it, the chamber continues to function well, but you know whenever where in we fire a missile or a rocket.

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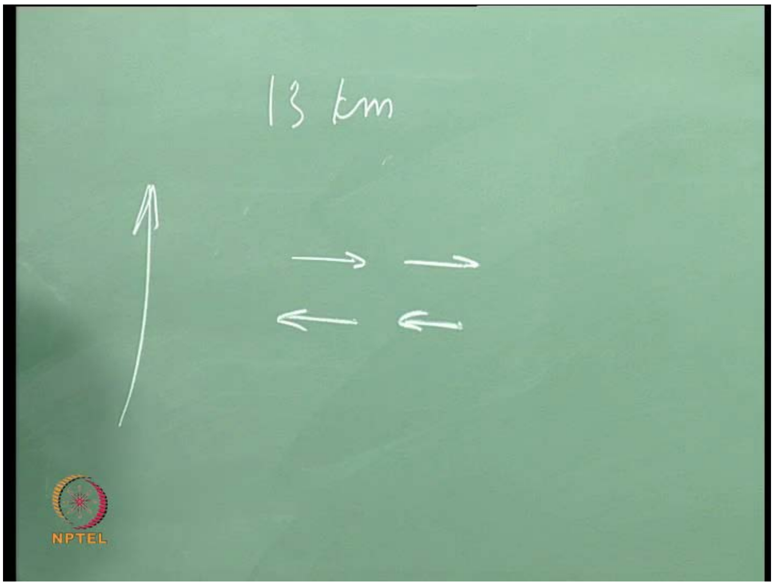

It goes through the atmosphere at around may be something like 13 kilo meters height when it was going, we have wind in a particular direction, and at the bottom wind is in the opposite direction we called is as a wind shear. Some wind moves in this direction some wind moves in this direction. When the vehicle is moving up let us again put it together. Now the vehicle is moving up, and what is happening some wind is in this direction and some wind is it sees wind shear, it get’s shaken and therefore, at that point in time the breach takes place.

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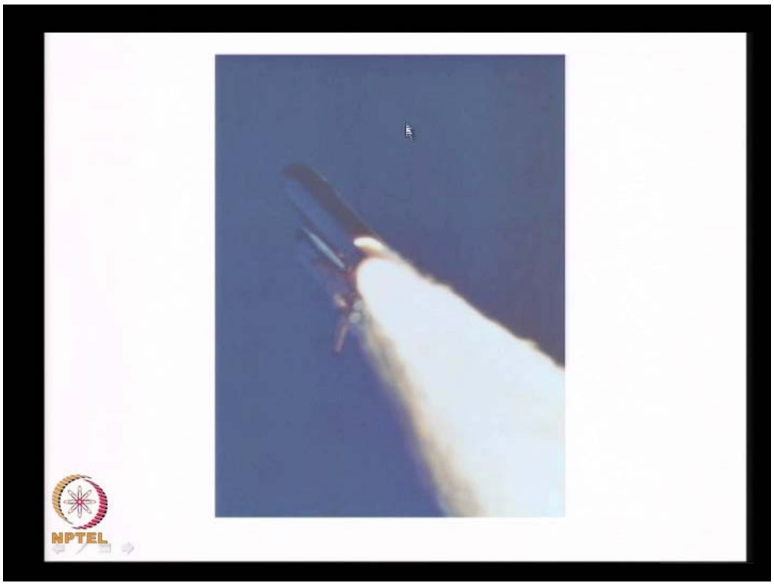

At the bottom on the hand side the opening opens out some flame comes out. And when this flame comes out it hits against one of the attachment which is attaching this to the main rocket. And that gives way and this fellow comes out and it gives a thrust in some other direction. Not only that this flame hits against that what we said is the hydrogen tank which is available in between, spills the hydrogen this happens at a height of around 14 kilometers. And well what what could happen well there is a huge fire ball, and the entire mission is a failure. Therefore, we too see the corrective action of aluminum oxide in sealing the hole in fact one of the recommendation is whenever you use an igniter for pyrogen we never put aluminum, because the nozzle will get clog.

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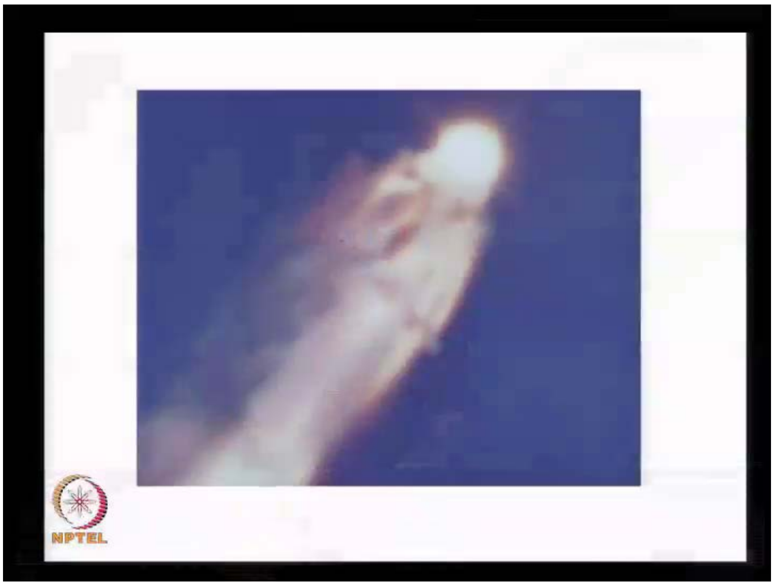

But here it helped, but the failure was, because of the o rings which were not doing the job well well this is about space shuttle.

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You know one last example, I will take you know this is also me thing, which is interesting, I will cover the details of this, when I look at instability.

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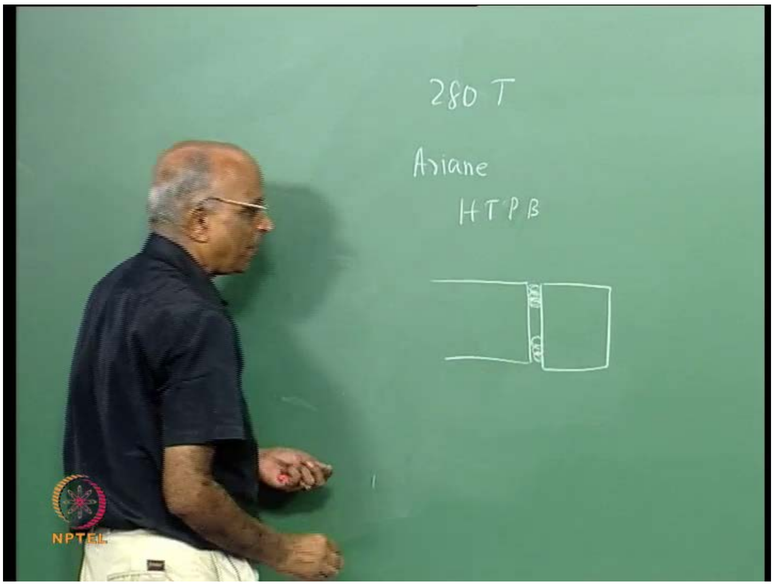

You know we have the second largest motor. I just picked on these two something like space shuttle has 500 tones of propellant; the second biggest is something which is 280 tones of propellant. This is in the case of Arian. Arian is the French rocket. And it uses something like a HTPB base propellant, hydroxyl terminated polybutadien. And in this particular case, what happened is again being a large rocket we have segments different segments. And how do you assemble the segments? Well in between the segments, I put glue or some inhibitor, join it together.

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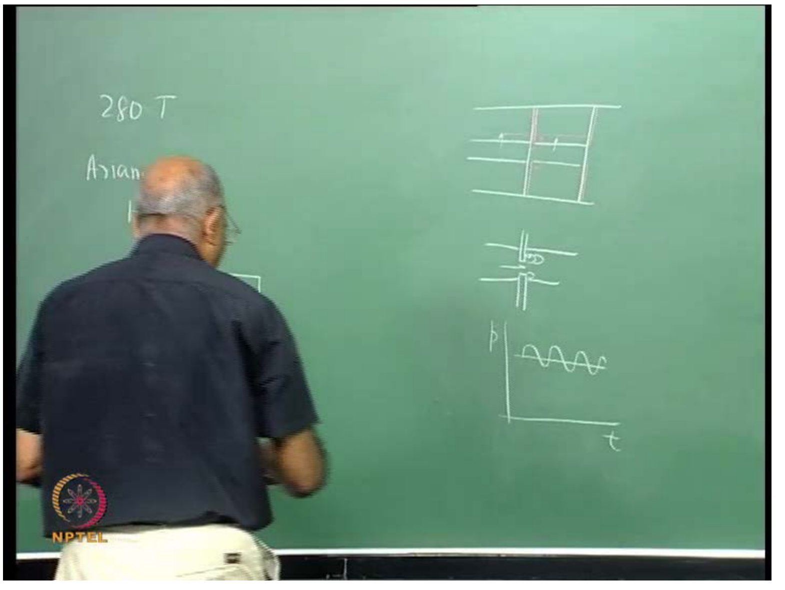

And let us now consider a segment joint. The segment joint is well I keep this open I have one segment over here, this is my inner diameter I put a segment joint over here, then I have the next segment coming over here, and then I have the inhibitor over here. Now when the propellant burns the propellant burns fast where as this fellow does not burn fast therefore, after sometime I have the inhibitors standing like this the propellant is over here, the flow takes place here, and therefore, some eddies are found. This eddies in the flow have a characteristic frequency or a or disturbances and these disturbances get amplified and the thrust instead of being something like this starts oscillating. And the oscillation is, because of the eddies formed, because this fellow projects when when the propellant has burnt over here. Well I have this protrusion here I have something like this standing and this causes the pressure to oscillate. We will see such mechanisms when we look at the chapter when we look at combustion instability.

Well, this is all about solid propellant rockets; maybe we all should try different problems and may be one problem, which I think.

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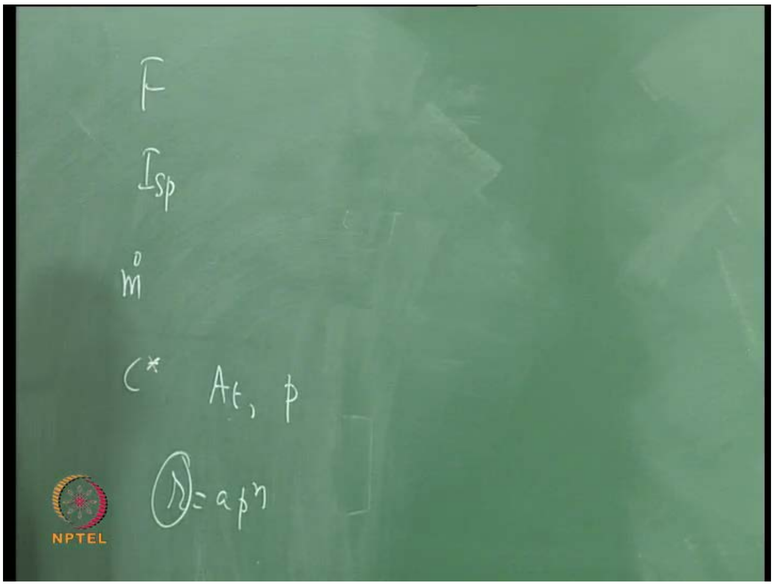

We all should think of is. May be if I am given something like a thrust of a solid propellant rocket, given the specific impulse of the rocket. I can find out what is a mass flow rate I can also use the c star find out what is the value of A t or what is the value of p and using p. And the burn rate relation r is equal to A p n find out the burn rate and then solve the problem this is how it is quite simple. And in the assignments I have given you something like 10 problems may you all should try it out. Well we we have finished the portion on solid propellant rockets in the next class I will start with liquid propellant rockets. Well thank you then.