Rocket Propulsion

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Lecture No. # 41

Good morning this will be the concluding lecture in this course and what we do in this class is the following;

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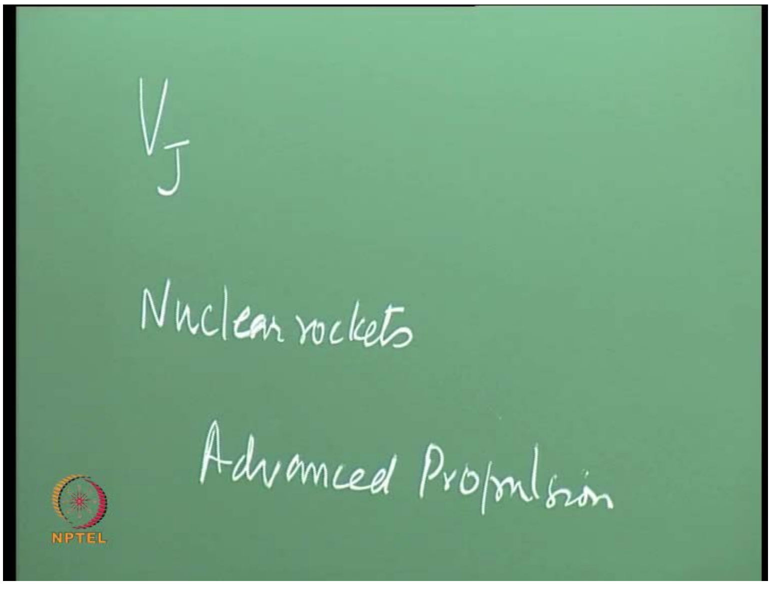

We said v j must be high, let us see other some limitations to v j. After looking at this, we will try to see whether there are other possibilities of using let say nuclear forces for generating thrust like lecture nuclear rockets something which we must take a look at rather we can use the light, light intensity like protons or rather the deep space energy which is available in deep space for developing trust and these are some of the newer areas like we say, may be advanced propulsion is what we would try to look at. The question of advanced is something relative because in some cases may be electrical rockets are also little bit more advanced. But, anyway let us see whether anything more than electrical propulsion something like newer types of propulsion are possible in the years to come. And I think all of us must concentrate on this because may be all you all will have a chance to develop something new and something beautiful right.

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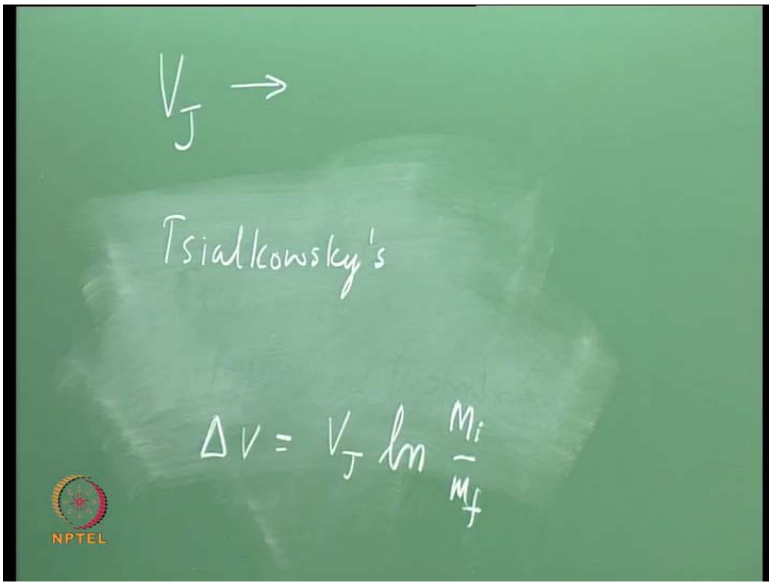

Having said that let us see, let take look at v j. we Should we v j be extremely large? I have been telling these points a couple of times namely may be then Tsial Kowsky's formulate the rocket equation and put in today's class we will go back to the equation because we would like to conclude something Tsial Kowsky's equation and what was rocket equation? We said that the delta v which rocket gets not only comes from its exhaust jet velocity likes less pay i s p are v j but, also the logarithm of the initial mass to the final mass. When he was working on this if I have to get a high v j maybe I should have electrons which can be pulled in a magnetic field and I could get high v j but, it so happens that electrons have very low mass and therefore, it does not give you force. Well after him well (( )) another ten years maybe twenty years, eighty something like 1930's 1940's he was also interested in training out maybe using electrons itself. Can I get the electrons to go at the speed of light and therefore, get a high value of v j? Are there some limitations? Not limitations in getting a high v j but, is there from from the basic equations what we consider is there some limit to v j which is possible? And that is what we will try to do in the next five or ten minutes.

Let us lets now take take a realistic picture of the electrical rockets what we discussed in the last class.

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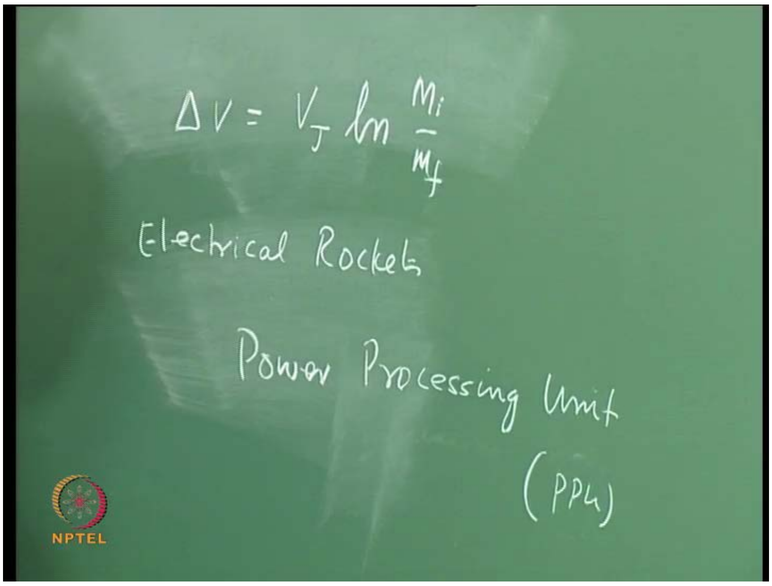

See what we needed in this was, something little more. We needed propellant and propellant was let us say xenon, we also said I need the electrical field in case of iron rocket, I need a voltage of something like 1.5 k v a. In terms of hall thrust I needed 30 k v a. That means I need something like a power unit. Even if I had solar power; I convert into electricity in my spaces craft. I still have to recondition the power to give me a high voltage that means I have something like a power. I can now write as power processing unit. It has to process according to the voltage current. What I require I call it as PPU.

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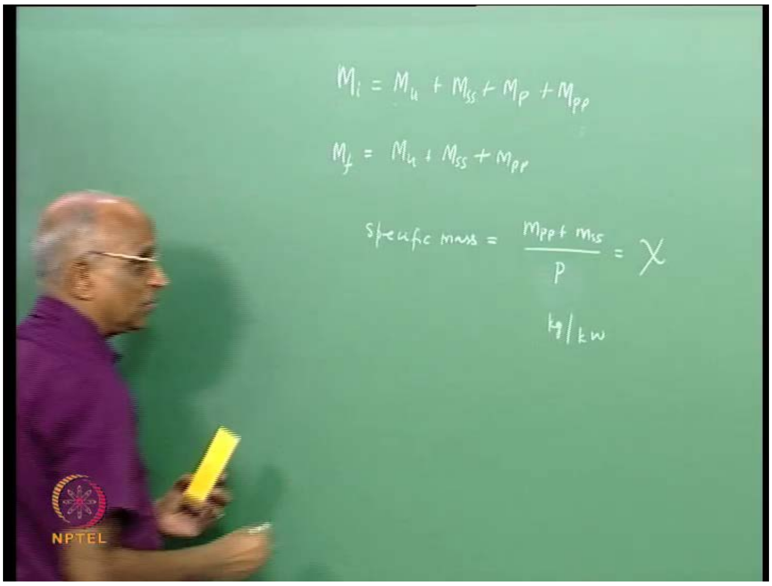

Now, if I have a battery it is going to be heavy that means in addition to the usual chemical rocket which consider, which had let say initial mass. Let us go back to what we discussed when we were developing the Tsial Kowsky's (( )) that is the space capsule.

It had be structural mass it had be propilant mass. Now what is it that I am saying? Now, I am having a power processing unit which has some weight and therefore, I should add something like MPP in addition to propellant mass, in addition to structural mass. But, the structural mass will also go up because this has some weight and must have a structure to support this weight and therefore, I say in that initial mass in the case of electrical rocket will consist of useful plus structure and this one together and propellant mass over here. And what is going to be my final mass? Final mass is going to be the useful thing, the propellant is burnt out and I have structural mass plus the propellant mass over here. Therefore, I find I am unnecessarily carrying some part of the carrying this this power plant which has which has a certain invert mass also structural mass associated with the power plant and therefore, I can say something like as specific mass of the power unit coming like mass of the power plant plus mass of the structure associated with the power plant divided by power which is generated by the power plant p and this is denoted by chi which unit is kilogram per let us say kilowatt or kilogram is a unit of this.

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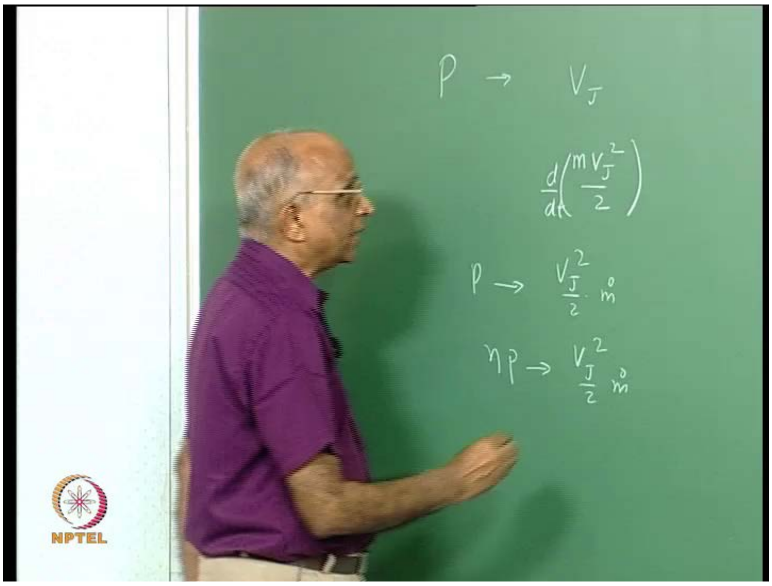

Now what is it that I am trying to aim at? When I supply power p and use this power to enhance the velocity v j, what we are essentially doing is the rate at the energy getting this namely is power gets in to the kinetic energy and what is kinetic energy? m into v j squared divided by two but, then we are talking of energy here whereas it is power that is rate of energy therefore, you have something like d by d t of the kinetic energy. Therefore, power gets converted into lets us say v j is a constant therefore, I take v j squared divided by two into m dot or rather power get converted into the rate of kinetic energy. Whenever some conversion take place there is some loss of efficiency because I put in a electrical power convert it into something like kinetic energy over here and therefore, have an efficiency and if the efficiency of conversion is let us say etta. Therefore, I have etta p which gets converted in to v j squared divided by two into m dot or rather I can write that power is therefore, equal to from this expression I get m dot into v j squared divided by two etta.

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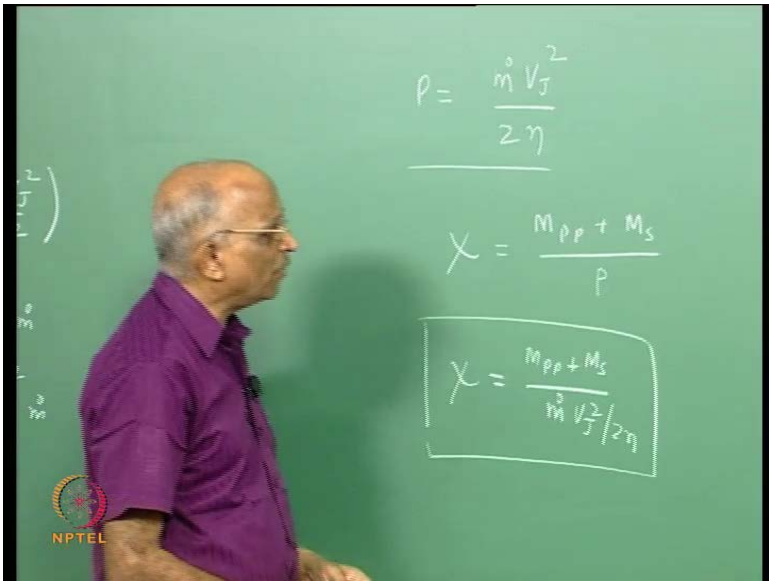

Thus gives me the power and therefore, now I say well my efficiency is low for efficiency is poor that means I need a higher power to get the same jet velocity. Having said that let me now work with this and also you will recall we add some expression for the specific mass what we define as equal to we had it in terms of let me put the expression down; the value of kiye was equal to m, mass of the power plant plus you have the mass of the structure divided by power and we said that the efficiency of the power source is defined in terms of the specific mass of the substance which is specific mass of the power source, which is the total mass of the power unit and the structure associated with derived by power. Now, if I can use this value of power to be substituted over here, I get kiye's is equal to m p p plus m s divided by I substitute this, I get m dot into v j squared divided by two etta over here. Why why is it that I am doing all this? The reason being, we know that if I have a higher jet velocity and we were looking at the rockets Tsial Kowsky equation; when I get a higher jet velocity I get a better pay load. But, however it is not only the higher velocity but, know I find if I give a higher value of jet velocity, my power goes up. If my power goes up, well my mass also goes up and it quiet possible therefore, now if I start plotting these values

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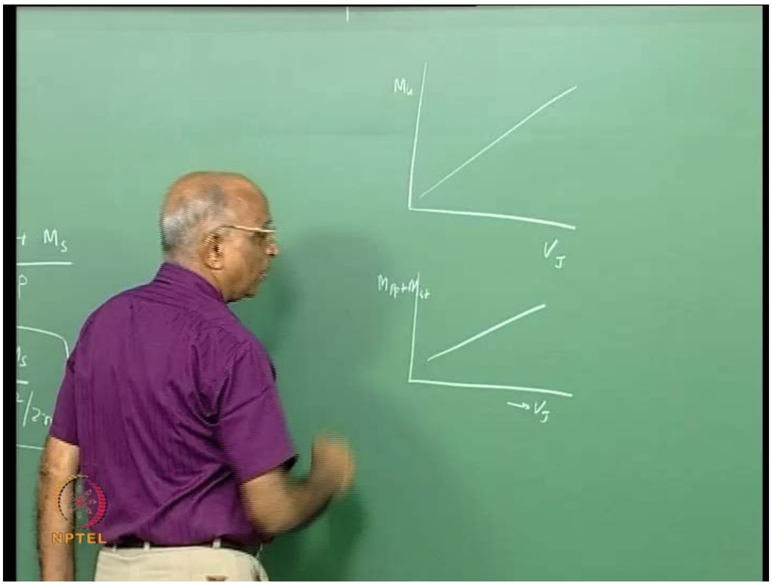

I say, well my pay load mass is now I call us mass as function of v j. If I look at v j alone may be us v j increases, my useful pay load will go up. Because I am I am having a higher jet velocity over here. But, a higher jet velocity results in a higher power and therefore, my my power that means my values of m p p plus m s t also increases as v j increases and this increases.

It will adversely affect my value of the useful pay load and this is what I want to work out. Therefore, to able to do that let let me go again and and write this Tsial Kowsky equation which I can write as let us say that the useful value I I write the Tsial Kowsky equation as the incremental velocity

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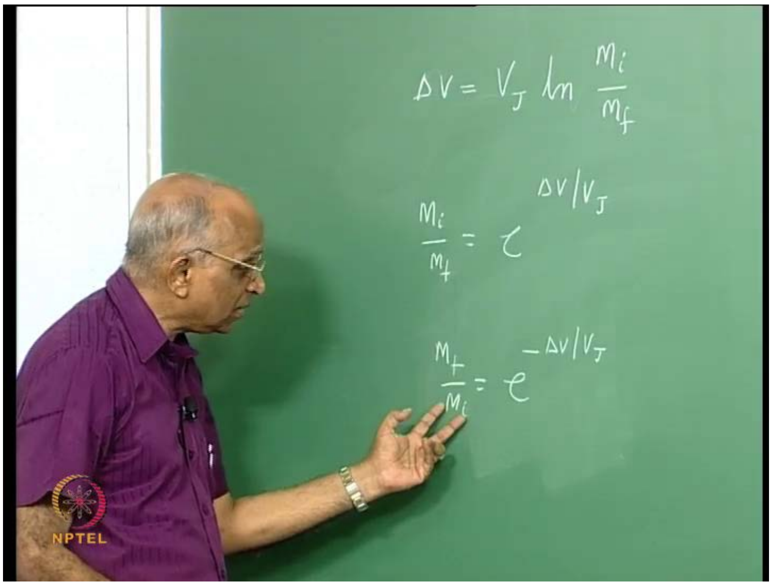

Delta v as equal to v j logarithm of by initial mass divided by the final mass. Rather this particular equation I can again write as initial mass to the final mass is equal to e to the power delta v by v j and now if I invert it and say I am interested in the final mass divided by the initial mass I have the value as e to the power minus delta v by v j. Now what is it that I find? As v j increases; my final mass for given the initial mass will go up. But, then I am also telling another thing over here namely that my mass that is my unproductive mass also goes up. Therefore let us try to build an equation which results, which will give us something like the the useful pay load mass. Let me write it over here.

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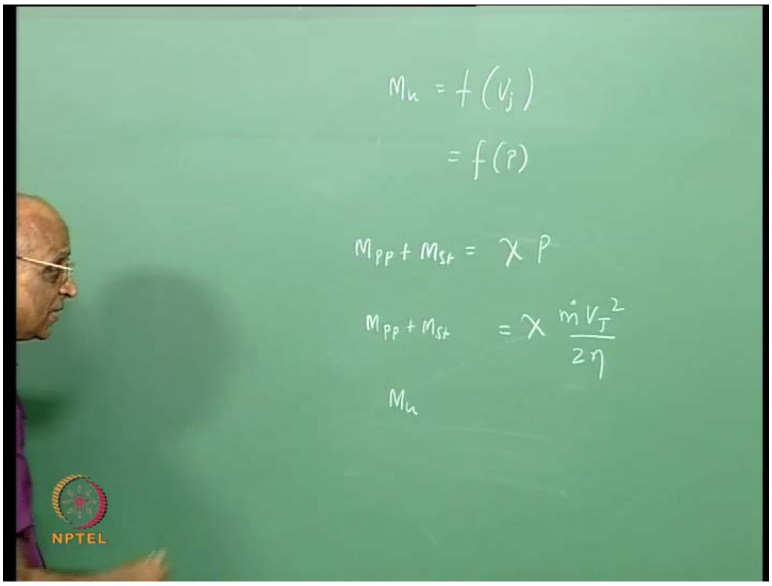

The value of the useful pay load as function of v j which is also of the function power and this is what I am searching for. Therefore, if I come back to this I have m f m i is equal to e to the power minus delta v j or rather now I can I can write the whole thing as m of the power plant plus mass of the structure over here from this particular expression I write it as equal to kiye of the power. Well the power, I again write it from an expression as equal to m dot into v j squared is equal to kiye of m dot v j squared divided by two etta and therefore, now I get the value of the power plant plus the weight of the structure is given by this value. Somehow I want to bring in the value of useful mass over here and therefore, I look at this expression again and look at this expression again and want to express the value of useful mass as a function of initial mass, as a function of v j and that is what is my particular particular aim with which I am trying to solve this equation. So let me again for this over here.

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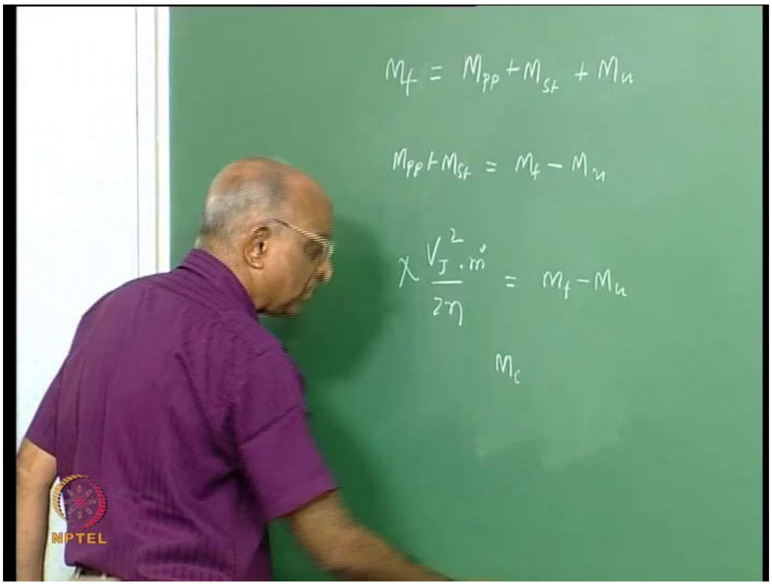

I can I can now write the final mass what we get in a rocket is equal to the mass of the structure and the power plant which is left behind as m p p plus m s t and what is that you also get the value the value of useful part of that, of it which is available and therefore, if I can write this equation. Now, I can write it as m p p plus m s t is equal to m f minus m u and now I substitute the value of the power plant weight and this structural weight through this particular expression namely this becomes is equal to kiye into v j square divided by two etta into m dot over here is equal to I I get the value of m f minus m u but, now I would like the initial mass also to come

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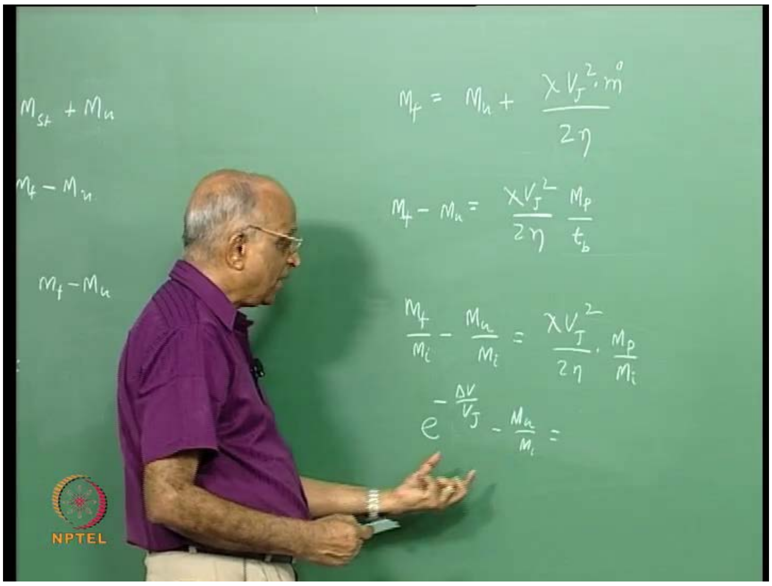

And therefore, I can write this expression as m f minus m u in terms of m I also and for this I I simplify the expression over here, write the expression over here. I now write mf is equal to mu plus kiye into v j squared into m dot divided by two etta and immediately I find that as the efficiency decreases; that is the efficiency of conversion of the power into velocity decreases, well this factor goes up and for the final mass therefore, the value of m u will decrease which what we should really expect also. Because the efficiency of conversion of the power into the velocity decreases, I will have a less useful pay load which comes over here. Having said that let me try to again arrange it in some particular form. I will write it again as m f minus m u as equal to kiye v j squared divided by two etta. What is that rate at which masses getting depleted? It is the total propellant weight that means m p is the total propellant mass divided by the duration of burning let us say, a t b therefore, I get the value m f minus m u as equal to this and therefore, I again that the duration of burning also affects my value of the useful payload.

Now, I want to arrange in this in some form and therefore, now I write this as m f by m I I divided for by m I and I write it us m f by m f by m I minus m u by m I as equal to the value of kiye v j squared divided by two etta into m p by m I and this I can further simplify and express it as m f by m I, I already known it is equal to e to the power delta v by v j and m u by m I is what I am interested in the value of m u by m I and this particular expression can again the put. I know the mass of the propellant and what is the mass of the propellant? Again it is equal to the final mass minus the initial mass and therefore, I can again put it in terms of the value of e to the power of minus delta v by v j and therefore, I will right the final expression over here

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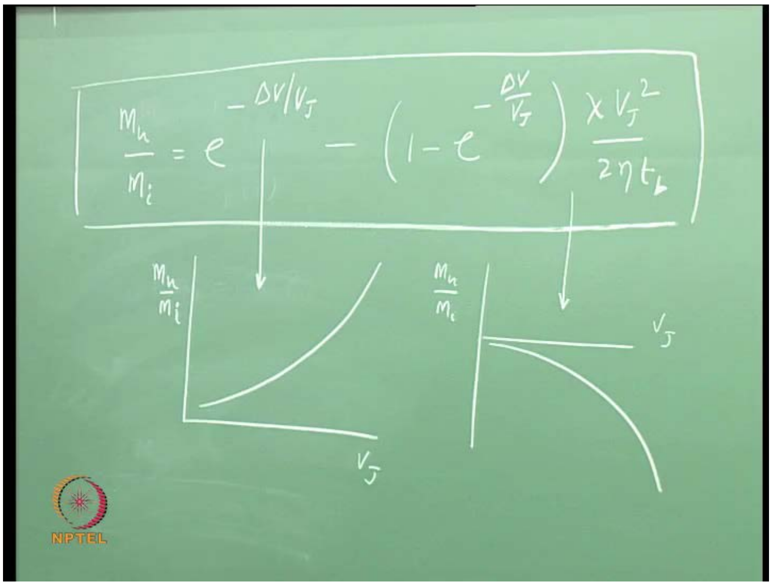

As m u by m I is equal to e to the power minus delta v by v j minus I get m p is equal to m f by m I m f by m I divided by m I is equal to m f by m I minus one m f by m I is equal to again e to the power minus delta v by v j is equal to we get one minus e to the power minus delta v by v j into kiye of the value there. tThat is v j squared divided by two etta is the value and of course, the value since we say m p that is t b comes over here. That means we had the value m p by m i. I forgot to put this it over t b and t b also comes here and therefore, this becomes my final expression for the useful mass.

Let me simplify this a little bit and try to point out the dependence what we get. We can we can write this particular expression as same that yes whenever I have the useful to the initial mass this this expression tells me that the value of m u by m I as a function of v j as v j increases; the negative exponent decreases and therefore, it goes like this. Whereas as I am subtracting some quantity over here. Therefore, this is my zero over here. As v j increases this quantity decreases but, then v j squared decreases, this is goes up like this or rather I can say that m u by m I contributing from the first term on the right hand side comes like this the second term comes like this and the net of the two things put together perhaps this is again v j.

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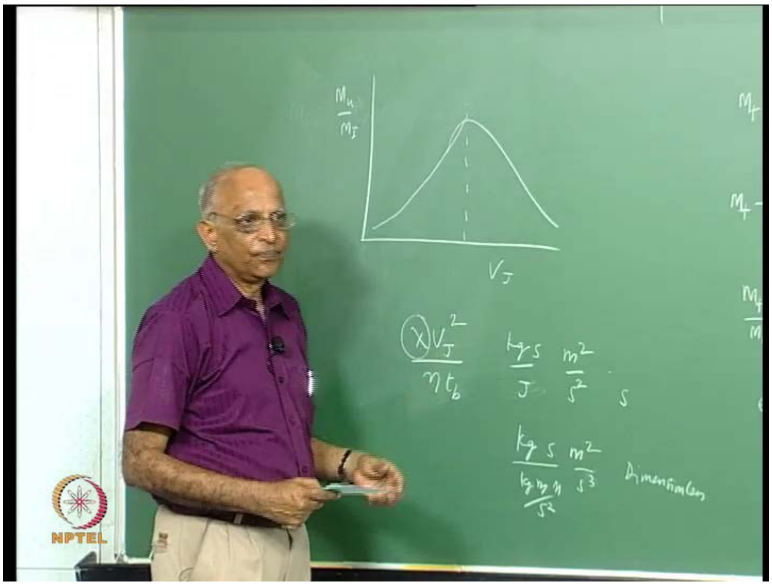

May be looking something like like if I put both of them together, I have v j m u by m I and this may really go up initially when the initial value is small over here goes up. When this value catches up well it will decrease over here and then you have something like this. In other words, there is the value of v j we on I will it will leak to my useful mass coming down rather than going up and that is why I cannot really operator operate under high power conditions.

Now, one last point when I am this particular expression is if I look at the value of this particular value what I have here; I have the value of kiye v j squared divided by two etta t b and if I look at the dimensions of this you know we said, it is a specific mass so much kilogram per watt and what is watt? What is per second kilogram per second? v j squared is meter squared by second squared, etta is efficiency does not have unit, t b has units of second and now if I were to the put the units again, if I put the units of joule what is it that I get? Kilogram second meter squared by second, cube second, cube here and joules. Joules is again Newton meter, new new Newton is kilogram meter per second squared and your meter here and therefore, this net expression becomes dimensionless number and therefore, we will now take a look at the block of this particular expression as a function of this this is a non dimensional number and we will try to express the useful mass as a function of v j, as a function of this non dimensional number.

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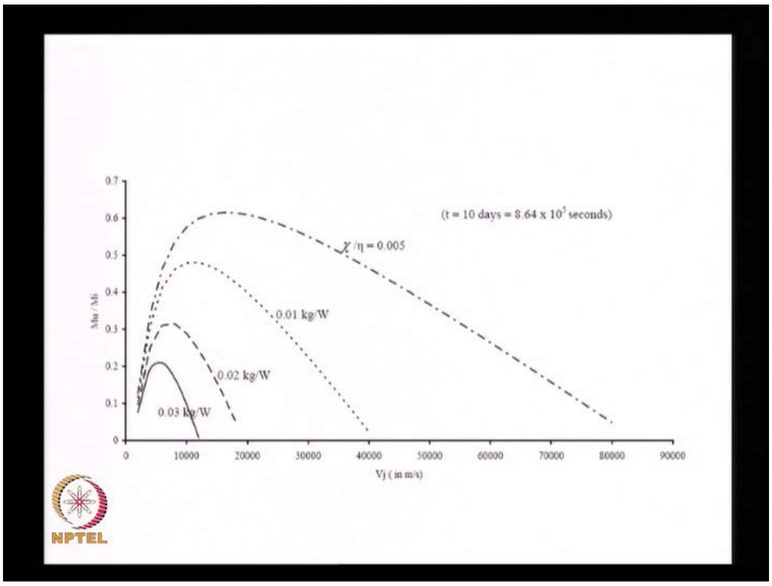

And this is this is what I show here the value of kiye by etta I keep changing, the value of v j is on this scale, the value of m u for a particular machine which takes ten days and its gives a delta v of something like two into two kilometers per second, I find that the optimum depends on the specific mass of the system and therefore, there is no way in which may be for a higher specific mass, there is no point in me having a velocity greater than some limit and therefore, there is a limit on the velocity. This is all I want to illustrate using this one. In other words, the effect of increasing the power is to increase the specific mass are increase the mass of the system and it does not really help in anyway

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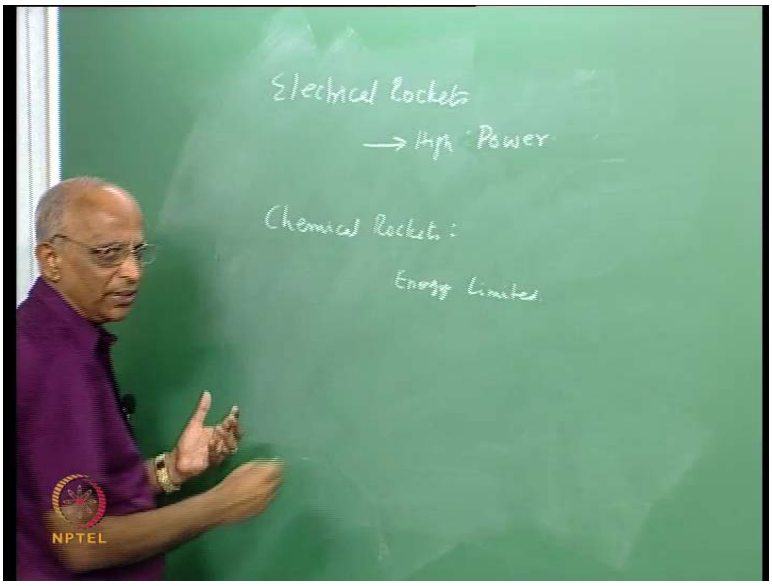

And therefore, we say electrical rockets cannot be operated for very high powers. That means there is a power limitation. That means beyond the power is not useful any more. Why is this? This is because as power increases, v j increases and a large value of v j is therefore, detrimental. But, when we talk of chemical rockets where there any limitations? Can you immediately recall any limitation we had? We had a limitation in temperature because champers could not take any temperature. That means the energetic of the rockets are we say energy of the propellant have a limitation. That means chemical rockets are energy limited where as the electrical rockets are power limited. I think this is something which we need to keep in mind and with this we sort of conclude our discussion on electrical rockets. But, let see whether we can really have rockets, which are different. Why not have something like a light which can give you some pressure or may be something like nuclear or we talked in terms of try propellant rockets are other mechanism to generate the thrust and that is what will be doing in the next few minutes.

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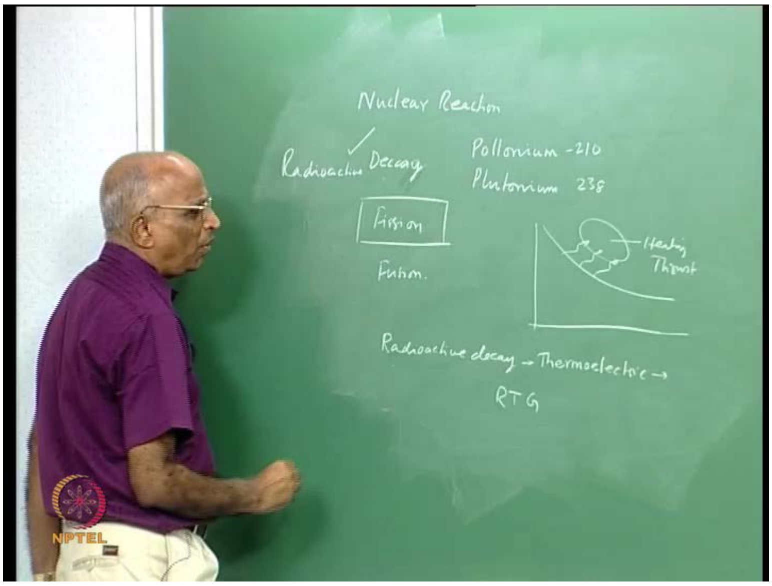

Let us consider nuclear reaction. After all nuclear reaction also generates heat and power. Nuclear reaction what are the nuclear reactors we can say? It could either be based on let say nuclear decay, let us say decay of nuclear reactions or it could be something like a fission reactor or it could be something a fusion reactor what is it that we are saying? You know whenever we say some nuclear reaction has taken place; the time to decay, the ready active decay that means, the time taken for the reaction to stop once something is go on is several several thousand of years. That means certain substances like polonium, or let as say plutonium two thirty eight; when they they are basically isotopes they keep on emitting radiation and then time taken for the radioactive waves or the radiation to decay take several, several thousands of years and during this thousands of years they are generating generating chemical reactions are in progress or we say radioactive decays taking place and thus could be use for heating and generating thrust. And therefore, we say well pollonium and plutonium could be used in the radioactive decay modes to generate hot gases and these hot gases could be expanded and uses a rocket. But, I am not seen radioactive decay been used in rockets.

What we see is; the use radioactive decay that means you have the radioactive decay. It is use to generate hot gases and that is that is converted to electricity using let say thermo and how do you have thermo electric, may be effect are something we use thermo electric effect and you generate electricity these are known as radioactive thermal generators thermo electric generators. This can generate power and using that power I can I can power my space craft or I can also convert it using, if I can generate sufficient power I can convert it using some electrical thrusts. Well, there well radioactive decays one particular method of having nuclear reactions in incase I am interested in a rocket but, what has been tried extensively been used? The fission; what is fission? You know you have some substances,

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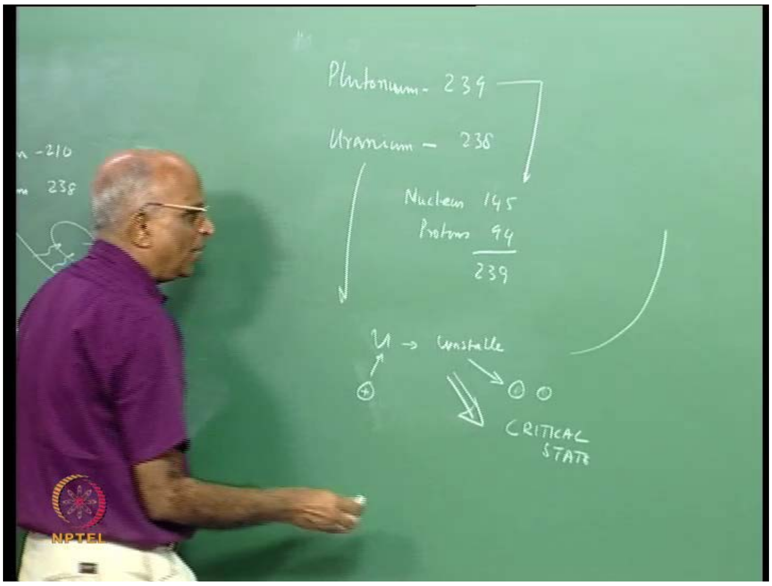

Again you we talk in terms of plutonium, may be plutonium two thirty eight, plutonium two thirty nine. May be a substance like uranium. Uranium two thirty eight. What do this numbers mean? See this numbers are giving an indication of the some of the nuclear are the protons and nuclear what is available. I think the the the sum of, let us say if I take plutonium us two thirty nine the nuclear consist of one forty five nuclear and the protons are ninety four and which gives me a total of two thirty nine and you know these are all isotopes in that. You know they are not very stable and and when I take uranium two thirty nine and interacted with neutrons and when uranium is hot and the neutrons has high energy; the interaction leads to generation of more neutrons and this additional neutrons again interact with uranium produces more neutrons and the neutrons keep multiplying so that an avalanche of neutrons get created in this particular neutrons reaction.

The reaction taking place within the nucleus and is therefore, known as the nucleus reaction and its leads to generation of large quantities of neutrons. And the more it produces, it also reacts further with the uranium and therefore, you have an avalanche of these nuclear which as being formed and you say the substance reach as critical state. In other words, nuclear reaction keeps starting. It goes in exudes, it start slowly goes spirals and you have this nuclear reaction taking place and therefore, now if I can imagine I want a rocket using nuclear reaction; all what I do is I have a reactor in which some fission is possible.

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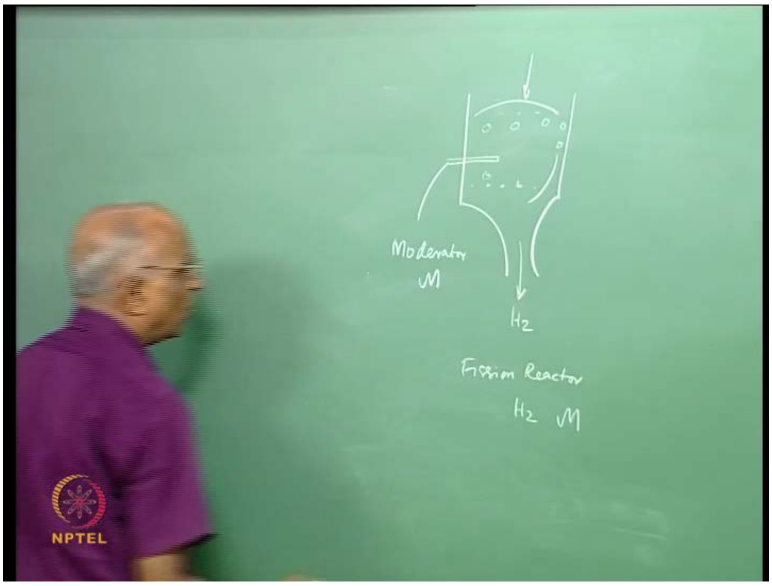

I have something like a nuclear reactor here but, I need to control the reactions and how do you control it in in a chemical in a nuclear reactor? You put something like a like a moderator. What is a moderator? A moderator has a low molecule mass something like a carbon and what does it do when this when this neutrons are generated it tends to scatter it away and therefore, you you can moderate it since it does not allow it come back to the substances. It scatters it away. You also have some some mirrors which will focus the neutrons on to the body. In other words when these neutrons are generated and these neutrons get generated in a large number it becomes critical. But, if you want to control the amount of neutrons which are generated; well I put a moderator but, I can also use reflecting lamps to be able to control it and if I can put something like a pebble bed along with the reactor and now I pass hydrogen on to it the hydrogen gets in contact with the neutrons absorbs the energy from neutrons and it generate heats and I pass out the hot hydrogen over here and this is the principle behind a fission reactor in which I use a fission reactor to heat my hydrogen gas and why do I use hydrogen? Because the molecular mass of hydrogen is small. Therefore, the construction of let us say a nuclear rocket would therefore, be something like I have, something like a tank which contain liquid hydrogen.

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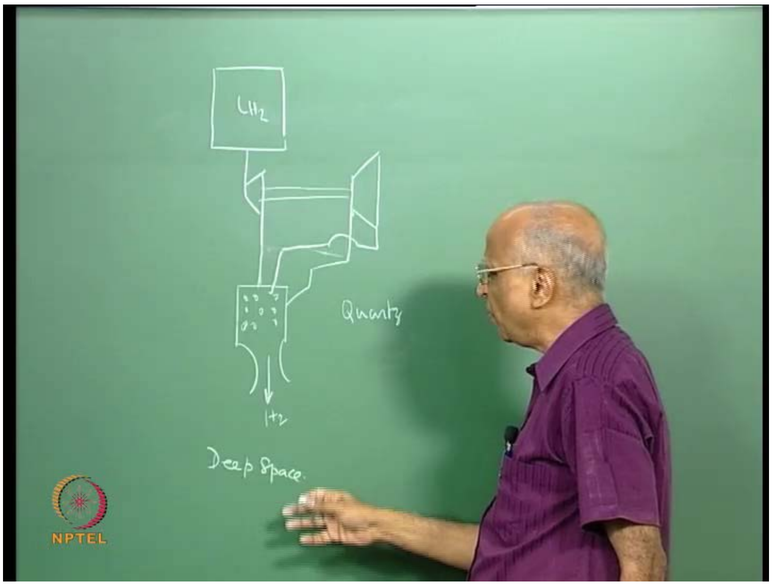

I need something like a pump over here to pump it and what do I do? I pump it along the walls of the chamber or along the walls of the reflector, heat the hydrogen and once I heat the hydrogen I pass it. That means I allow the hydrogen first to come over here into my reactor, I I cool the chamber, I cool the reflector materials and I allow the hydrogen to come out over here. I I pass it throughout turbine over here. I I expand the gases in a turbine and I allow the expanded gases in a turbine and I allow the expanded gases to come into my reactor that is the pebble bed reactor where in it is contact with the neutrons, where in it gets further heated.

And now I get the hot hydrogen coming out. The problem with this in use the turbine to drive my form and therefore, this becomes my rocket. So, it is similar to the expander cycle but, I have a nuclear reactor which heats my hydrogen and generates the hot gases. The problem with this is, the problem is something different you know see what I do is heat the hydrogen but, along with in the pebble bed heat some radiation is also giving, is also getting into my exodus gases and it is a source of concern. Radiation is always the source of concern, you have all this (( )) and all that where in people are scared, stuff like that. Therefore, it can only be used in deep space. Instead of using a pebble bed heater for allowing the gas to come in, you can also use something like a quartz glass which permits the radiation to go through and allow on one side the nuclear reactor, the other side the hydrogen and through the quartz glass I get the the the neutrons to move and heat my gas and I could have it. Therefore, this is what we say a nuclear reactor which can be used for rocket propulsion. As such in our the performance will be very high but, this this development has been going on for quiet sometime but, concerning the safety features none of them have been but, it is quite possible in the years to come especially for may be other machines to other planets, not to only other planets but, other galaxies, may be we do need something like a nuclear propulsion.

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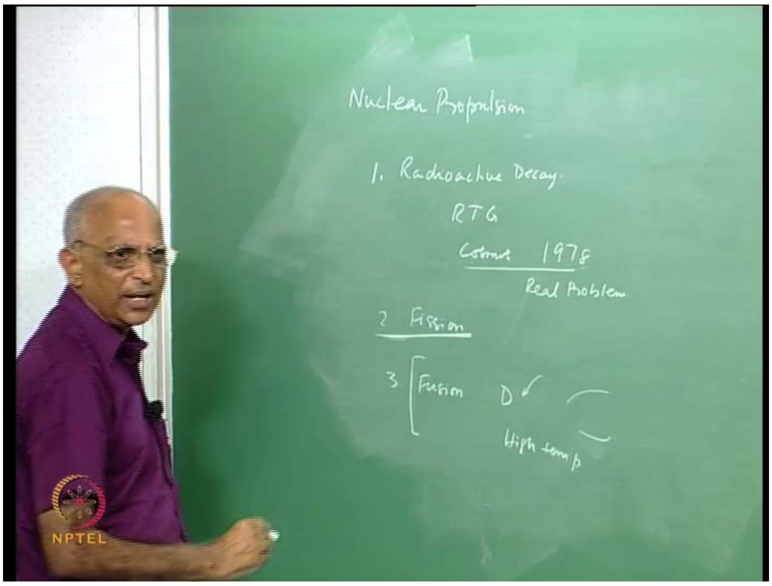

You know we have to consider one small thing though I said may be we had talking in terms of radioactive decay and this radioactive decay has been used to generate power and that is what I say this r t g has been used to generate power and wants such space craft as cosmos series in you know, I think it was the in the year 1978 or so; it was carrying nuclear reactor for generating power. It crashed over Canada and people were worried that lot of radiation may be that people will be affected. But, what happens is that the amount of nuclear power is so small, the radiation is so small and everything vanishes once its gets burnt out in the atmosphere. There is no real problem but, you know to be able to to apply some of this nuclear reactors is little bit scary. Therefore, we say well radioactive decay is used in in r t g due to generate power or in a fission process to heat hydrogen and generate it. It is also possible to use fusion which has not been done but, let us see what is fusion is. I I have to few something on it, I need very high temperature. Therefore, I I supply extremely high temperature in the, again cause a nuclear reaction may be by the fusion process and I could have similar to a fission reactor. But, this is some what more difficult because I need to concentrate very high temperature gases. For this, I need something like a magnetic focusing or stuff like that and it becomes a little bit more let us say difficult compare to what are fission reactors. What is being pursued is in the area of fission reactors? It is all about nuclear reactors.

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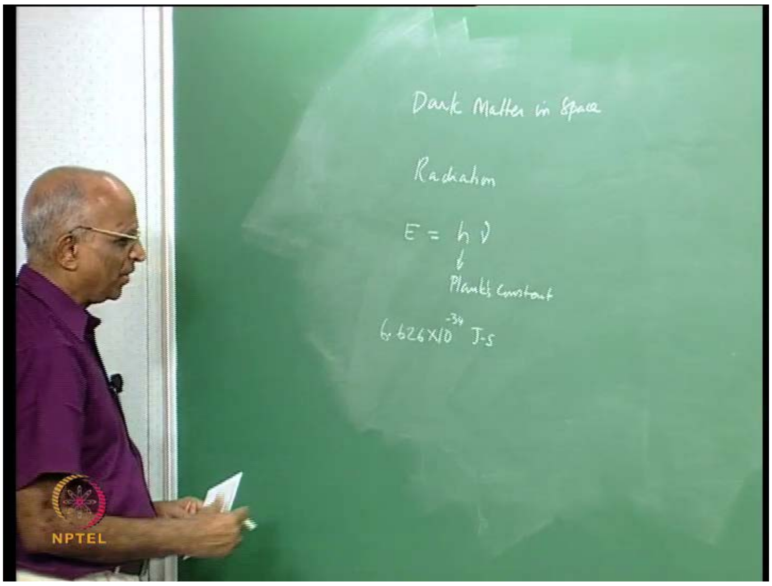

Let us come back to something which excites all of us because we keep reading about about something like dark matter in space and all of us have studied radiation as one of the subjects. Let us see whether using radiation radiation that means essentially electromagnetic waves, can I generate some thrust? What is it we are saying?

May be we are talking of may be some photons having some energy e goes as h into nu where nu is a frequency, h is plank's constant. And what is the value of plank's constant? Unit is joule second (( )). I will I will diagrase a little. 6.2 626 into ten to the power of minus thirty four joule second is the value of plank's constant. What is the significance of plank's constant? Well in radiation, we use the plank plank's constant but, we must also remember it from the Hyzenbergs uncertainty principle.

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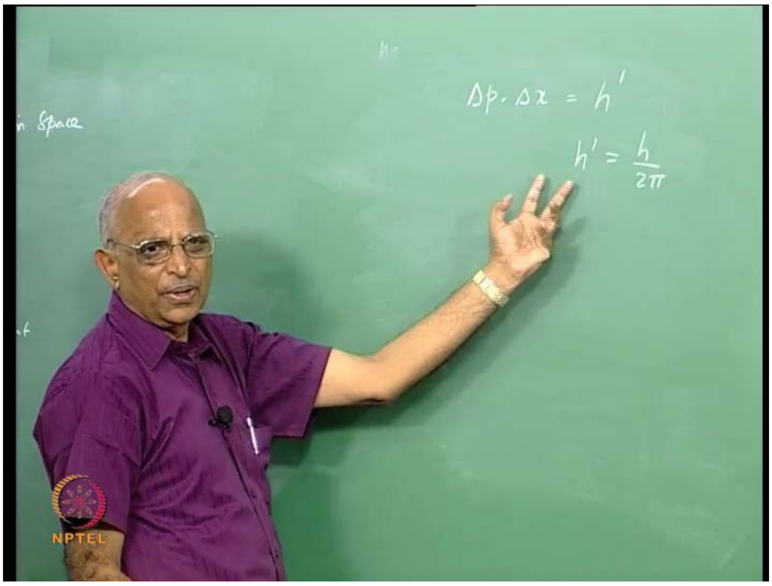

And what is this principle of uncertainty? He tells you know whenever we measure momentum, change of momentum I need a sensor to measure the change of momentum. That means I must have change in a physical displacement or a time and if I take the product of change of momentum into delta x then it says I cannot measure something more accurately than some value and delta p by delta x is what you say is the value of Hyzenberg's uncertainty which is modified plank's constant and modified plank's constant is h over two pi. In other words I cannot measure something more accurately than the product of this two. This is what is that the principle of uncertainty and this is given by Hyzenberg but, what is this plank constant about? Plank's constant has units of joule second and this is frequency and when we talk of zero, dark matter in space

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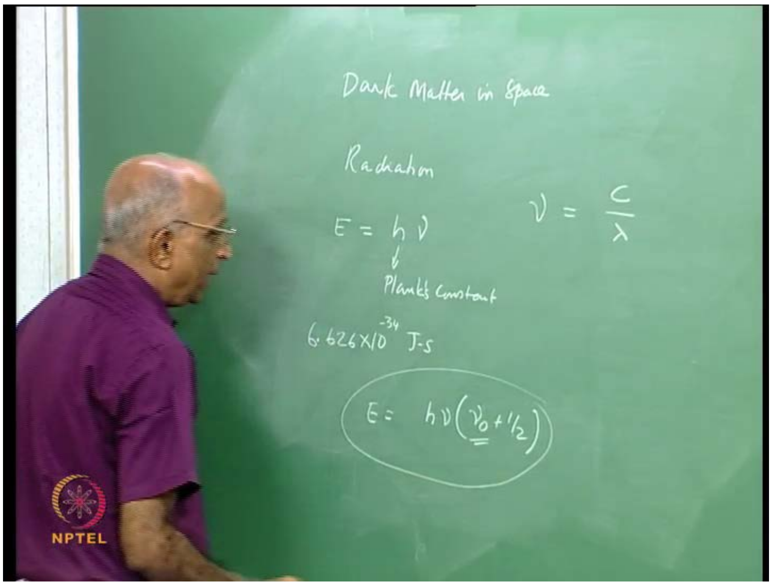

We say that dark matter is that may be zero Kelvin because there is no no really temperature or no vibration available and for dark matter we we being at zero Kelvin, we write the energy as equal to h nu not into nu plus half. For the particular case of of dark matter, I I get the value of nu is equal to zero since no vibration are energy of the substance in dark matter and I get the energy of dark matter as equal to h nu not by two. I can write as speed of light divided by wave length of light and therefore, I can put the value of e as equal to per proton per per radiation

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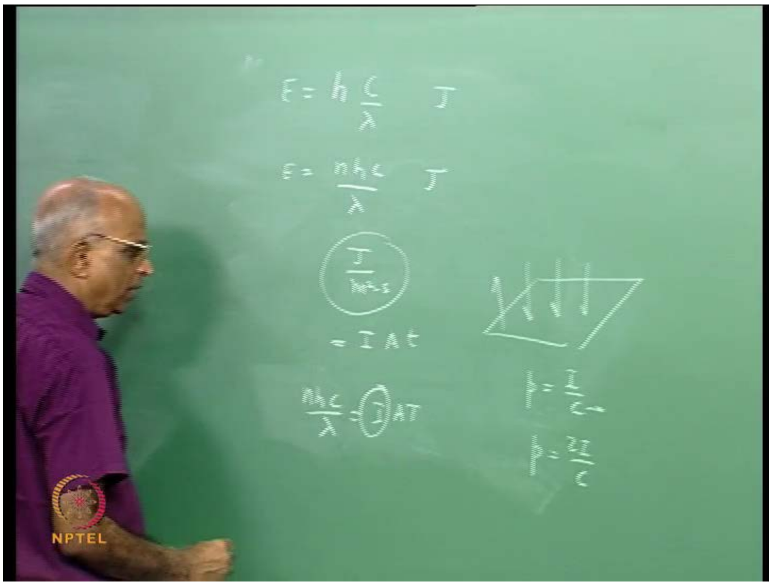

I put it as e is equal to h into c by lambda or rather now I say I have n protons which are coming therefore, the total energy is n h c by lambda. And this e is equal to h h into nu. nu is equal to frequency is equal to the speed. That means meter per second divided meter one over second and therefore, the the value of energy is joules. This is so much joules. I would to convert this into intensity and what is intensity?

Intensity is joules per meter meter square second is the intensity of radiation and therefore, I can write this is equal to intensity into area over which the radiation is falling into the time over which it is falling. That means I have area into this is joules or rather I have the value of n h c by a lambda is equal to I have I at or I can find out my intensity of radiation in joules per meter square second. Now this intensity of radiation, if it falls on a surface; I is falling and if the radiation goes through the pressure which the surface feels that is pressure is equal to the value of intensity divided by c whereas if it is totally reflected I get an intensity which is equal to two I divided c where c is the speed of light. You know you can you can readily see this if I were to put the units intensity is equal to we said joules per meter square second.

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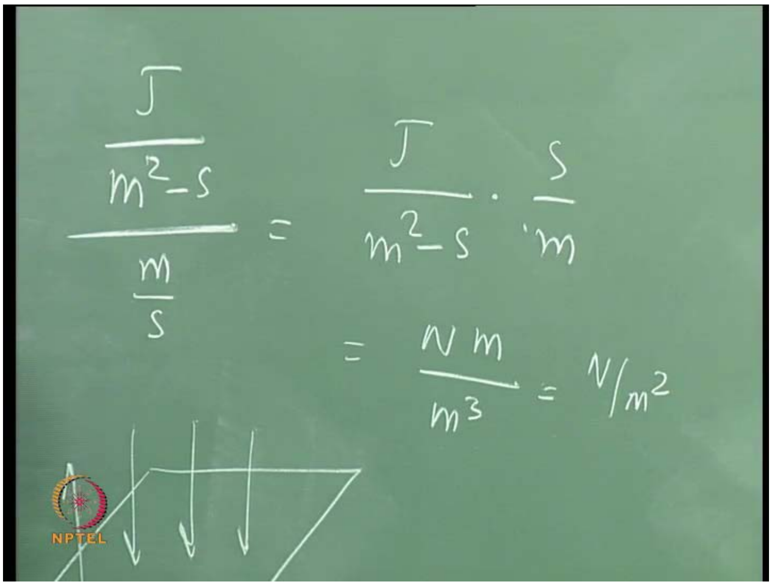

The value of c is equal to meter per second and therefore, this gives me joule per meter square second into I have second by meter and this gives me Newton meter divided by I have meter cube here. This is equal to Newton per meter square which is the pressure due to radiation is. Therefore, pressure due to radiation from a reflecting surface is equal to two I by c where I is worked out using the proton equation over here. Therefore, what is it I am saying?

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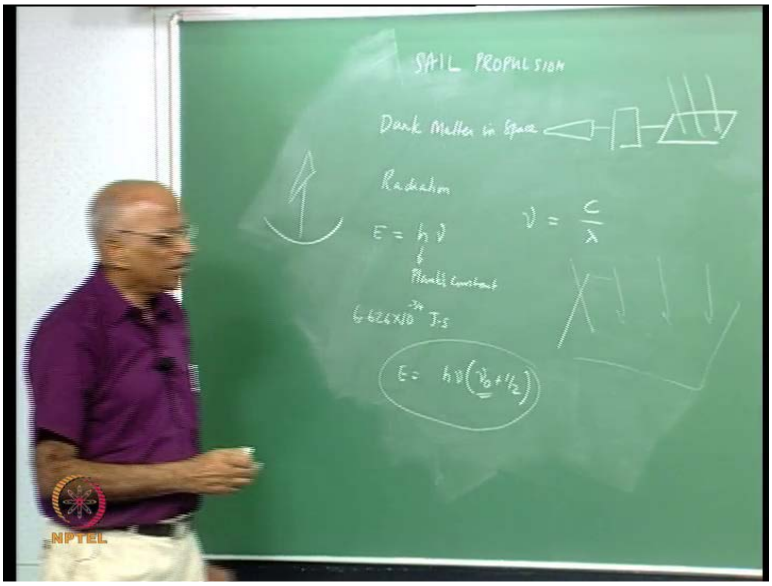

If I have now huge reflecting surface may be the size of the play playground, let us say there is a football playground and into this I have may be the sunrays or rays of some coherent rays are coming over here. Well, I can build up thrust and this thrust is given by p into a which is equal to two I c into the area of surface. Well I need not have essential sunlight infact when I when I showed you the picture of insact space craft; I showed you on one side we had be solar side, on the other sized I also showed you something to relieve the pressure. That is because solar light when impinges on this, generate particular pressure which had to be offset by this particular rod which was there on that surface. Therefore, we say well pressure can be generated. This pressure could be generated not only by solar radiation but, I have a laser beam which impact soon as surface and I can generate as thrust or else even I can use chemical reactions like I have a surface which is coated with some material which evaporate, I pass some laser beam, I cause it to react some masses generated and this could also gives the thrust and so on. It goes you know, this particular way in which I use photons for generating thrust is known as Sail propulsion.

Very similar to something like you have a shift in which you have the sails and what when pushes the shift? So also so you have this electromagnetic radiation falling on a surface and the pressure so generated keeps on pushing that thing.

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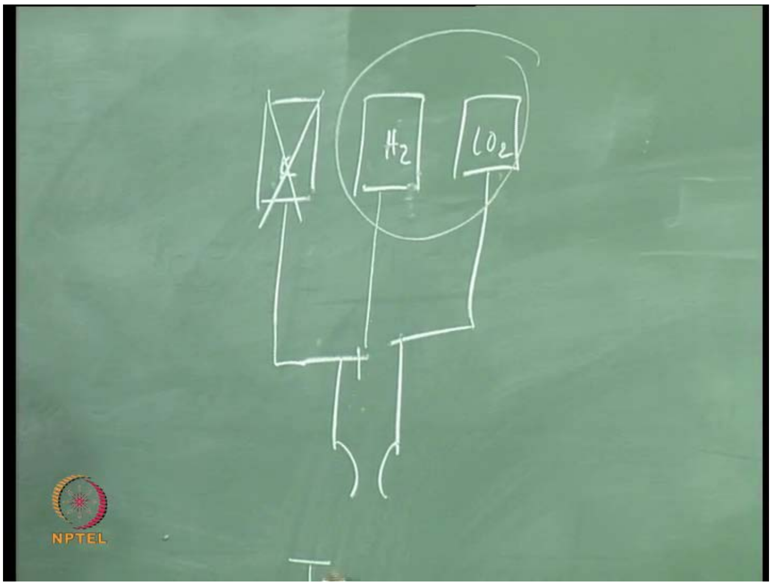

Therefore, the subject keeps on going like this and it possible for us to evolve more and more around this factors but, I will not go any further other than say the following. Well we talked in terms of mono propellant rockets, bi propellant rockets, we talked about the tri propellant rockets and what were tri propellant rockets? We had three propellants; one was hydrogen. We could in have kerosene, we could have liquid oxygen. Initially I could inject kerosene and hydrogen along with liquid oxygen in the chamber. I could have all three burning. Now, we know hydrogen its fast burning, it stabilizes the compression, initially the rocket goes up in a three propellant mode and once it goes up you know, I cut of kerosene because I I do not want high thrust but, I want better performance and the rocket are raise on hydrogen and oxygen.

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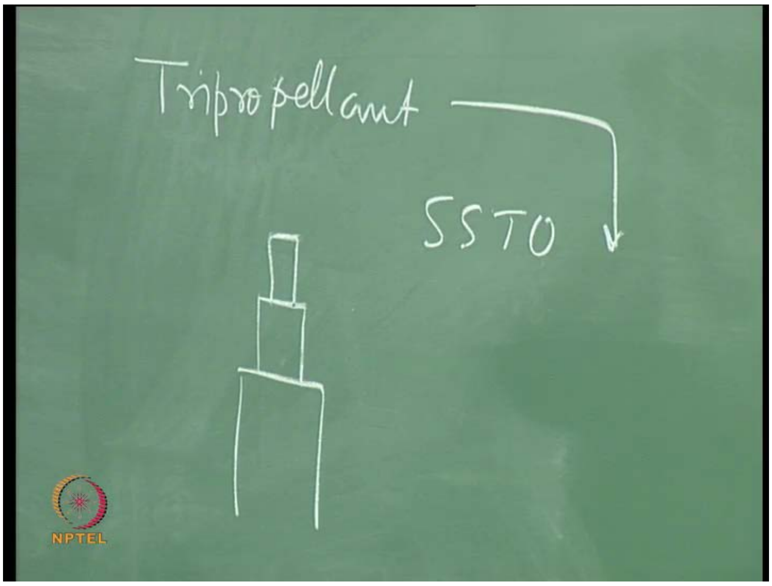

This is known as tri propellant and this is something which is being followed up in some of countries especially China for something like reduce the number of stages you remember, we got started by saying we need a number of stages in a rocket. Maybe I can think in terms of a single stage to orbit using tri propellant rocket. This is something which which is fanciful, which looks feasible.

But, the problem is, we still need better materials of construction which do not have a large structural mass and which can cause a problem later on. In other words all what I am saying is we said m f is equal to mass of structure remaining, mass of useful payload because we did not have a power plant over here. And therefore, if the structural mass can be brought down you know, I can have a much better yield on my final mass or rather I can I can do away with some of the things with propulsion has to do by having lighter structural mass. I think this something which we have to take a look at. Let me say one thing which I which I thought maybe I should, we read a lot of things in new forms of propulsion; one is people talk in terms of bomb propulsion.

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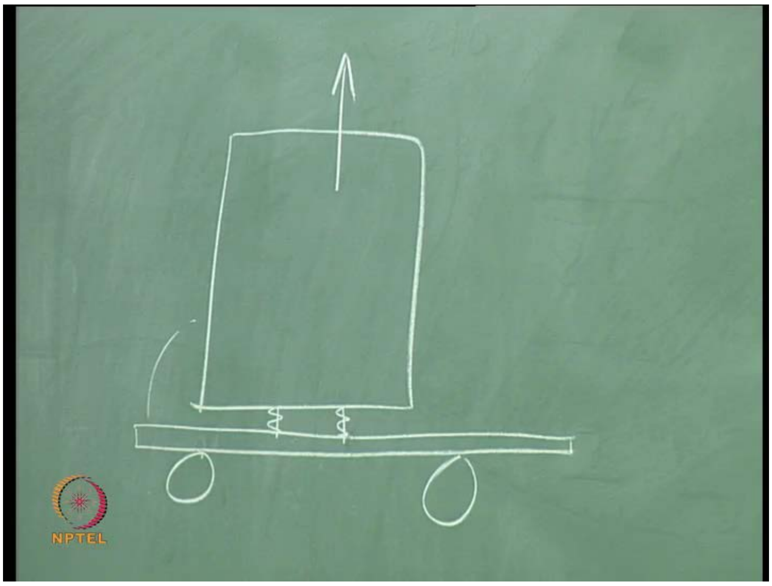

In other words you should have nuclear reactors, I have let us say as space craft; I have to space craft or space capsules it most through space, I need to propel it. May be I have some some suspension here which can take care of vibrations. I have something like a huge iron or may be some material here, I put this nuclear bombs over here and whenever I want to push it I I make this bombs critical. I fire them and the thrust so generated, force so generated pushes my thing up.

This is known as as pulsed because I do not use the nuclear reactor. Pulsed nuclear propulsion now you can keep on thing of new ways but, then I need a suitable suspension. Well these things are still not applied because I need something to soak the energy and all that or such the vibration is not transmitted. Then it is quiet possible to use that. Well something which is which is recent, in which there are lot of claims being made.

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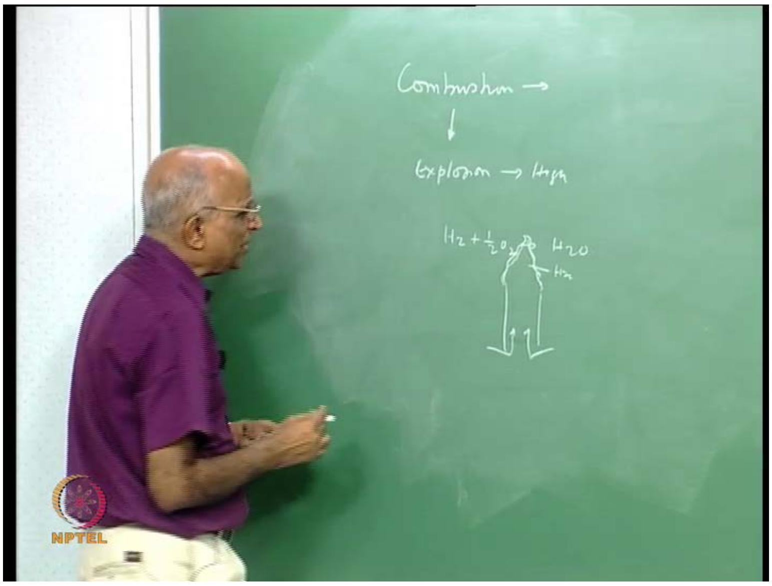

It has been used is, instead of using combustion on which we spent a lot of time what did we do in our course? We started with the theory of rocket propulsion about looking at the different planets which are going around the earth and all that. We formulated the the the we understood what is mean by a gravitational field, law of gravitation. From that we built up theory of rocket propulsion and from that we came back to nausal theory, found out that how the v j changes and from there we came to chemical propulsion requirements of substances and this chemical substances essentially react to form combustion. Instead of having a combustion can I have an explosion to drive my rocket?

What is the different between combustion and explosion? In combustion we have may be hydrogen plus oxygen reacts to form let us say h two o. In an explosion well, this has to happen because products have to be form but, in an explosion the thing is different that than from combustion. In combustion when I do this may be I pass hydrogen gas over here, may be I pass oxygen gas, I have a flame, the recombination. This is where the flame is there and it burns and generates the hot gas quotient is. If I can have the explosion taking place what is goes happen is we know that the pressure in an explosion is very high compared to the pressure in a combustion. Why is it so high? You know we have to understand a little bit more and what is it I am saying?

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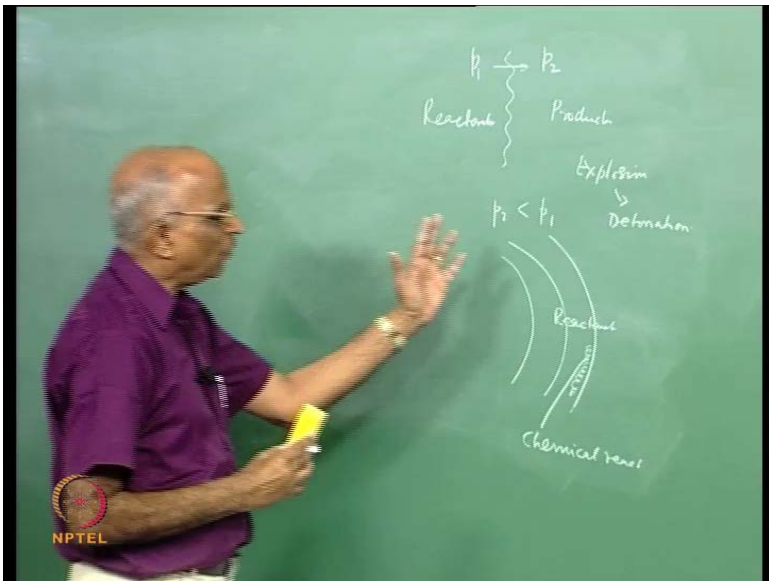

If I have a combustion taking place, may be I have a flame over here, I have the reactants over here, hydrogen and oxygen I have a products over here. Products are hotter. There is a drop in pressure that means the pressure here is p one, there is a pressure p two here. I have p two is always less than p one. But, instead of having a combustion like this happening and this is what we did in our solid propellant, we did this liquid propellant, we did in hybrid propellants and we did it in mono propellants. We had combustion taking place. Something like a flame. Now, if I can have something like a shock or a compression wave which travels into a reactant; mind you what is it I am telling? I have a strong compression wave travelling into the reactant. There is increase in pressure taking place across the wave. That means I have a propagating compression wave getting into a reactant. That means I have high temperature high pressure across the wave and since I have high pressure across the wave, high temperature across the wave, behind the wave I have chemical reactions happening and this chemical reaction will start driving the compression wave and this is what we call as an explosion or also technically known as Detonation.

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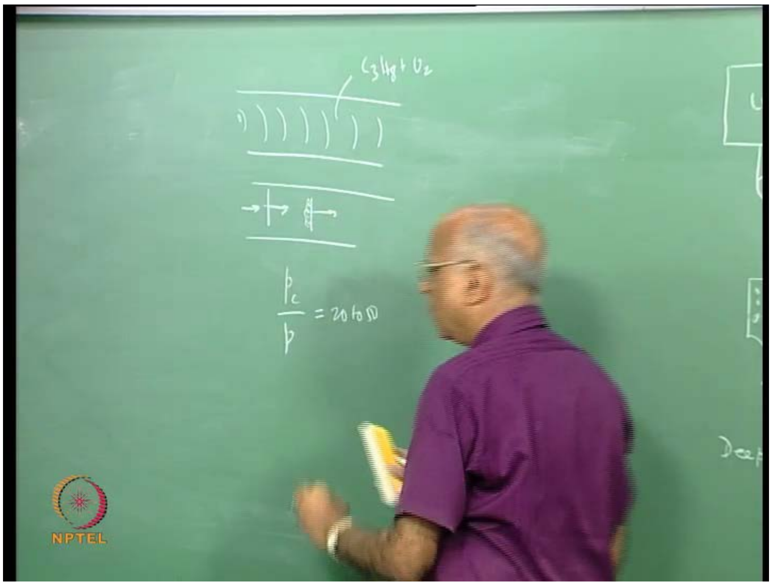

Let us the again tell you what what I am trying to aim at and what is the propulsion system we have trying to aim at. Supposing, I have a gas contained in a tube, let us say I have propane plus oxygen here in stock metric proportions and then I ignite at this end a flames sort of travels in this and this is how of flame travel but, instead of having a ignite source which starts a reaction and flowing over here, I create a strong compression wave something like a shock wave travels into it. Behind the shock wave, chemical reactions will occur and this wave will travel. This strong compression behind it in other words instead of having expansion are rare faction behind a flame I start getting compression behind and that amount of compression I have is very much higher than may be it could something like twenty times the initial pressure in it or rather the type of compression I get behind the wave divided by the initial pressure could be of the order of twenty to fifty. That means I am talking of the very strong compression taking place

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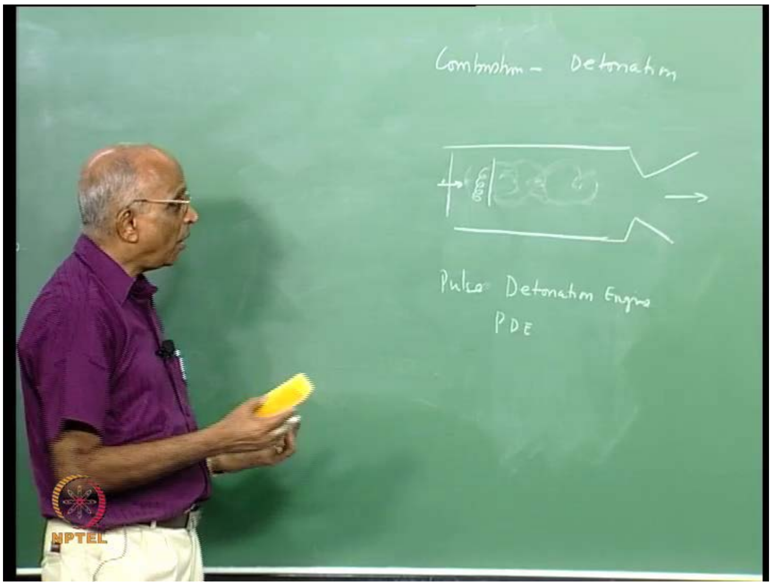

And therefore, if I can use this principle it became very easy for me to make a rocket like what we say is, instead of having a regular combustion I have something like a detonation. That means I have a chamber, let us say a simple tube. I fill it with a particular gas mixer and instead of forming, instead of putting and igniter here, I form a shock wave or a strong combustion wave therefore, what is going to be happen? My pressure behind it goes up and therefore, I have a high pressure zone and this if I can expand it out I get fantastic thrust because I have extremely high pressure therefore, instead of a regular combustion engine, I have something like known as a detonation engine and this engine I need to periodically do it, use it in pulses. Therefore, I have something known as pulse detonation engine that means p d e and this is something about which lot of work is going on but, people said it as been flown. I am not sure if it as been flown because some of this things get into the into the restricted area of defence and all that not very much is known but, the area is maybe I could use a pulse detonation engine

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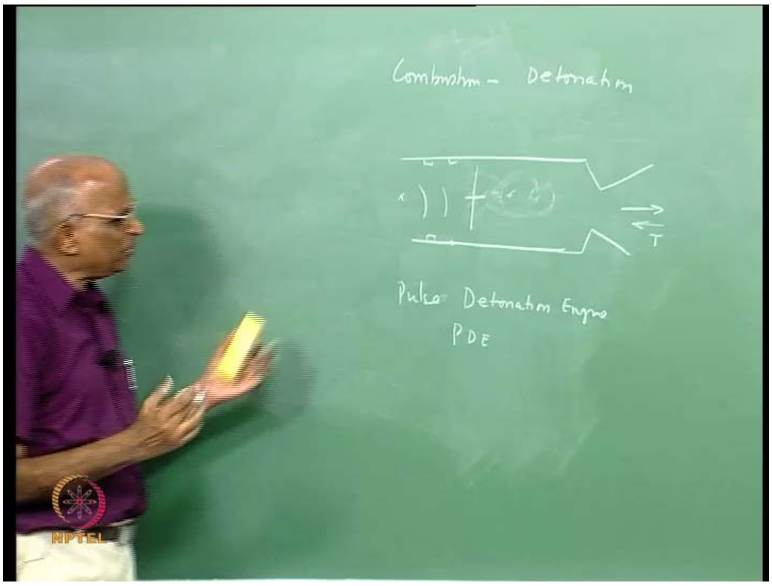

To generate thrust and how do I do it? Well I ignited, I put some blockages here such that a flame which is travelling becomes a detonation after some time and this detonation gives me a high pressure and therefore, value of high thrust. Therefore, the subject of propulsion as you see is endless, we must learn to dream a little bit, study the basics and try to see whether we can keep on improving different ways of pushing our self in spaces to get back where we got started.

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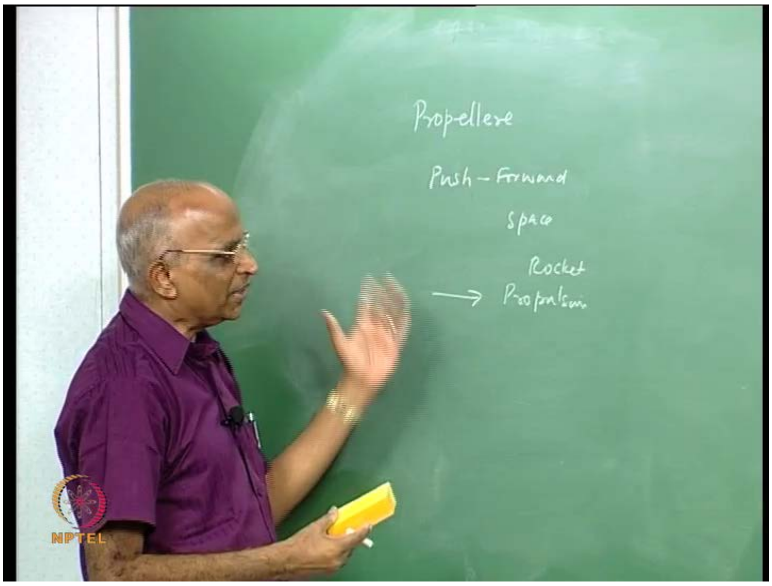

We get propulsion comes from the word propellere which is essentially to push forward and where do we push forward? In space and therefore, we can as long as we get something to push using different fields, using different different mechanisms, using different substances, using different principles, well I can push in spaces and again what we say is rocket propulsion because we are moving about in space. I think with this we finish are subject. I must tell you it was a nice getting going through the different aspects in this class and I hope you all will go through whatever I have taught and it will be nice if we can advance ourselves by looking into the newer principles, may be looking more at sail propulsion, may be at a proton propulsion and I think there must be a good future in this subject. Well thank you then. That is about it.