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Aerospace Propulsion
Liquid Rocket – Propellants

Lecture 31

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The next set motors that we are looking at or next set of engines that we look at is liquid rocket engines.

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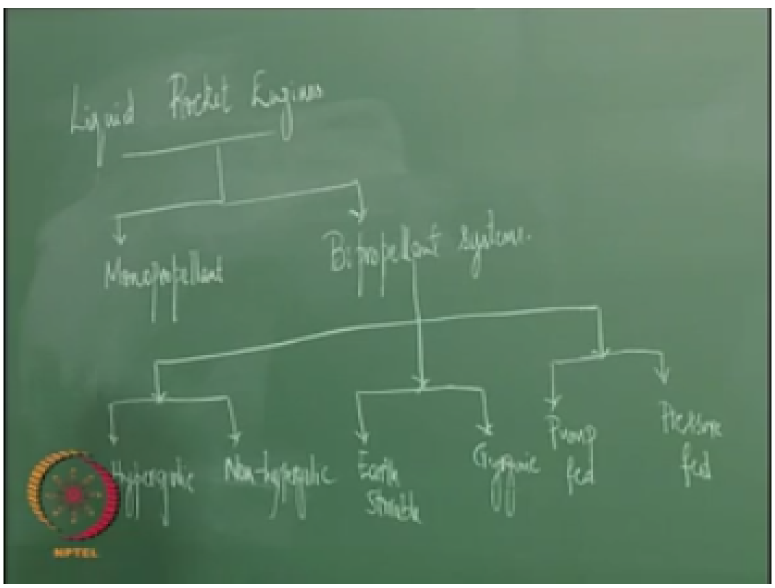

Now just like we had certain classifications of solid rocket motors depending on whether it is a double base propellant or a homogeneous propellant we also can categorize the liquid rocket engines into mono propellant, now a monopropellant system is one wherein the propellant decomposes okay, in an exothermic fashion and then the energy is released whereas in a bipropellant system you have fuel and oxidizer which makes it burn and then you get the high pressure high temperature, right.

We will discuss this a little more in detail but firstly the bipropellant systems are themselves further classified as hypergbolic, non hypergolic that is durable cryogenic and pump fed then, now what do we mean by hyperbolic and non hyperbolic, hyperbolic systems are those wherein if you introduce the liquids as soon as they come in contact with each other the reactions take place they do not need any source of ignition okay.

Whereas a non hyperbolic system you need some ignition energy to initiate. The reactions this does not need any ignition and earth storable and cryogenic the earth storable systems are those wherein the propellants can be stored under ambient conditions, ambient conditions of pressure and temperature.

Whereas if you look at cryogenic engines they use typically hydrogen and oxygen or kerosene and oxygen kerosene and oxygen is a semi cryogenic system because kerosene is in some sense earth storable and oxygen liquid oxygen if you use that is a cryogenic, cryogenic essentially means that these are gases at ambient conditions of pressure and temperature and you need to cool them in order to ensure that they become liquid.

Why do we need to have liquids primarily because the density of liquids is much more than the density of gases and if you store them as liquids then you can store them in a smaller volume, gases you can argue this way that you can pressurize them and increase their density right, that is one of the other routes. But when you pressurize them we will see that the thickness of the pressure vessel keeps on increasing depending on the pressure.

So in therefore it does not become useful after some time to store them as gases at high pressure okay, so therefore it is seen that if you go to liquids then it is a lot better. So cryogenic liquids typically are liquid oxygen and liquid hydrogen systems, okay and last case pump frayed or pressure fact you know liquids when you store them in certain tanks okay, they need to be pumped in or fed into the engine.

Now how do you do it is what determines this classification if you have a turbo pump right system okay, then it is called as a pump fed system and if you just pressurize the tank and let the liquid come out at high pressure that is called as a pressure effect system. Usually pressure effect systems are lower thrust devices whereas double pump fed systems are very, very high thrust device or we will discuss them a little more in detail, firstly starting with the mono propellant thruster.

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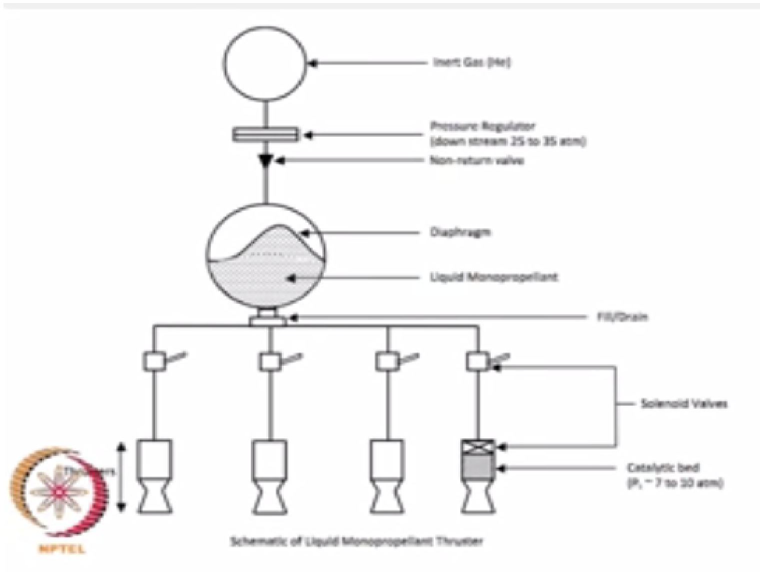

Now if you look at this figure this is the typical mono propellant cross system you have an inert gas bottle that pressurizes the liquid here why do we need to use inert gas it is because you do not want reactions to take place inside the tanks itself right you want the reactions to take place where you have the thrust chamber.

So you pressurize it with an inert gas either helium or nitrogen helium is if you use it is very obvious that helium has a lower molecular weight. So if you even if you have a very large tank then the molecular weight being low for helium the weight of the gas in this tank will be lower.

But unfortunately if you want to store them for a longer time right, because this is very low molecular weight it is usually seen that it tends to leak over time and you not store it for very long times and therefore people also use nitrogen as a pressure okay, nitrogen you can store it for a much longer time then you have a pressure regulator which regulates the downstream pressure.

The pressure in the inert gas bottle is typically of the order of 350 bar okay, so 350 bar you come down to something like 25 or 35 bar and then you have this liquid monopropellant tank you have a diaphragm here right, that is basically to ensure that you know most of this monopropellant systems are operated in space or under very low gravity conditions. Now under normal gravity conditions you will always find that the liquid will be at the bottom.

So therefore if you have gas that is pressurizing it will expel it out but there is no guarantee of that happening in very low gravity conditions, so therefore you need a diaphragm so as to make sure that the pressure in on this side otherwise this situation could be inverted too and you would end up pushing in inert gases only. Then you have the liquid monopropellant here there are two liquid monopropellant that are typically used one is hydrazine.

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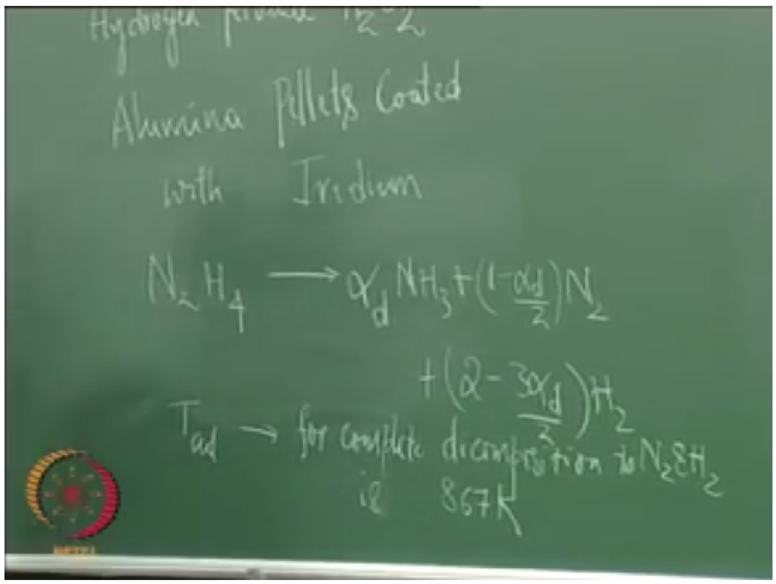

Or N2H4 the other s hydrogen peroxide or H2O2 both of this are unstable compounds and if you see here this hydrazine breaks up into ammonia and hydrogen and nitrogen and this breaks up into water oxygen and hydrogen. So this is the mono propellant tank and after this there is a there are thrusters small thrusters a cluster of them these are typically used in satellite systems for station keeping of applications okay.

There in you need very, very low thrust now there are solenoid valves attached here solenoid valves are typically off and if you give them a particular voltage and current they turn on so they can be remotely operated okay, and it then feeds into what is seen here as a thruster. If you compare this with a solid rocket motor.

A solid rocket motor the propellants and the thrust chamber were identical and then there was no other right, they were both stored in the same place and which is why we said that the specific impulse of a solid rocket motor would be lower because you need to have compatibility between fuel and oxidizer, so you are not free to choose the best oxidizer and the best fuel.

Whereas in a liquid rocket motor you have this freedom of choosing the best oxidizer and the best pure, so therefore you need to have storage and thrust chamber separate the portion above the thruster is known as the feed system or the storage tanks and this is the thruster here, now in this thruster there is something known as a catalytic bed typically used catalyst is aluminum pellets.

Alumina pellets coated with iridium and because of this catalyst the decomposition of either hydrazine or hydrogen peroxide takes place okay, and if you look at hydrogen per hour hydrazine decomposition that is N_2H_4 it can decompose into $\alpha_d NH_3$ $1-\alpha_d/2$ N_2 here if you decompose it completely to nitrogen and hydrogen okay, you will not get a very high temperature.

Typically the T adiabatic if it completely decomposes is something like 867 K okay, but you would not want that kind of low temperatures so what is done is there is an optimal value that is.

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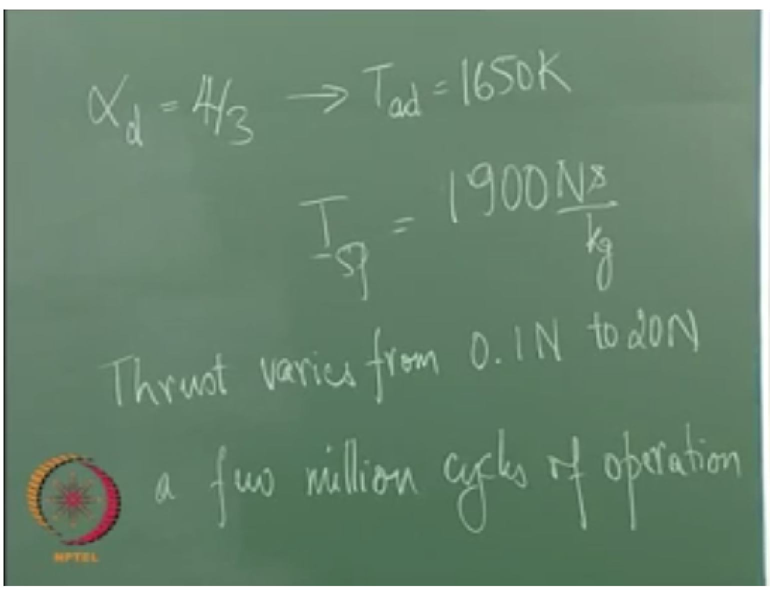

if this α_d is somewhere around 4/3 right, then the temperatures T adiabatic corresponding to this would be 1650K and ISPs would be something like okay, as you can see here this has a lower ISP compared to solids but these are used as I said in Satellite applications primarily because you do not want a continuous operation you want a pulsed operation right, and liquids are very convenient for such an application and therefore although it is of a lower ISP you tend to use this.

The typical thrusts that these thrusters will have to deliver is thrust varies from 0.1N to something like 20N, it is very small primarily because if you look at the application where it is supposed to be used it is in space, so there is no of the sense a pressure there is very, very low right, there is no sensible atmosphere and correspondingly there is very, very little drag. So if you give it a very large thrust you typically want it to be corrected by small magnitudes.

If you give it a very last thrust it could move very far away from the stated position, so therefore you tend to have very small corrections that are made so as to make sure that it goes to the position that it has to be in, and there these thrusters will have to be operated typically around the undergo a few million cycles that is they are switched on and off and the burn time is typically very, very small.

So there if you look at the thrust time curve for them it will be like okay, they are switched on and switched off after a certain time okay, they are not in continuous operation and if you look at the life of the satellite right, the one that determines how long the satellite will stay is how much propellant you can calculate, okay.

And in some sense if you can have a higher specific impulse for this then you will find that the satellite can be kept in position for a much longer time okay, which is why people are now looking at plasma thrusters and other electrical thrusters. The good thing about these electrical thrusters is they have very low thrust which is what is needed for this operation, but there are ISPs are typically two orders of magnitude more than what is seen here.

So therefore your operation time will increase if you have a higher ISP, so that is the direction in which people are moving. Now let us move on from the mono propellant thrusters to bi propellant systems, let us first look at this pump fed and pressure fed systems.

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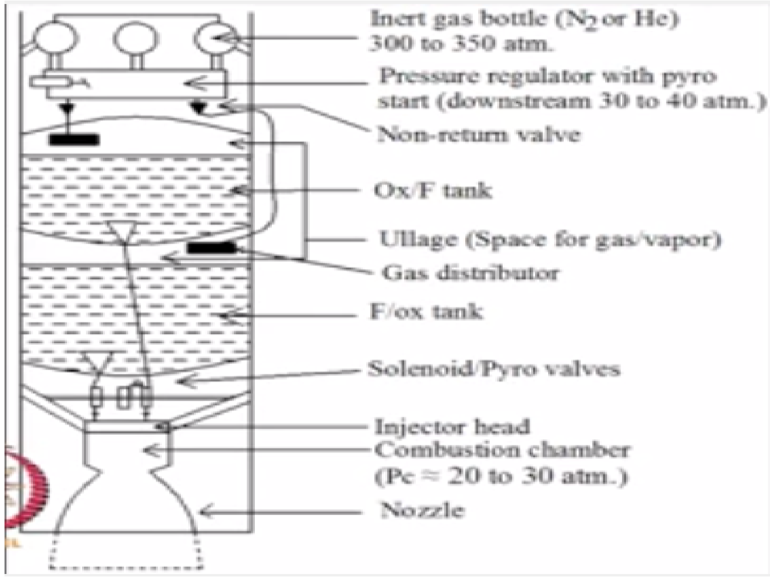

This here figure here shows bipropellant pressure fed system you will have inert gas bottles and then the pressure regulator as I said you have both nitrogen and helium and then you have a separate oxidizer and fuel tank okay, and if you look at the pressure downstream of this gas bottle in the tanks it is somewhere around 30 to 40 and in the combustion chamber it comes down to something like 20 to 30.

So these are basically fed by because of the high pressure here okay, and then you have the combustion chamber and then the nozzle as opposed to this if you remember if you add heat at the highest pressure right, then you can extract more work out of that system so therefore if you also if you want larger thrust if you remember the thrust equation is nothing but Cf/Ct so if you have a very low pressure then the thrust will also be lower and if you have a very high pressure your thrust can be much more larger.

So that is the idea behind the pump fed system and the schematic of that is shown here what you see is again pressure bottles that these pressure bottles are much smaller in size and what happens here is you do not pressurize it to something like 30 or 40 bar, you pressurize it to something like 3 to 6bar which is higher than the vapor pressure why that is so we will discuss a little later in the course okay.

And therefore the tanks are essentially maintained at low pressures they are not at high pressures they are not at 20 bar or 30 bar right, there at very low pressures so therefore the thickness of the tank material can be smaller.

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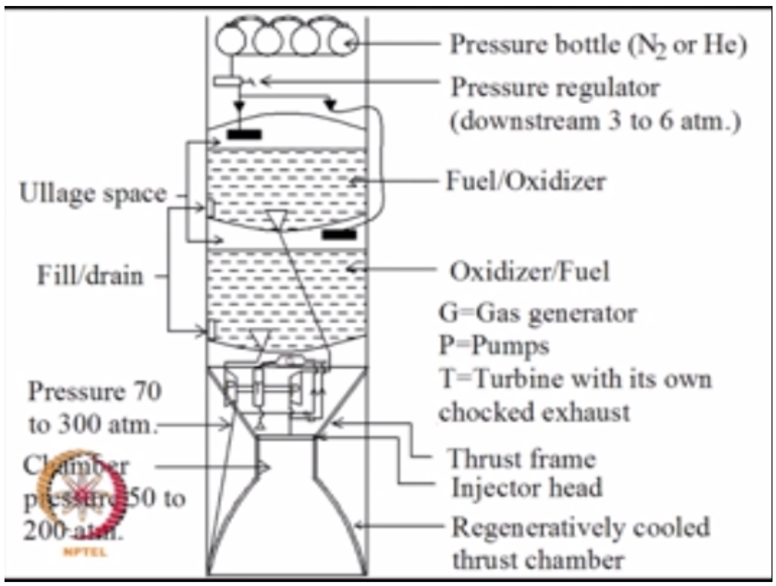

And then you have turbo pumps here okay, you have a pump a separate pump for fuel and separate from for oxidizer and then you have a if you have to run these pumps you need a turbine right so this turbine uses a part of this so fuel and oxidizer system okay, part of this feed is given to the gas generator indicated by G here the pumps are indicated by P and the turbine is indicated by P.

Now if you remember what your disk studied earlier in an earlier course that is on gas turbine engines you will see that the turbine Inlet temperature needs to be smaller they cannot be very high, although here in the combustion chamber of the rocket motor you can go up to 3300 there it is restricted to something like 1600 to 1800K, so here in the gas generator you need to be careful so as to ensure that the temperatures do not exceed that and then you have a turbine which essentially powers the two pumps, okay.

And if you have to start it initially right, initially if you have to start the system you need a small propellant charge typically a solid propellant is used to provide this and that we first run the turbine right, if the pumps are not run then you would not have anything coming into the gas generator.

So initially to run the turbine a small solid propellant system is used and then the turbines are turned on and then the pumps become operational and they start feeding in the propellant and the gas generator can then be used to run the turbine and then you have in the combustion chamber here, you can go to something like 50 to 200bar okay, the combustion chamber pressures are very, very high here.

In space shuttle to the combustion chamber pressure in the space shuttle main engine liquid engine is somewhere around 200 bar so somewhere in the pipeline you will have pressures exceeding 300 bar very, very high pressure systems. If you have a high pressure system the other advantages that your size of the thrust chamber right the size of this rocket motor can be very, very small.

And as I said if you want a very large thrust, thrust is dependent on PC right, so if you have a very high chamber pressure then you can get a very high thrust. So this also in some sense needs a lot more cooling because of the high heat that is generated here and typically a fuel part of the fuel is pumped through a regenerative jacket okay, there is a jacket around the nozzle as well as the thrust chamber, okay.

And typically liquids are pumped through this and these liquids take in the heat and then this is used up again the combustion chamber, so in a sense what we had discussed when we would discuss nozzles right, we said there is a loss because there is a loss of heat to the ambient that is minimized if you have regenerative cooling because you are essentially using what is been lost to the walls again is re-circulated back, okay.

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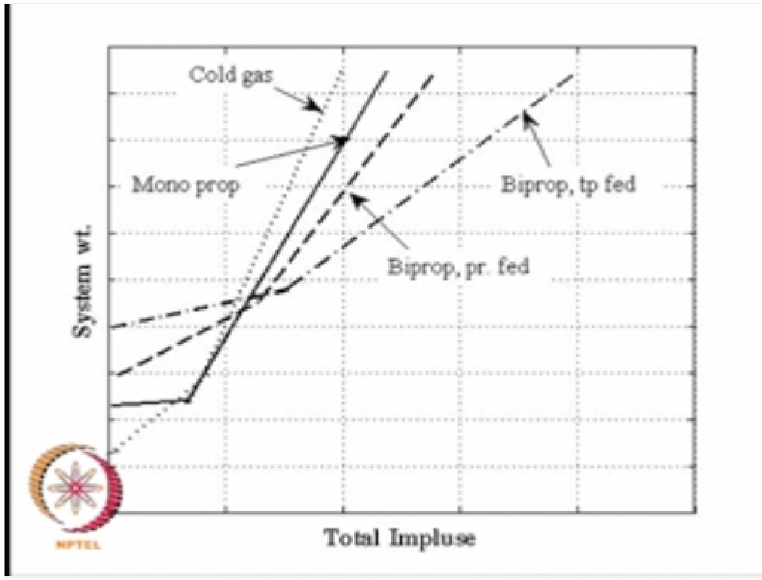

And this as I said is going to give you very high thrust it is important to note this that if you want to decide on what system to use for a particular application. Remember we said we the satellites because it is a low thrust system we wanted to use monopropellant systems when do we use a bipropellant system, when do we use a pressure fed when do we use turbo pump fed.

Now what is shown here in this plot is you have on the x-axis total impulse total impulse is nothing but.

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Impulse is nothing but F into operational time okay, or T burn so either if you have a very large thrust or if you want to have the operation for a very long time right, then your impulse becomes larger. Now if you see this is x-axis is total impulse and y-axis is system weight okay, if you see this if you can use coil gas for certain applications that is when the impulse requirement is very small then this becomes a very good system, right.

If you have impulse requirement of the order of 10^{-1} there is no point in using a bipropellant system, bipropellant system will in fact have a very heavy weight because you need to have pumps you need to have all kinds of devices, so it is better to have cold gas if you are you using it for a very small impulse and then further this curve the mono propellant system comes in that is if your impulse is up to 10^{-1} it is better to use a monopropellant device and then pressure fed bipropellant device and then lastly turbo pump fed pressure bipropellant system.

Now the difference between the bipropellant the pressure effect system in turbo pump fed system is essentially because of the tank weight, if you notice in the earlier figures in the pressure effect system the gas bottle is the one that is pressurizing it, so it needs to have a very large volume in order to fill the entire tank volume.

So if your thrust is large and as well as burn time is large then you are going to have a lot of liquid in the tank so the time needs to be that something like 30 to 40bar so the inert gas bottle weight goes up as well as the tank weight goes, okay. Because if you remember from the structures it is Pd/2T right, so the thickness goes up as the pressure goes up.

So therefore the system weight is going to increase and that is why you will find that beyond a certain fraction of the impulse if you use a pressure effect system then it will not be very beneficial its system weight is much higher than compared to something like a complex system, if you have something like 10^5 you can see that the system weight will be something like 10,000 kgs.

If you use a double pump fact system but whereas if you use a pressure fed system it will probably be something like 10^7 or 10^8 okay, so in a sense this graph gives you an indication of what is to be used if as per your requirement. So the essential thing to notice you need to know what is your impulse.

If you know the thrust time curve you can calculate the impulse and therefore you can choose the appropriate system. We will stop here and in the next class we look at little more in detail on the liquid propellant systems okay, thank you.

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