Jet and Rocket Propulsion

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Lecture – 3

Welcome back. So far we have discussed what are the rockets, historic perspective of the rocket, the development of rocket science.

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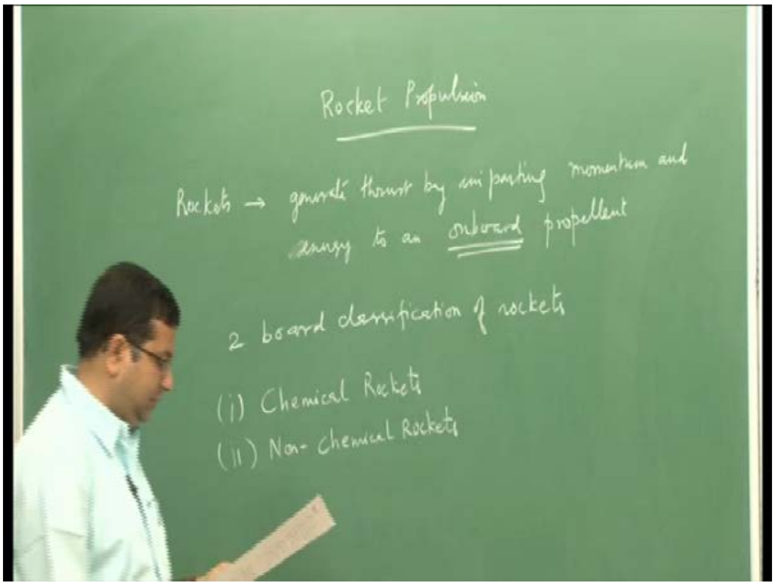

Now, let us back to the actual course; to start discussing rocket propulsion. First of all in the previous class, we have talked about what are rockets; the basic definition of rockets. Rockets are the devices, which generate thrust by imparting momentum and energy to an onboard propellant. This is the catch word – onboard propellant. So, the propellant is onboard. Rocket is carrying that propellant and it initially energizes that propellant or adds momentum to it. So, therefore, unlike air breathing engine, which draws most of its propellant from air or surrounding environment, a rocket essentially energizes its onboard propellant. Now, there are two broad classification of rockets. Rockets can be classified under two broad categories: first is chemical rockets; and the second is non-chemical rockets. So, in this course, we will primarily deal with chemical rockets, but towards the end, we will have some lectures on non-chemical rockets like the electric propulsion systems. So, first let us look at the chemical rockets.

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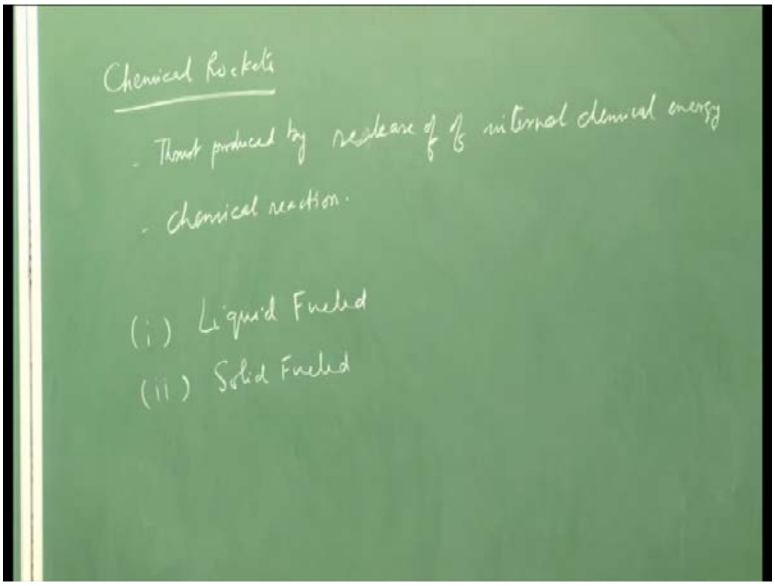

As the name suggest, the chemical rocket generate thrust through the release of internal chemical energy of the propellant. So, thrust is produced by release of internal chemical energy of the propellant; and that energy can be released only through chemical reaction. So, the primary source of production of thrust is the chemical reaction in chemical rockets. Now, this is the broader classification of rockets. The chemical rockets also have two primary subcategory. Actually sometime we can also call it three; but, primarily two subcategories: first is liquid fueled; and second is solid fueled. So, we also have sometime hybrid also; but, primarily, it is liquid fueled or solid fueled; where, it depicts the phase of the propellant. Either the propellant is in the liquid phase; both oxidizer and the fuel in the liquid phase; or sometime we have mono propellant; where is a single propellant; it can be in the liquid phase or it can be in the solid phase. Again solid phase also we can have separately oxidizer and fuel blended together. Or, sometime we have a mono propellant as one rod or we can have them separately also.

And, one subclass of liquid fueled as I have said before also is cryogenic, which essentially means that, the propellants, which are in their natural state gases; but, if they are stored under extreme conditions – pressure and temperature; then, they are in the liquid form. So, they are stored in the liquid form, but the combustion occurs in the gaseous state. By the time they are sent to the combustor; actually in cryogenic, by the time they reach the combustor, one of them have already gasified; other come as the liquid state, but one is already gasified. Therefore… But, liquid fueled – primarily both the fuel and oxidizer are in the liquid state. So, the basic principle of operation as far as the chemistry is concerned is same in both; only the rocket design is going to be little different; the subsystems are going to be different. For liquid fuel, you need to have liquid storage, pumps, gas generator, etcetera; for solid propellant, you do not need that. Thus, entire pallet is put inside the rocket chamber and it is burned inside that; you do not have to have separate systems.

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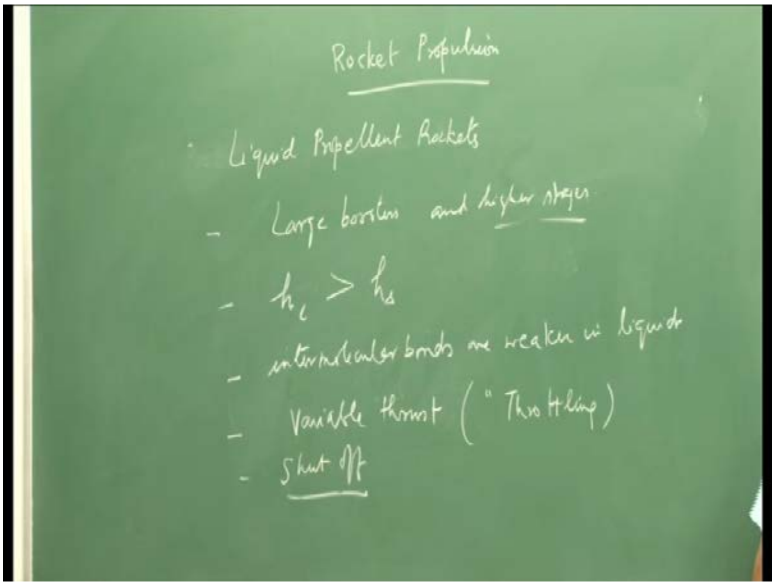

However… So, coming to the liquid propellant rockets, look at the merits and demerits of these two systems. The primary use of liquid propellant rockets are in large boosters. Now, liquid fuels generally have higher enthalpy per unit mass relative to solids. So, if I look at the specific enthalpy or enthalpy per unit mass; then, typically, liquid fuel will have a larger enthalpy compared to solid propellant. And, there is a reason for it. What is the reason? How do we ((Refer Time: 07:17)) heat of reaction? By bond energy. So, typically, the molecules are much closely packed in solids than liquids. So, they can be very easily broken. Therefore, the energy content will be more in liquid because very less goes in breaking the bonds. So, energy release will be more; whereas, in the solid, lot of energy has to go to break the bonds, so that energy is available. Therefore, overall delivery of enthalpy or energy will be less. So, typically, the specific enthalpy are the enthalpy per unit mass for liquid fuel is more than that of the solids.

Now, this is because of the fact that, the intermolecular bonds are weaker in liquids. Therefore, they are easy to break the bonds; easy to vaporize. Now, one thing – we have taken course in combustion. I have said that, combustion typically actually occurs only in the gaseous phase. Finally, the combustion to occur, it has to be in the gaseous phase. Therefore, whatever propellant we take; first, it has to vaporize; and only then, reaction will occur. Liquid is easy to vaporize; solid is little more difficult to vaporize. Therefore, the combustion process is easier in liquid compared to solid as far as the physics is concerned. Of course, it is easy to light up the solid propellant and it will be keep on burning. But, as far as the energy release is concerned, liquid fuel will be much more efficient than solid fuel.

Now, one of the prime advantage of using liquid fuel is providing variable thrust. Now, this is very important; which is also called throttling. Liquid fuel can provide variable thrust or throttling, because we can very easily control the flow rate. And, flow rate is what? Essentially dictates how much total energy is produced. So, by controlling the flow rate, we can very easily control the total thrust produced by these engines. This is a very important feature as far as the engines are concerned; because of the fact, if you look at mission requirement; typically, all the missions – they have a well-defined period for every application. Something has to burn for five seconds for particular thrust; two seconds for particular thrust; like that; which is very difficult to achieve the solid propellant. But, liquid propellant can very easily attain that.

Another advantage is allowing throttling is shut off. Liquid propellant can be very easily shut off. So, from safety point of view also, it is much safer compared to solid propellant. As I have just said, challenger disaster was started with solid propellant booster. Even if you have… You see that something is going wrong; cannot do anything about it; because once the solid propellants are lighted, it is impossible to stop it from burning up. Whereas, liquid propellant can be very easily put off. So, shut off is a very important condition. Now, shut off provides variable thrusts and set of combination of these two. Essentially, alloy used to go for multimode missions; where, at different stages of the mission, you will have different requirement. But, with solid propellant, you just light it once it is gone.

So, if it is a very specific well-defined motion, solid propellant will be better. But, if it is a flexible mission, we are talking about liquid propellant has to be there, because we have that control of controlling the total thrust or duration of thrust, the amount of thrust. Both are important particularly for many applications like satellite mission chipping and all. Many times you may not know a priori – how much thrust you will be required at what condition for how much time. So, have a liquid propellant – liquid-rocket system; and you can provide that amount of thrust – required thrust. So, that is the biggest advantage. That is why liquid propellants are primarily used in boosters and at higher stages also. Higher stages – typically we use liquid propellant rockets. However, there are some disadvantages also. One biggest disadvantage is it requires the fuel feed system.

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So, the disadvantage is first fuel feed system – feed and storage. In order to store this liquid fuel, liquid typically will have much less specific volume than solid. Gas has even less, but liquid has specific volume as solid. Therefore, the rate per unit volume is relatively low as compared to solids. So, in order to store enough mass, you need to have larger volume. So, you need storage tanks. Now, this storage tanks do nothing but just store fuel. If you look at the space shuttle, it has separate storage tank for storing fuel. But, that adds on during lift ((Refer Time: 13:28)) because that has to be carried onboard. So, this ((Refer Time: 13:33)) tank – this do not take part in production of thrust or any mission requirement. But, they have to be there to carry the fuel that adds to the weight. So, this adding storage tank adds to the weight.

Now, for multistage missions, they can be discarded. But, if you are talking about mission, where you do not have to discard it; then, you are carrying that weight as a dead weight. And, other is the fuel feed system; that is, pumps – very important. Now, these pumps are special turbo pumps. They are again… These are also technological marvels. If you look at the total operational time of a liquid fuel rocket; let us say you have a liquid rocket in the second stage like PSLV. Second stage is a liquid fuel. Now, the first stage is solid propellant; it has burned out. Within fraction of a second, you have ((Refer Time: 14:31)) a second stage. And, ((Refer Time: 14:34)) light it. You have to light at its full capacity. Full capacity means almost about 50-60 kg per second of fuel. So, 50-60 kg of fuel we have to put in first within one or two second. So, the pump has to pump in that much amount – huge amount of flow within such a short duration.

Development of this pump – the pump material, the pump bearing, pump blades – everything is very critical for the operation – proper operation of a liquid fuel system. And, that again is dead weight, because it is not participating apart from supplying the fuel. So, once again is a very expensive component. It is a very difficult component to design and manufacture; but, does not directly take part in the first generation. So, it can curtail a mission, make a mission tripled; but, it does not add advantage to the mission. Therefore, that is one of the biggest problems in liquid fuel systems. So, liquid propellant rockets – one of the bottle necks is a fuel feed system. And then, we have to maintain the distribution. Typically, there are many injectors. We have to maintain the distribution – equal distribution everywhere. So, there are various issues that come into picture.

Then, second – now, because of this, they are heavier than solid propellant – heavier than solid fuel rockets, because these are the ways that we have to carry. So, for the same amount of thrust, they will be heavier the solid propellant rockets. And, there are lots of dead weight, which you need to carry in a liquid fuel system. And, one of the major problems in liquid propellant rockets is persistence of combustion instabilities. Combustion instabilities are the major problem in liquid propellant rockets. And, what happens; these instabilities actually couple with the feeding system. So, if the instability occurs… Instability is pressure variation in the combustion chamber. Now, the combustion chamber pressure or variations are of large amplitude. And, the fuel feed system – the delivery mass flow rate depends on the pressure differential between the feeding system and the combustor. So, if the combustor instabilities have large amplitude, there are lot of oscillations in the pressure; then the differential also oscillates. So, that feeds back to the fuel feed system and change… oscillates the mass flow rate.

If ((Refer Time: 17:36)) to oscillate, the thrust will start to oscillate. And, that actually augments the combustion instability also. So, can lead to disastrous mission failure. So, this is a major problem with the fuel feed system and combustion instability coupling. So, essentially, what is done is that, in the design stage, we design in such a way that these instabilities do not occur, because these are system level problems and operating condition level problems. Then, the designer specifies that, keep away from these operational ranges. So, ((Refer Time: 18:12)) specify the operational range, that is, the flow rate, temperature, pressure, etcetera. And, you have to operate within that parameter; otherwise, we may get into combustion instability. So, this is something in the designer development stage has to be addressed. And, that essentially adds to development cost or time. But, without that, it becomes a dangerous preposition to operate the liquid fuel engine.

On the other hand, the solid propellant rockets are simple and reliable. As we can see as we have talked about the history, as we have seen in the history, the original rockets were developed in eighth or ninth century; they are all solid propellants. Without ((Refer Time: 18:55)) detail critical predictions or anything, they are very simple and reliable. Solid propellant rocket – once you light it, it is going to fly. It may not fly in the intended manner, but it is going to fly somewhere.

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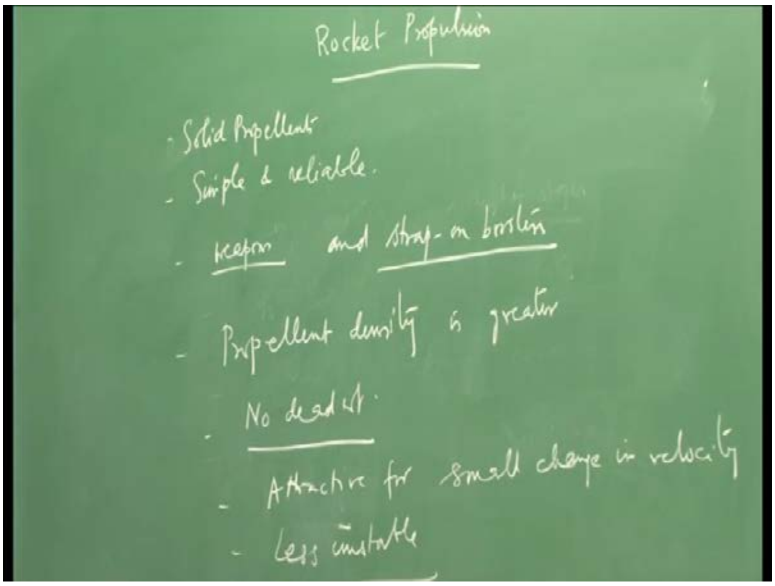

So, solid propellants are simple and reliable – biggest advantage. This simplicity and reliability gives its robustness or repeatability in operation. Because of that these are very attractive as weapons. Most of the missiles – particularly short range missiles are solid propellant rockets like even the stinger missile – the solid propellant. So, they are essentially preferred for weapons. Advantage is you do not need this storage and everything and huge portability, because they are very compact, closely packed. So, can be taken very easily, carried very easily. So, gives the portability. That is why they are preferred as weapons as well as and strap-on boosters.

Now, strap-on boosters are the attachments fitted to the rocket vehicle to provide the initial thrust. They have to run for few seconds; provides the huge initial thrust. So, you can have huge solid boosters like in the special program and then let them burn off. Once they burn off, you can discard them. So, the cases can come off and then the main rocket can take over. But, to provide the initial thrust, you need reliability and you need lot of it – lot of thrust, which can be provided very easily by the solid rocket boosters. Therefore, these are usually used as strap-on boosters. Also, they are used as retro rockets and ((Refer Time: 21:01)) rockets for stress separation, because those are well-defined mission requirement; you fire it for very short duration, because when the two stages separate, they need to be moved apart. So, one of them will be in the forward motion and other will be in the backward motion, so that you can move them apart. And, those are usually achieved by very small solid propellant boosters – small… You call it rocket pallets. Small rockets are fired to provide little amount of thrust, so that the stages separate. Again the reliability is very critical in that. And, that is why solid propellants are preferred.

Then, the propellant density as I have talked about before, density is greater than liquid rockets; that I have already talked about, because they have very high specific volume compared to the liquid propellant. Therefore, the propellant density is greater. And, the biggest advantage – no dead weight. Apart from the casing, nothing comes in; no rotating part, no supply system; nothing is required. Apart from the casing, it is just a full solid pallet, which is lighted and that burns. So, we do not need any separate storage; you do not need any feed system; only thing required is the ignition system; that is it. Apart from that, nothing is required. So, that is the major advantage; no carrying, no dead weight. So, which any weight you save adds to the payload or to the range. Both of them are beneficial. Therefore, this is the major advantage of solid propellant rockets. And, these are especially attractive for small change in velocity; you do not need very large changes. But, for small changes, these are very attractive; it provides the initial ((Refer Slide Time: 23:19)) of… Again why do we use for the initial boosters? We do not need to require very high velocity there; small change in velocity, but you have to lift lot of weight, because you are lifting the entire system with all the propellant and everything. So, lot of weight with small velocity change, solid propellant is preferred. Once it starts to become lighter, switch over to liquid propellant and take it forward, because we have already got the initial push as the initial velocity.

So, after that, the liquid propellant can take over. So, this is very attractive for small change in velocities. And, as we have just mentioned that the liquid rockets require heavy tanks and pump, which they do not; and they are usually more stable; combustion instabilities are… Although add there, because combustion is a phenomenon of the rocket chamber acoustics. So, they are there, but less than this. Secondly, it does not feedback. Combustion instrument if it is there, does not feedback to the fuel feed system. So, the combustion system and instability – rather the combustion or the evaporation and burning process and the instabilities are kind of decoupled, because there is no feedback back to the evaporation rate or burning rate. So, less unstable. This is another advantage of this. Disadvantages is liquid propellant had the major advantage of throttling; whereas, solid propellant – one of the major disadvantage is throttling not possible.

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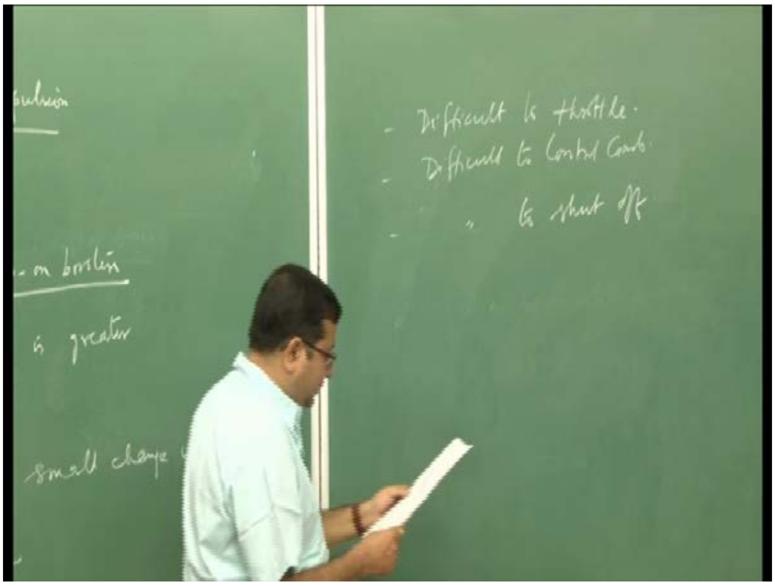

So, difficult to throttle – major disadvantage; difficult to control combustion. Once the combustion process starts, it just have to let it burnt, because it cannot control it. Nowadays of course, for the ((Refer Time: 25:32)) mission requirement, the pre-program of the entire pallet with different burning characteristics; but, that has to be done a priori; it cannot be done on flight in an active manner; it has to be passively programmed. So, these are the major disadvantages of solid propellant rocket. And, there are some instabilities, which do exist. But, primary disadvantages are these two: difficult to throttle and difficult to shut off. So, once these are fired, either they complete their mission or they can have disaster consequences, because they work like a missile for space ((Refer Time: 26:12))

So, solid propellant – if they are fired; and that is one of the reasons that, most of the launching sites are very close to the areas, where they are not much of ((Refer Time: 26:22)) not much of people, because if once you light the solid booster and mission is a failure, you have to abort the mission; and then, it may take it to a populated area and have disastrous consequences. Therefore, all the mission areas are essentially are… Or, that the launch pads are essentially away from the inhibited areas. So, now, in the latest development… But, solid propellants because of this energy density and disadvantages, are still very attractive.

Therefore, technology had been developed to somehow provide some control and throttling to the solid propellant rockets. And, one of the Indian success story is solid propellant. Indian SLV program is completely solid propellant is a very successful program. All the solid propellant rockets are very efficiently used. So, India is one of the world ((Refer Time: 27:20)) solid propellant rocket technology. So, so far we have been talking about chemical rockets; we have discussed the liquid propellant rockets and solid propellant rockets. Now, let us look at the other variant of rockets, which are non-chemical rockets.

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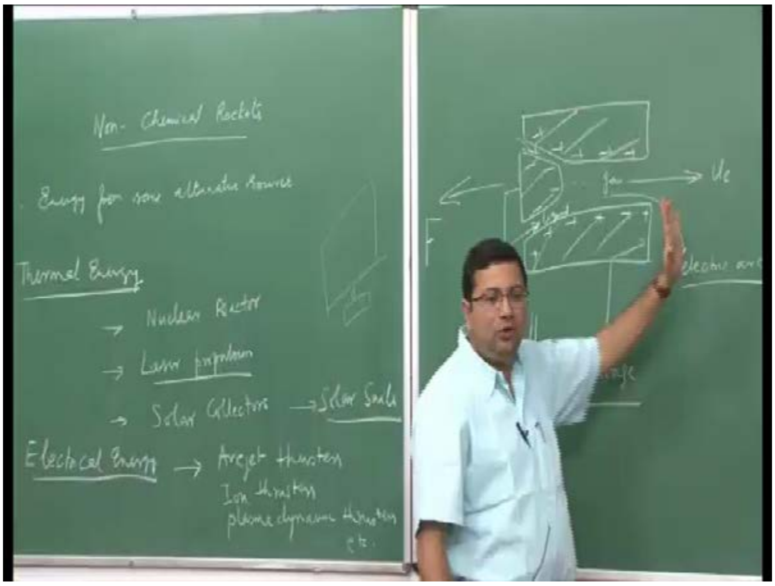

So, next we talk about – little bit about non-chemical rockets. Now, as the name suggests, the primary source of energy is not chemical energy in non-chemical rocket. So, instead of releasing the chemical energy of the propellant itself, the energy is imparted to the propellant from some alternative source. So, energy from some alternative source; not directly the chemical energy. Now, this type of scheme of imparting non-chemical energy become attractive when large changes in velocity are required without carrying a large amount of propellant. So, we need to change the velocity, but not with large amount of propellant. Or if we need very small propellant, it is to be… Even if the delta v or the velocity change is not very high; if we can afford to use only small amount of propellant; in that case, we have no other option, but to use some alternative means of energy production to get that acceleration or velocity increase. So, this extra energy to give the velocity increment delta v is provided by non-chemical sources. That is why they are called non-chemical ((Refer Time: 29:14)).

There are various examples of non-chemical rockets. The energies are transferred to the propellant can be of different forms. First is thermal energy. So, primary source of energy can be thermal energy. Under this category, one of the thing that can be talked about is a nuclear reactor. Nuclear reactor is a very good source, a very compact source of energy. It can provide very large amount of energy with very little amount of propellant. Therefore, ideally it will be a very attractive; very attractive for rocket propulsion. And, as we have discussed in the previous lecture, actually it is something like that, was proposed by ((Refer Time: 30:07)) a longtime back – nuclear propulsion. But, nuclear reactor although are attractive… Or I would say not politically correct, because whenever we have a rocket, we have to propel through atmosphere and we do not want to have open nuclear reactor moving through the atmosphere. So, nobody will allow it. That is why even though it is a very attractive concept, it never became reality.

And, the issue with nuclear reactors are not ((Refer Time: 30:38)) the energy relation; but, the safety issues to content the radiation or insulation, etcetera; or, the auxiliary systems for power production. That becomes heavier. Therefore, although nuclear reactor can be a good source, it is never practically used. Now, one of the ideas of using nuclear reactor or actually nuclear explosion was to have something like a ballistic launch, where you can have a nuclear explosion underneath a rocket or a ballistic missile or something. And then, because of that explosion, it will move. But, once again, it is too riskier business to be practically implemented. That is why even though nuclear reactors can be a good source, never used so far for space exploration.

Now, the other alternative can be laser propulsion. Now, lasers can be used in two ways in propulsion. First, laser can be used as an igniter in a chemical rocket, which is essentially a low powered laser; can be very easily used. Or, laser can actually be used as the source of energy, because laser lights are very intense source of energy. And therefore, they can be used to propel up to last distances. Therefore, laser propulsion is one alternative; where, essentially, it is thermal energy; where, laser light can be used to heat up; and that can be used then to propel.

Then, other alternative is solar collectors. Once again it is a thermal root, where solar rays can be collected and they can be used… The electricity generated or power generated by the solar rays can be used to propel. So, that is one of the ways of propelling through thermal root. So, that can also be used in some other way, which are called solar sails. This is not C E L L cell, but S A I L – sail. In solar sails, actually we have large solar arrays, which are mounted over the satellite – typically used in satellite; and they work like the sails that are used in boats. The solar rays have its electromagnetic nature can produce small amount of thrust to this sails. So, these are pretty large devices, which can be used to use solar radiation to propel by using this type of sails. Again these are some concepts, which are also sometimes has been used. But, they require very large structures.

Now, another root of non-chemical rockets can be electrical energy. Electrical energy unlike the thermal energy actually is very widely used in various satellite operations. And, first of all, let us give some examples of electric propulsion systems. One is say arcjet thrusters; then, iron thrusters; then, plasma dynamic thrusters, etcetera. This revises primarily used electrical energy to produce thrust. Therefore, they are called electrical thrusters or electrical propulsion devices.

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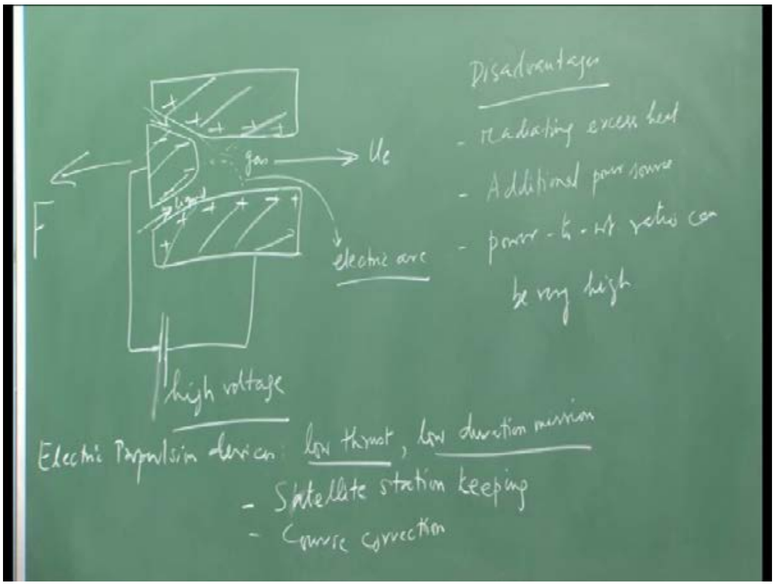

So, if I look at… I will just take one example. Later on when we go to electrical propulsion systems, we will discuss them in detail. Let us just look at arcjet thrusters. Typical schematic of an arcjet thruster is we have a solid cathodes and anode. And, this is the anode and some propellant is passed between these two – in the gap between these two. And, very high voltage is applied between the two – high voltage ((Refer Time: 35:38)). Very high voltage is applied across the two. Because of this high voltage just like a welding mission, electric arc is produced in this gap; and the propellant, which is typically xenon is fed into this gap. This comes in a liquid form when power crosses this arc. Across this electric arc, there is a very high temperature. So, in this arc, it evaporates into gas. So, it comes as liquid evaporates into gas and not only gas is actually ionizes.

Now, because of that, there is a massive decrease in density because liquid has much higher density than the gas. Now, if the density decreases so much in order to maintain the overall mass flow rate, it has to accelerate. So, this accelerates; gets a very high velocity. And, this produces the thrust. So, thrust is produced by the high velocity that is produced by this re-revise. So, this is our electric arc. And, that is responsible for production of the high velocity jet. This is very hot. Temperature can be very high as 20 to 30,000 Kelvin. And, this is how an arcjet thruster works. There are other thrusters like iron thrusters; very similar principle, where we ionize the gas and let the ions pass through. Then, we have plasma dynamic thrusters, where we get plasma. And, the plasma is then allowed to pass through them and this thing come out of this nozzle and that produces the thrust. So, essentially the basic principle in all these electric propulsion systems is that, the electrical energy is responsible for the production of very high velocity exhaust.

Now, here we are still using some amount of propellant. Propellant is required; we are energizing the propellant. Only the energization process of propellant is not through a chemical source, but through an electrical source. That is why it is considered as a non-chemical rocket. So, here also the propellant will be used, because that is what needs to be accelerated to produce thrust. We need to have an action. And, that the action comes from the propellant momentum. Therefore, this is how the electric propulsion systems work.

So, the basic characteristics of electric propulsion devices are – first of all, they would not produce very large amount of thrust; pretty low thrust will be produced by them; and they are usually used for low duration missions. Now, since they are producing very low thrust, they cannot be typically used within that ((Refer Time: 39:01)) atmosphere, where the forces acting are very large. But, if you are in the outer space, where there are no frictional forces, nothing to slow down the vehicle and the vehicle is moving at a high speed, a small amount of thrust will provide required acceleration to carry out certain maneuver. And, that is good enough. Therefore, they are very efficient in outer space. Now, the advantage is since you are not carrying any… Rather you do not have any chemical propellant; we do not need to carry lot of propellant. Therefore, the specific impulse, which will come to later is much higher compared to the chemical rockets. So, this is one of the basic features – low thrust. And secondly, also they have to work for low duration mission; they cannot be operated for a long period.

Now, one of the examples of application of electric propulsion devices are satellite station keeping, where as I have said in the previous lecture that, the satellite may deviate from its path. So, that needs to be brought back to the intended orbit. That is done by this devices and they can operate over a very long period of time; that is, the total life span of these devices are much larger compared to chemical rockets. So, that is one of the major applications. Other is of course correction. And, most of the deep space props like Sassine or Galileo – they have some kind of electric propulsion system, because to them, for these type of missions, you require to have very long operational life and chemical rockets cannot have that large long operational life. Therefore, most of those missions actually have some electric propulsion system onboard. Now, these are the advantages of electric propulsion system.

The disadvantages are – first of all, because we are using electrical power, electrical power always produces heating. Now, radiating this excessive heat is a very difficult proposition; something that we have to somehow inbuilt in the system; so radiating this excess heat. Then, another disadvantage is you require some additional power source. Now, for example, here in the object thruster, in order to produce the electric arc, you need fairly high voltage in the range kilo volts. Where is the source of energy? What you can have is some batteries, some capacitors. If their batteries are need to be charged, the only source of charging is the solar sails.

They will take a long time to charge. So… And, of course, that needs to be transformed because solar sail will not produce the kilo volt range of voltage. So, need to be… You need to have a transformer to step up. So, all those things essentially act to the rate. Therefore, this additional power source; then, the accelerate components actually add to the rate of the system. That is why it is… It becomes as a whole bulky. Then, because of this additional rate that it needs for the additional power source, sometimes the power to weight ratio can be very high; that is, power produced per unit weight of the entire system can be rather unmanageable; not very high; let us say can be unmanageable. It may require lot of weight to produce unit power. Therefore, that makes it not very much economical in the long run. So, these are the disadvantages.

Now, so far, then what we have done today; we have looked at chemical rockets; we have looked at solid propellant; we have looked at liquid propellant; we looked at non-chemical rockets. What we have observed by discussing all those type of various rocket vehicles is that, each of them have their own advantage, own disadvantage. So, they can be used for specific missions. For example, for the initial boosting, solid propellants are the best. So, that is why we use solid boosters. But, for the acceleration up to the escape velocity, best option is liquid propellant. So, that is why in the later stages, we use liquid propellant. Once we are in the outer space, non-chemical will be better. So… But, if you are talking about small scale applications like satellite station keeping, etcetera, non-chemical electrical is the best source.

But, if we have to produce more powers, thermal is the better source. So, if we have to someday think about going far deep into space, this may be the options. But, solar collector of course will be limited by the range up to which solar rays are available. But, nuclear and laser can be operated beyond that also. So, essentially, the bottom line is we choose the horses for the courses. There are various types of rockets available. We choose specific rocket for a particular application. So, the choice of rocket is dictated by the mission requirement. Rockets – most suitable for long journey – essentially, let us say Saturn 5 is not usually very much suitable for launching at ((Refer Time: 45:25)) orbit. Therefore, there you need to have modification.

And, many times, even different stages of same vehicle use different type of engine. Again, the biggest example is PSLV. But, you have a solid-liquid, solid-liquid. GSLV – solid-liquid-liquid cryogenic. So, they have different engine at different stages. Again, that choice depends on the mission requirement. How long a particular stage will be firing? What will be the payload fraction for that particular stage. Best on that we decide what type of rocket to be used. But, once we will be outside, after that, depending on the mission, typically, electric propulsion systems are used. So, with this, we complete our discussion on the introductory part of the rocket propulsion. Now, let us go into the more details of rocket propulsion.