Introduction to Launch Vehicle Analysis and Design

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Lecture - 27
Current Rocket Concepts

Hello and welcome. In this lecture, we will look at two concepts that while appearing to be somewhat futuristic do have practical utility, particularly in the context of the kind of missions that we are currently thinking of. These concepts pertaining to air-breathing engines and photonic rockets. So let us begin.

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Among the many ideas that are being explored we will consider in this lecture two ideas that have some value in terms of the kind of missions that are being synthesized.

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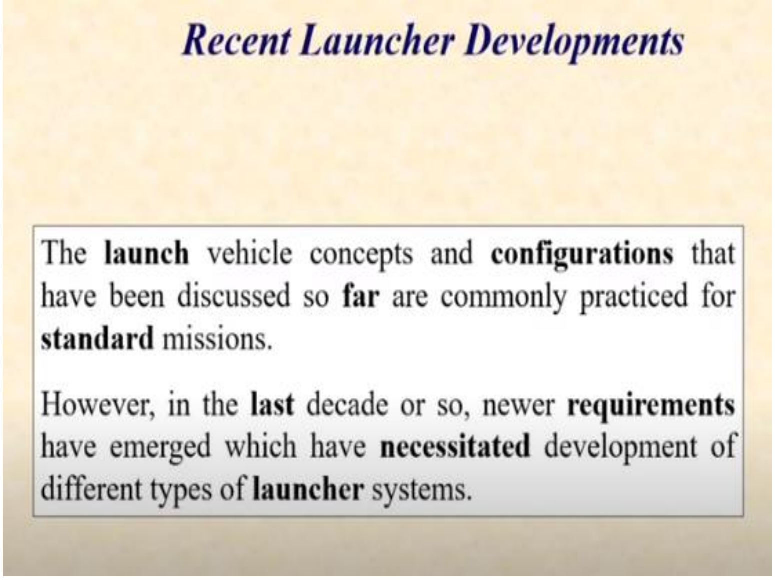

In this regard, it is worth noting that the current configurations that we have discussed using the conventional hydrocarbon fuels, including the cryogenic fuel are commonly practiced for most of the standard missions, as well as some of the newer missions that are being evolved over the last 15 to 20 years. However, in the last decade or so newer requirements have emerged, which have necessitated the development of different types of launcher systems.

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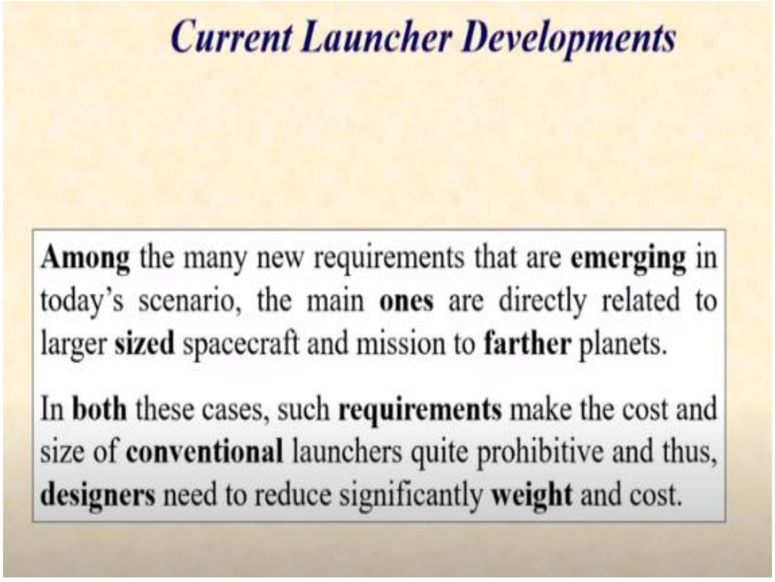

And among the many new requirements that are emerging in today's scenario, the main ones which are driving the technological developments across the globe are directly related to two specific points. One, larger sized spacecraft and mission to farther planets. These are the missions that most of the space agencies are currently looking at to increase the mass fraction capability of most of the launch vehicles and to also send spacecrafts to larger and larger distances in our solar system.

In both these cases, such requirements make the cost and size of conventional launchers quite prohibitive. And thus, designers need to reduce significantly weight and cost before such emissions can become feasible and practical.

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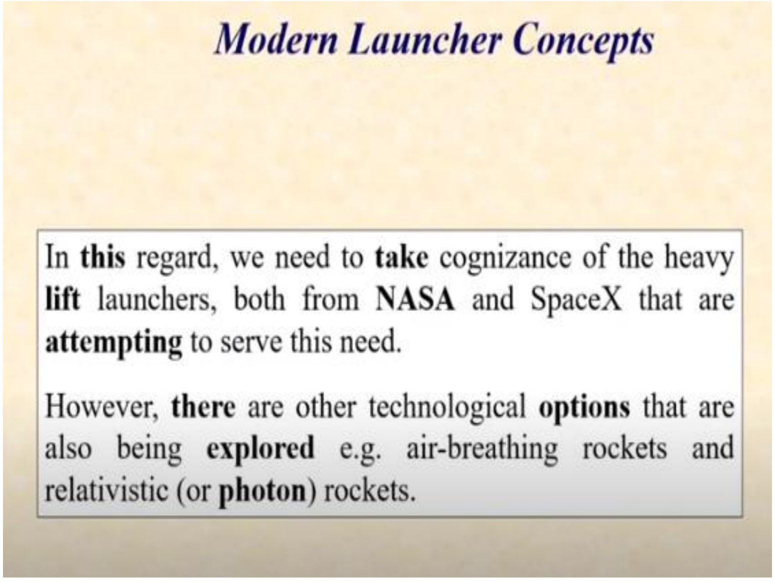

In this regard of course, we need to take cognizance of the heavy lift launchers that are currently in operation which is a reflection of such requirements of heavy lift for both NASA and SpaceX. The NASA has its Delta IV heavy development, which is supposed to lift much larger payloads and the SpaceX which is attempting the same option through what they are calling Falcon 9 Heavy.

So, it is not that we cannot lift heavier vehicles with the current technology, but then the cost is becoming larger, the vehicles are becoming massive and, in the process, there are also infrastructural and technological constraints that starts impacting the overall mission performance.

And in view of the above, there are other technological options that are also being explored of which the air-breathing rockets and relativistic or the photonic rockets are the ones which are being actively talked about including experimentally developed.

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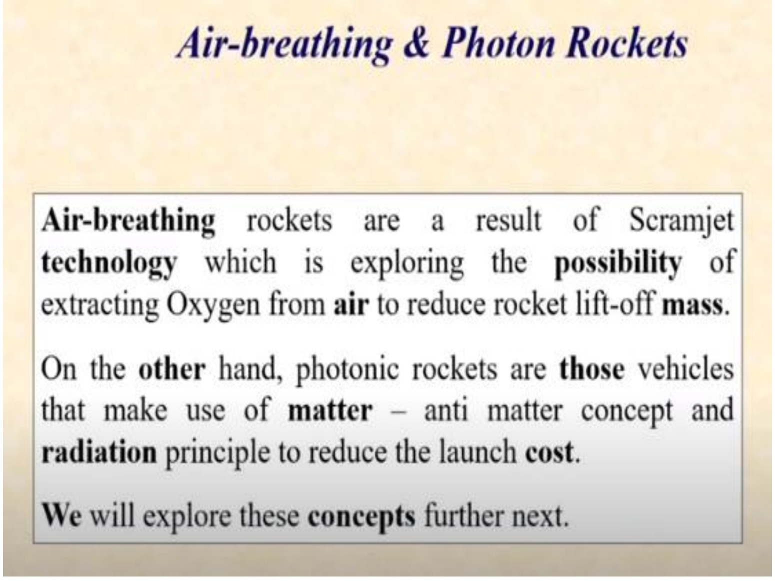

If we look at the basic ideas of these two concepts, we find that the air-breathing rockets are a result of Scramjet technology, which is not new to us and is exploring the possibility of extracting oxygen from air to reduce rocket liftoff mass. And we know that if we do that, then our payload fractions will significantly improve while keeping the cost within manageable limits.

On the other hand, photonic rockets are those vehicles that make use of or intent to make use of matter, anti-matter concepts, which are in the domain of scientific developments, along with the radiation principle to generate large speeds and still have lesser launch costs. We will explore these concepts a little more next.

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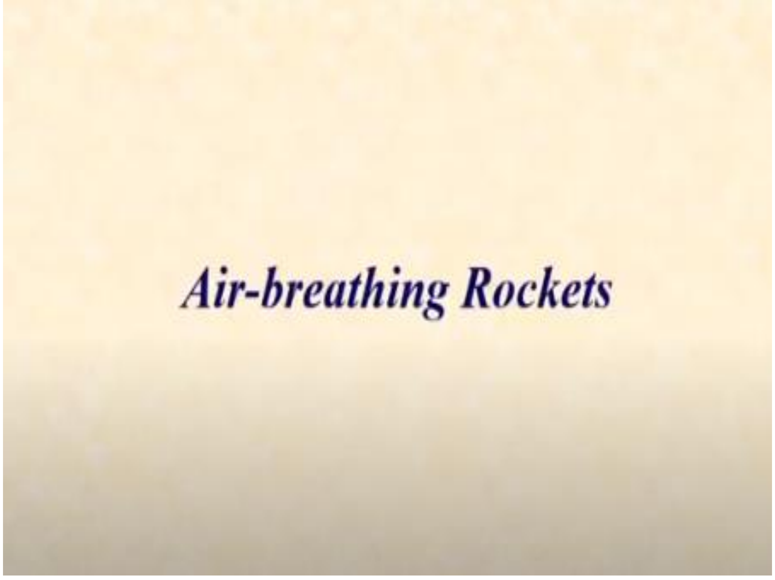

Let us first look at the air-breathing rockets concept.

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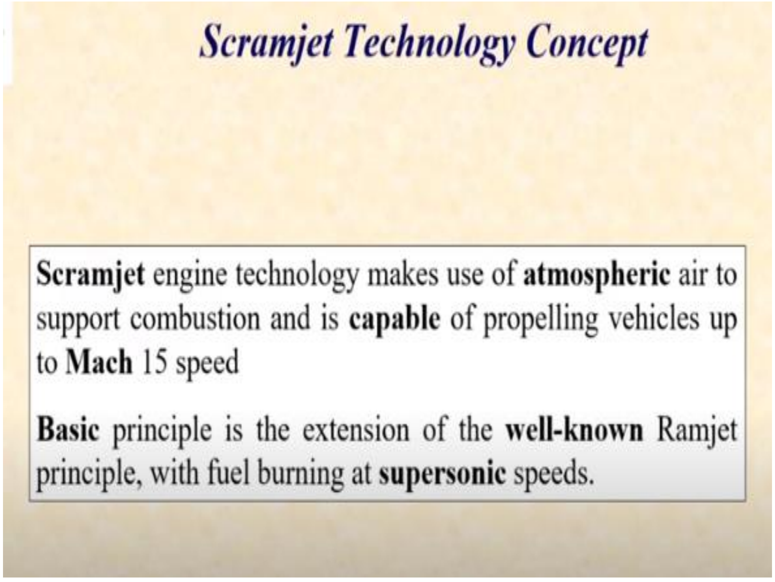

The Scramjet technology essentially makes use of atmospheric air to support combustion and is capable of propelling vehicles up to Mach 15 speed, which means that we can achieve very high speeds which is a requirement for sending the objects deeper into the space.

The basic principle of course, is the extension of the well-known Ramjet principle wherein, you create an engine which actually does not have any moving parts and you make use of the moving air kinetic energy to convert it into potential energy or pressure inside an engine. And then we burn fuel inside that engine to significantly increase the temperature and the pressure, which is then exited at a very high speed to generate large amount of impulse which is necessary for generating high speeds.

An important aspect of this is that we need to sustain combustion at supersonic speeds. Typically, most of the combustion in the conventional launch vehicle occurs at subsonic speeds. But, and particularly for air-breathing systems, use of supersonic combustion is something which requires lot of effort and challenging work.

In fact, the Scramjet is an extension of the Ramjet where SMC stand for supersonic combustion, which means, if you take a Ramjet engine and then you have combustion at supersonic speeds, you get a Scramjet engine.

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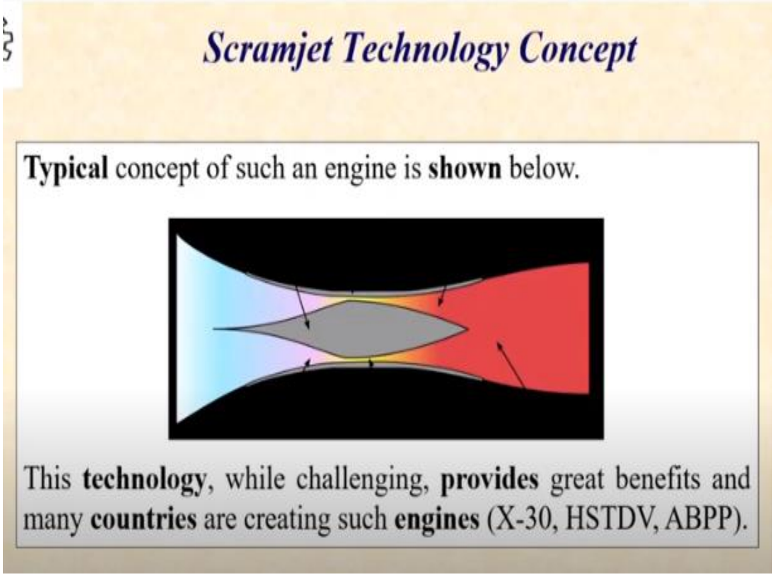

Typical concept of such an engine is shown below. So, this is a typical sketch of a Scramjet engine which takes in the air coming at hypersonic speeds that is speeds well beyond Mach 4 or 5. Then creates a supersonic diffuser of using cross sectional area that significantly increases the pressure until it reaches a very high value.

And in the process, the velocity is reduced to just about supersonic speeds at which the fuel is added and a large amount of heat is added to this flow at supersonic speeds to further generate very high pressure and temperature, which is then again expanded through a supersonic nozzle which generates again hypersonic speeds at the exit and in the process generates a very large amount of thrust.

This technology, while greatly challenging, has been found to provide great benefits and many countries are creating such engines. For example, X-30 program of NASA, HSTDV of DRDL and ABPP of ISRO, that is air-breathing propulsion project, which have also seen technology demonstrators in the last two or three years. This figure of course is courtesy Wikipedia. It just talks about the basic idea of a Scramjet engine.

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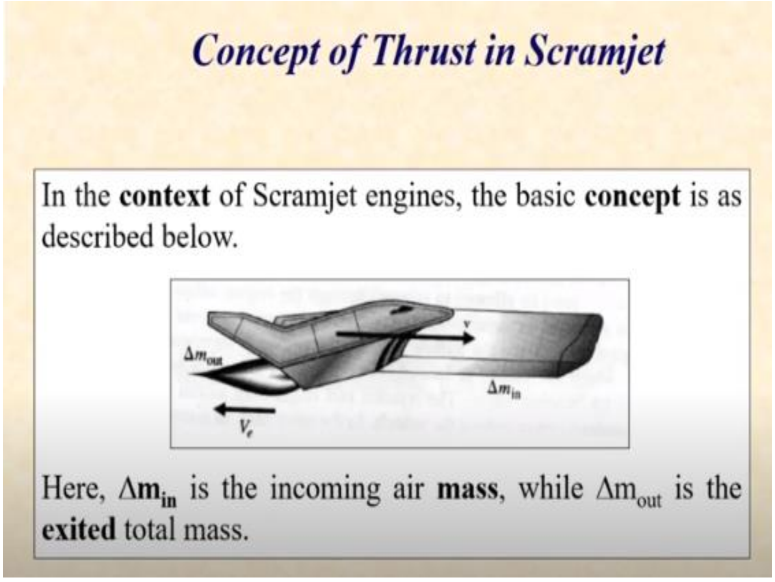

So how does one talk about thrust in such an engine? While you require a more complicated model to get the exact thrust expressions, certain simplified formulation is possible which gives us a broad understanding of what the implications of such a engine are. So, what you see below is a schematic of a Scramjet engine which is moving at a forward speed of V.

And it is taking in a certain amount of air delta m in, represented through that rectangular parallelopiped in front of the vehicle. The same air once it enters the Scramjet engine exits with a high velocity V_e and has the amount of mass exiting which is delta m out. Here delta m in is the incoming air mass while Δm_{out} is the total mass.

Which means, it includes the mass of the air which came in plus the amount of fuel which has been added in the combustion chamber and the related combustion products.

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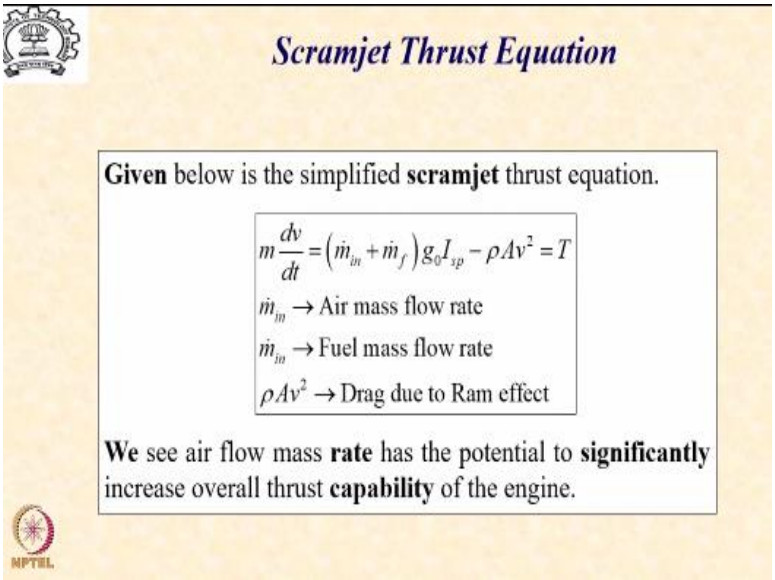

So given below is the simplified Scramjet thrust equation. And you will find that this is similar to the thrust equation that we had seen in the context of a conventional rocket except for one important difference which makes the Scramjet engine generate lot more thrust. As you can see, $\dot{m}_{in}$ is the air mass flow rate while $\dot{m}_f$ is the fuel flow rate. So, in the conventional rocket, the thrust is $\dot{m} g_0 I_{sp}$, which is $\dot{m}_f$.

Whereas, in the case of Scramjet engine, the total mass flow rate to which this I_{sp} is attached is $\dot{m}_{in} + \dot{m}_f$. Of course, there is also an associated Ram drag term. Because of the Ram effect there is a drag which is experienced by this vehicle and that subtracts from this thrust.

But we know that by appropriately deciding the inlet air, it is possible to significantly increase this term and hence generate a large amount of thrust through the air-breathing principle. And it can significantly increase the overall thrust capability of the engine and hence the mission itself.

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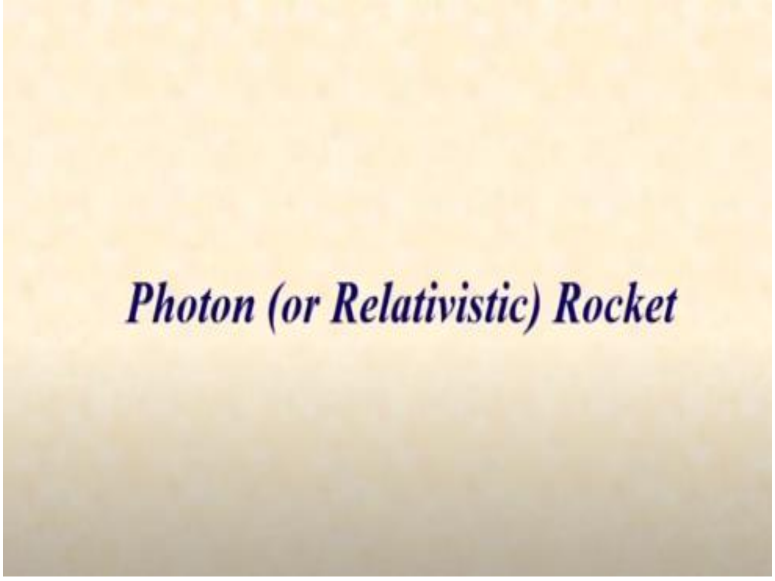

Let us now turn our attention to the photon or the relativistic rocket.

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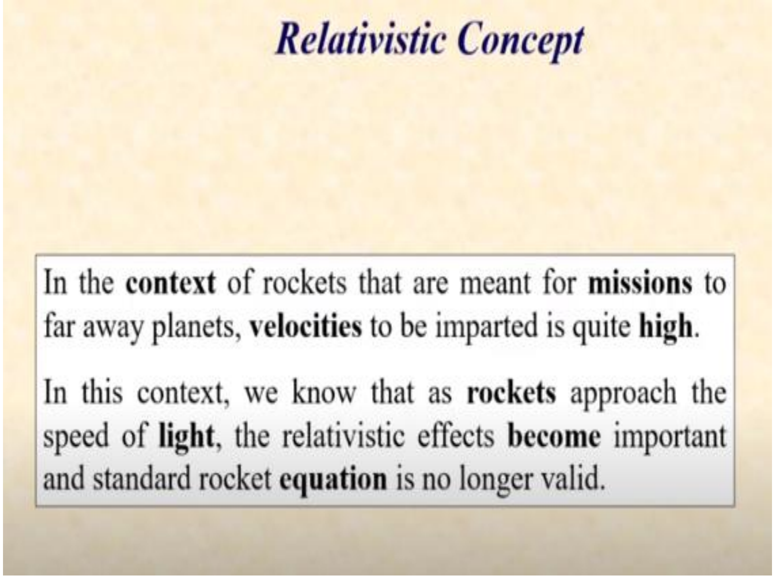

In the context of rockets that are meant for missions to faraway planets, the velocities to be imparted are generally quite high and possibly not feasible with the conventional hydrocarbon fuels or even cryogenic fuels beyond a certain point. In this context, we also know that as rockets approach the speed of light, the relativistic effect become important and standard rocket equation is no longer valid.

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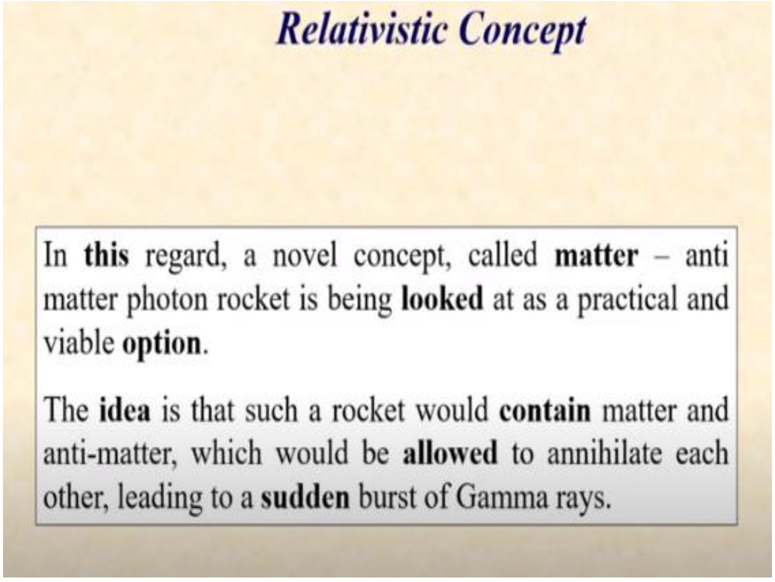

In this regard a novel concept though at the conceptual stage in the laboratories in scientific domain called matter, anti-matter photon rocket is being looked at as a practical and viable option in future. The idea is that such a rocket would contain matter and anti-matter which would be allowed to annihilate each other leading to a sudden burst of gamma ray radiation.

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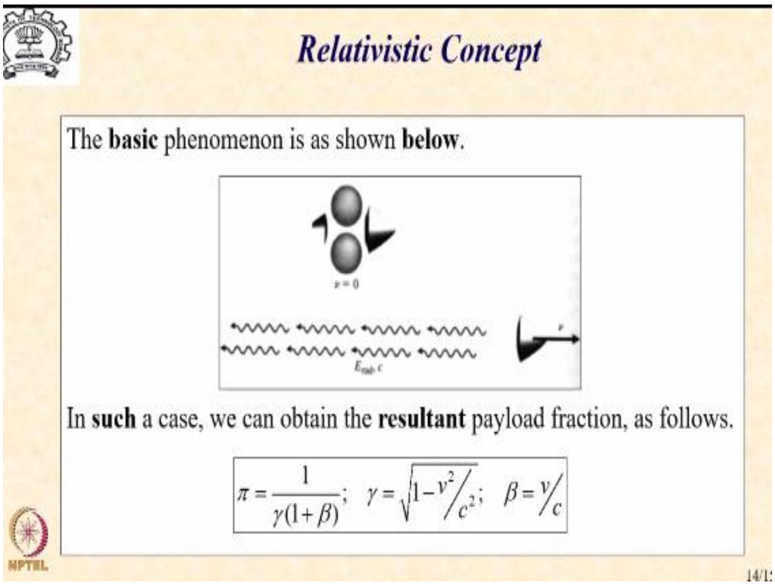

The basic phenomenon is shown as below schematically. So, you have a rocket which contains matter and anti-matter with zero velocity. And then they are allowed to annihilate each other generating a burst of gamma ray radiation which is directed in the direction opposite to the desired velocity. And as a result of this, this energy radiation energy, expended in a very short time can generate a large amount of instantaneous change in momentum and can generate an instantaneous large velocity of the object.

Of course, there is an important point that we need to note, that is the payload mass fraction, which is possible in such scenarios. And from simplified analysis for such a concept, it is found that the mission payload ratios are given by this expression. That is $\frac{1}{\gamma(1+\beta)}$, where γ is $\sqrt{1-\frac{V^2}{c^2}}$ and β is $\frac{v}{c}$.

Typically, you will find that these mass fractions are not very large, particularly when you start approaching the velocities, which are close to speed of light. I mean, it can be shown that if you want a velocity, which is one-tenth of the speed of light, the mass fraction that you would support would be of the order of 10^{-6}, not really useful.

But if you go to lower velocities, velocities which are let us say 100^{th} or 1000^{th} the speed of light, in such situations, you can still generate a decent amount of velocity for a decent amount of mass fraction.

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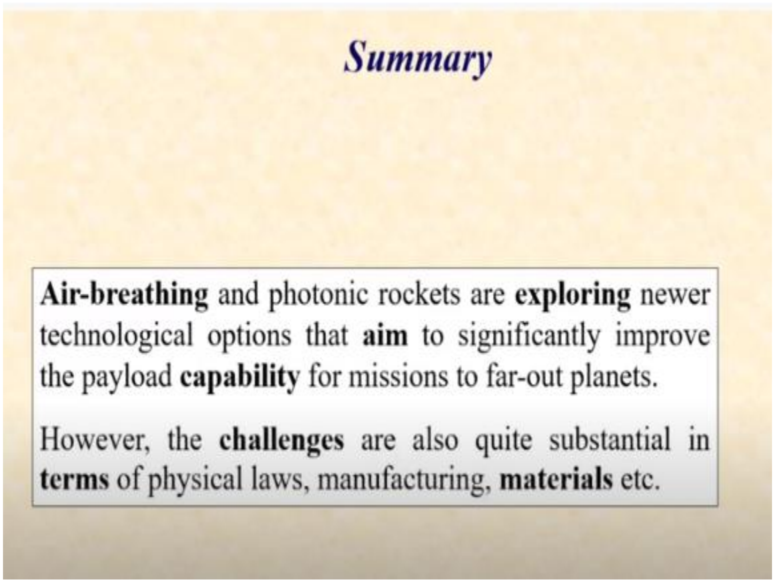

So, to summarize, air-breathing and photonic rockets are exploring newer frontiers of technological options that aim to significantly improve the payload capability for missions to far-out planets. However, challenges are also quite substantial in terms of physical laws, manufacturing materials, etc. Hi, so in this lecture segment, we have just looked at two possible futuristic ideas to help us synthesize missions that require large payload fraction and large velocities for mission to faraway planets.

With this, we have considered the launch systems and their configuration including their trajectory solutions. And we will now turn our attention to two important operational features of launch vehicles which is necessary for creating missions that we are currently talking about. One of them is TSTO or called the or SSTO, the single-stage-to-orbit or two-stage-to-orbit concepts directly.

And the other one is concept of launch window, which is an essential ingredient for synthesizing mission that aim to visit faraway planets, establish orbits around them and also land on the surface. So, we will look at these two ideas in the next lecture. So, bye, see you in the next lecture and thank you.