Introduction to Launch Vehicle Analysis and Design

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Lecture - 28

Launch Widow and SSTO Concepts

Hello and welcome. In today's lecture, we will look at the launch operation related concepts that are useful in specific situations. And we will also discuss some broad ideas of launch windows which are commonly included in the overall operational scenario of any launch vehicle. We will also spend a little time on the basic ideas of launch to orbit and their overall value to space missions. So let us begin.

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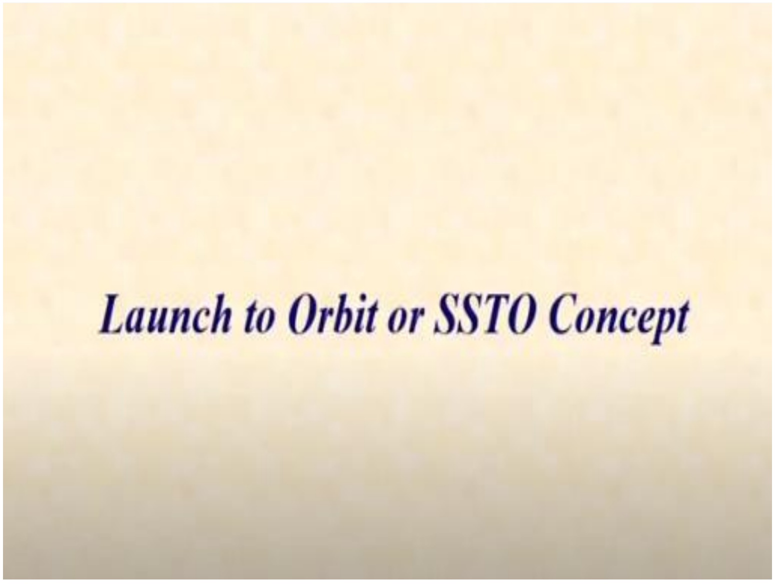

Let us see what launch to orbit or sometime what is called single-stage-to-orbit concept is all about.

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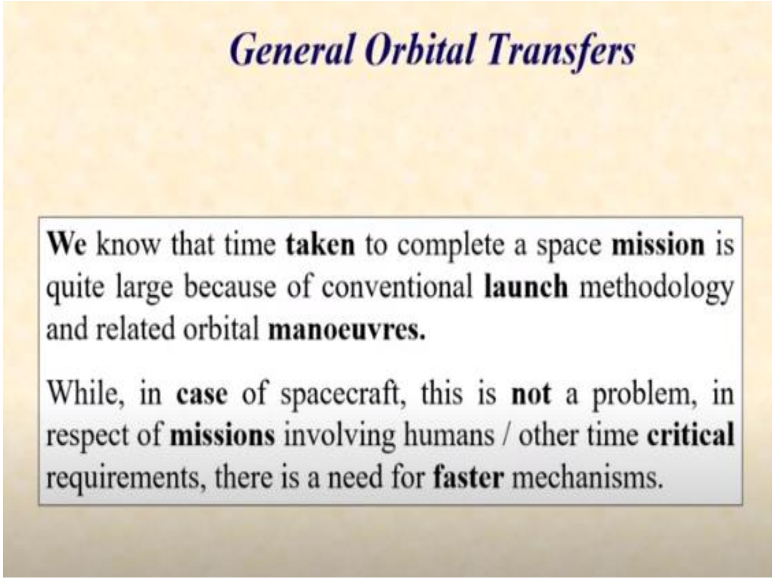

We know that time taken to complete a space mission is generally quite large because of the conventional launch methodology in which the larger spacecraft were designated point in space. And then there are a large number of maneuvers which are performed over period of days before the spacecraft is put into the final orbit that is as per the mission.

Of course, in case of a spacecraft which is unmanned, this is not a problem, because time is really of no great essence. But you will immediately notice that in respect of missions that involve humans or other time critical requirements such as a space-based rescue operation, there is a need for faster mechanisms to complete space missions.

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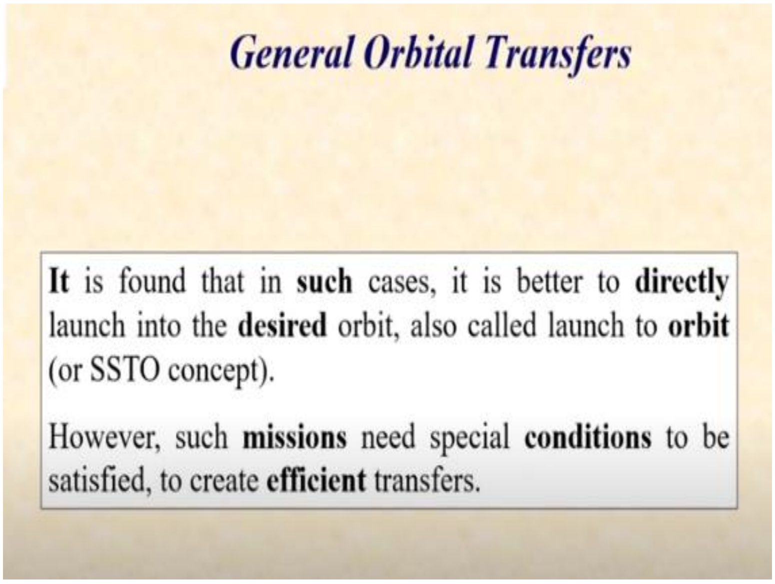

It has been found that in such cases where there is a time criticality attached to the mission, it is better to directly launch into the desired orbit in order to minimize the time taken to reach the orbit. These are also called launch to orbit or single-stage-to-orbit concept. However, as we will see shortly, such missions need special conditions to be satisfied to create efficient transfers.

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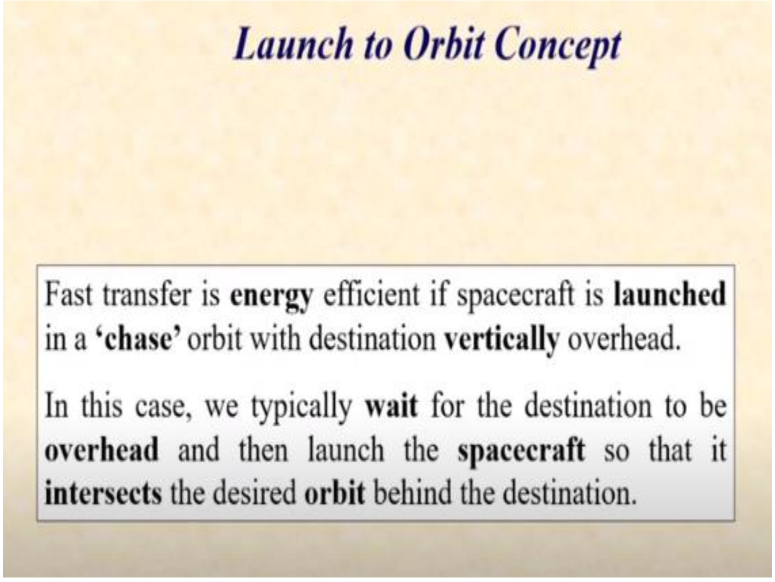

One of the points which is commonly recognized is the fact that fast transfer is energy efficient if the spacecraft is launched, in a typically called a chase orbit, with destination vertically overhead. In this case, we typically wait for the destination to be overhead at the launch point and then launch the spacecraft so that it intersects the desired orbit behind the destination.

In this context, it is worth noting that all spacecraft have a designated point in the space at which they must be placed in relation to other spacecraft and similar objects in similar orbits.

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Of course, it is not very difficult to realize that this would require a higher energy launch in comparison to the energy of the destination orbit, because you are in a chase orbit, and you must move faster in order to ensure that your destination is reached in the desired time slot. And in order to do that, you must spend extra energy to accelerate the vehicle.

SSTO that is single-stage-to-orbit or even two-stage-to-orbit that is TSTO missions are common examples of such fast transfers. Both SSTO and TSTO aim to reduce the staging related complexities. That is another benefit that you get from these technologies so that we can move towards a fully reusable rocket and significantly reduce operational cost.

In this context, let me make a mention of the various efforts that are going on with regard to the reusable technology, which started with the development of space shuttle in the late 80s. But in recent times, the efforts are being made to fully reuse the rocket as the Space Shuttle Program was only partially reusable.

The implication is that if you can fully reuse a launch vehicle, then the operational cost reduces significantly.

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An important application of the launch to orbit technology or the SSTO technology is for missions that involve docking with another spacecraft. And this has been very successfully used in the context of space station missions of space shuttle where the space shuttle is launched in such a manner so as to dock with space station as per the required time slots.

Now in order to understand this, we need to note that all spacecraft, which are visible from earth create a path on the surface of the earth which is called the ground trace. Ground trace is nothing but the locus of all points which is a result of the intersection of the radius vector of earth's surface over which the spacecraft completes one orbital cycle.

What it essentially means is that as spacecraft orbits around earth, its radius vector also sweeps one orbital cycle around the earth. And if you take the intersection of that radius vector with earth's surface, then locus of all those points is nothing but what we call the ground trace. It is almost like hypothetical shadow that the spacecraft would make on the surface of the earth as it moves around the earth.

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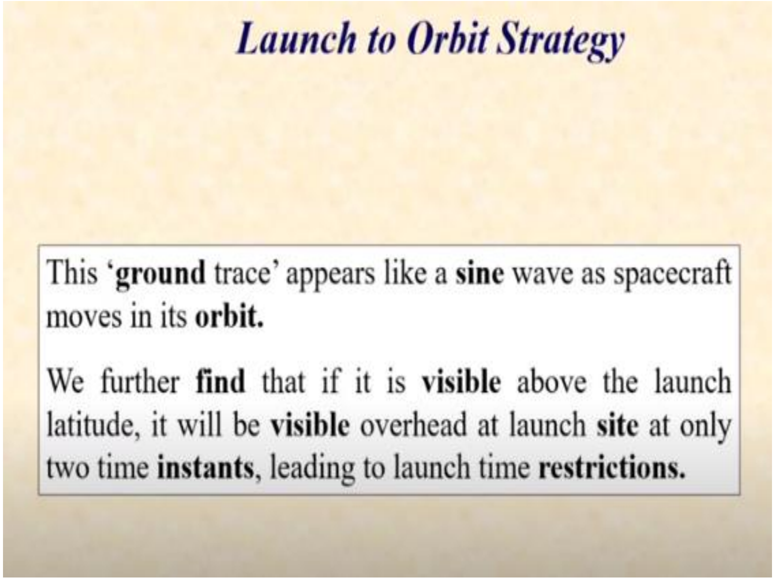

Typically, this ground trace appears like a sine wave as the spacecraft moves in its orbit. We further find that if it is visible about the launch point which has a specific latitude then it will be visible overhead at the launch point only at two-time instants in 24 hours leading to launch time restrictions or the concept of launch window.

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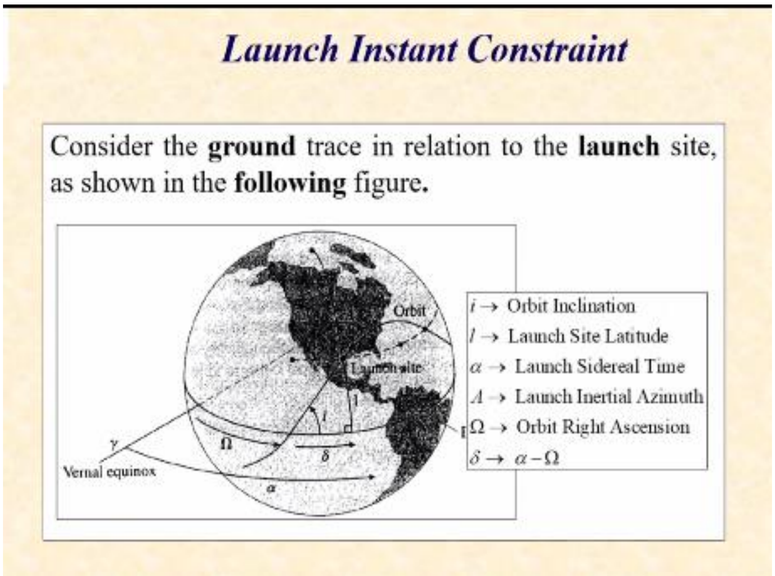

This launch window or the launch instant constraint can be visualized through a simple schematic as shown below. So here we have the spherical earth representation and we have a launch site determined by a latitude, the launch latitude, given by this one and a launch longitude with respect to the vernal equinox in terms of the right ascension and the angle δ.

The spacecraft also has an inclination with respect to the equatorial plane of earth. And with this we define the launch site. We can use simple trigonometric relations to show that the following parameters will directly decide the two-time instants at which the spacecraft will be overhead at this launch point or the launch latitude. Let us look at this relation.

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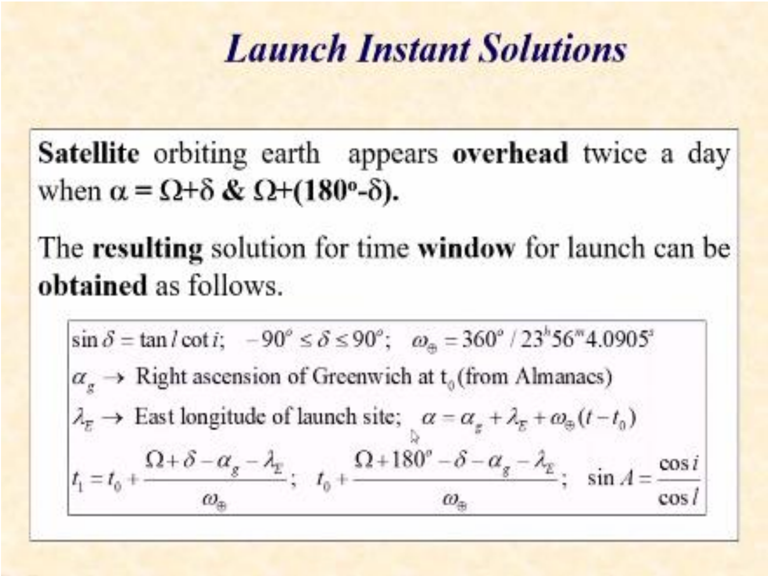

It is found that satellite orbiting earth appears overhead twice a day when α, the angle as shown in the figure previously, is either $\omega + \delta$ or it is $\omega + 180 - \delta$. That is, either it is on one side or it is on the other side. This is because both, earth is revolving around its axis and the spacecraft is revolving around this earth.

So that there will be two-time instances where there will be a coincidence of motion in such a manner that the spacecraft would be overhead at the launch point. The resulting solution for time window for launch can be obtained as follows. Here, we have taken the course to what is commonly termed as spherical trigonometry, where we use spherical triangles to establish the triangle relations.

And from that, it is possible to show that these two-time instants will be related to the parameters of the launch site as well as the rotation of earth.

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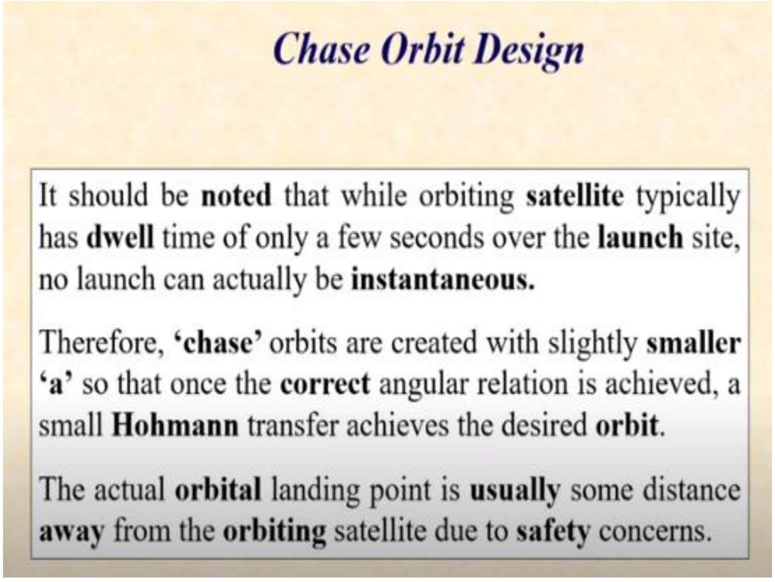

So how does one design this orbit or the launch trajectory? In this case, it is not an orbit but it is essentially the launch trajectory, which directly is decided by the requirement of creating a chase orbit for a specific destination. However, you must note that the orbiting satellite typically has a dwell time of only a few seconds over the launch site. Please note that the spacecraft is continuously moving in the orbit.

So, its visibility from the launch point will be only for a few seconds before it moves away due to the angular separation. So obviously, you cannot actually capture that moment because you cannot really have impulsive launches. While impulsive launches have been seen earlier, which reduce the gravity loss, they are highly costly in terms of the drag loss and also the other technological issues would preclude launching instantaneously.

It obviously means that you have to have a fast transfer on a trajectory which will generate a very large velocity in lower atmosphere in order to reach the destination with not very large gap. In this context, there are certain technologies which are used which permit design of such orbits which are capable of creating larger velocities in relation to the velocity of the destination point so that the desired objective of the mission can be achieved.

Of course, the launch mechanism or the launch trajectory generally leave the spacecraft some distance away from the final destination point primarily due to safety concerns.

And the final step is completed by performing small magnitude orbital maneuvers which then complete the mission as desired.

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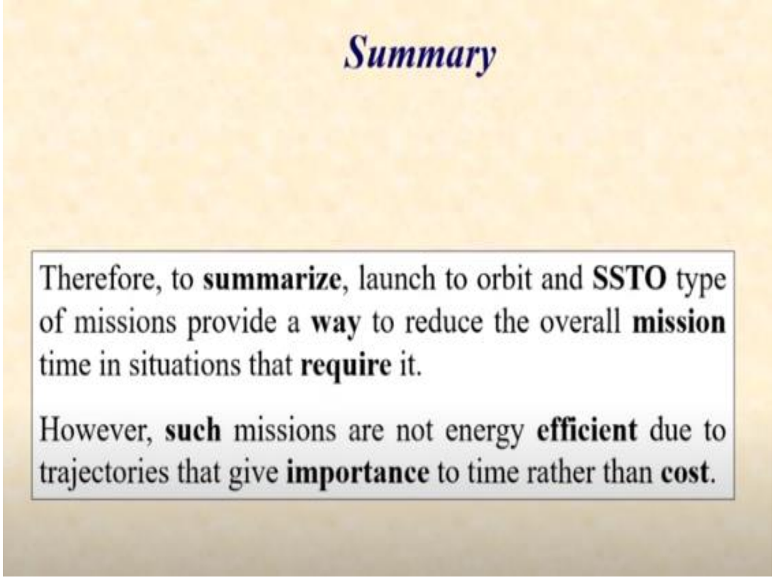

Therefore, to summarize, launch to orbit and SSTO type of missions provide a way to reduce the overall mission time in situations that require it. However, such missions are not energy efficient due to trajectories that give importance to time rather than cost. There is another drawback attached to such missions is that in case your payload fractions are high, the launch mass or the liftoff mass of the rocket is going to be large and it is going to be a huge rocket.

I may mention here that Delta Heavy and Falcon 9 Heavy, the heavy lift launchers are aiming to come closer to this concept. But in the process, they are becoming a bit massive because of the payload fractions and the requirement to reach the destination in shorter time.

Hi, in this lecture, we have seen some of the basic ideas related to launch to orbit, fast transfers, single-stage-to-orbit concepts and have established the need for creating an appropriate launch window that enables such fast transfers a reasonably energy efficient mode. With this we have concluded our discussion on the launch systems vehicles and some aspects of launch operations.

And now we will be looking at an important aspect of launch system technology that is connected to the reusable launch vehicles termed the reentry missions which also are an important element of reusable technology and find a place in any discussion on launch and launcher systems. So, bye, see you in the next lecture and thank you.