Introduction to Aircraft Design
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology-Bombay

Lecture - 83
High Altitude Long Endurance (HALE) Aircraft

Hello, everyone. Today we will look at a special class of aircraft which are becoming very popular nowadays.

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And you can see on the screen there are six of these modern versions of these aircraft. They belong to a family called as high altitude long endurance or HALE aircraft. Most of these are unmanned aerial vehicles.

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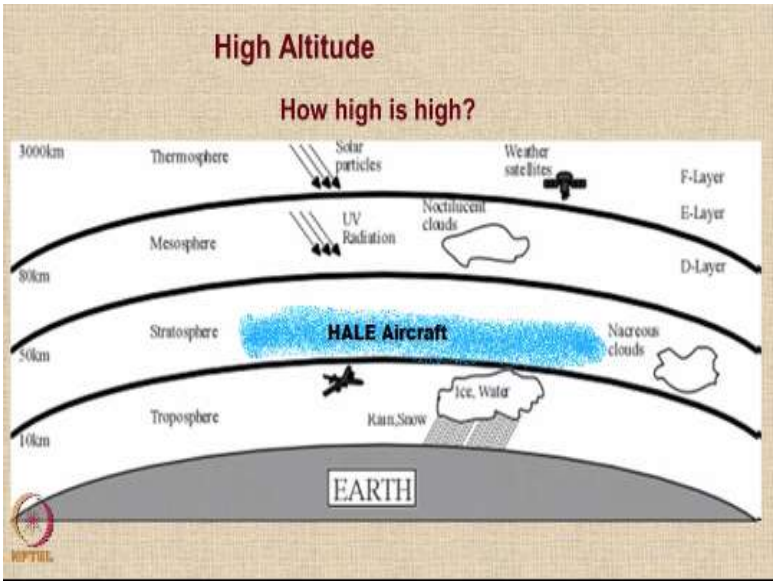

Let us start by understanding what is meant by high altitude. How high is high? So here is the sketch of the atmosphere just above our earth and the HALE aircraft or HALE UAVs they normally operate in the stratosphere, okay.

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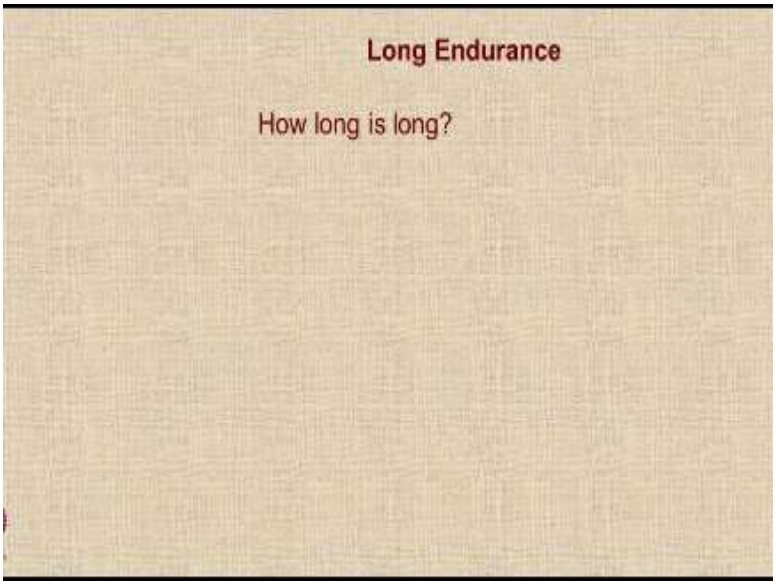

Now let us look at long endurance. What is meant by long endurance? How long is long in aviation?

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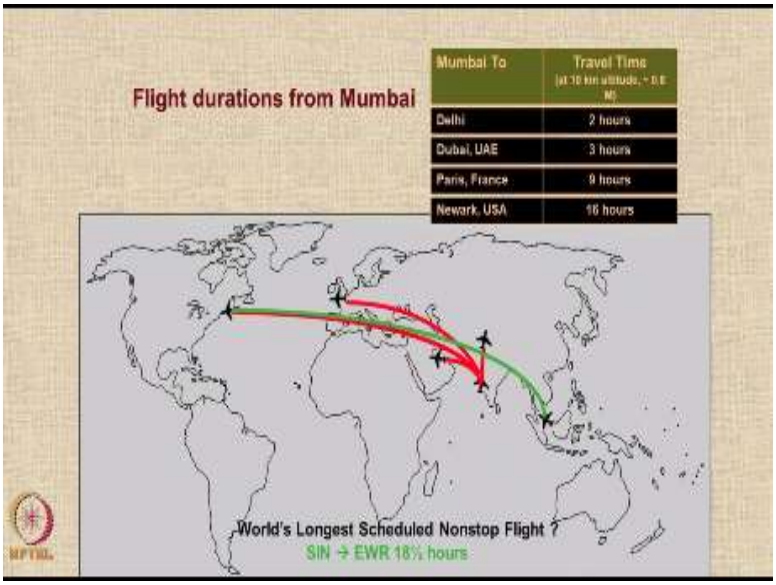

So let us look at some flights from Mumbai, okay. So here is Mumbai on the map of the world. And I have just chosen a few flights based on the travel time from Mumbai. We are assuming that we are cruising at around 10 kilometers altitude and we are flying at approximately 0.8 Mach number. So two hours from Mumbai is Delhi. Three hours from Mumbai is Dubai in UAE.

Around nine hours from Mumbai is Paris in France. And the longest flight operated by Air India currently is from Mumbai to Newark, which is a 16 hour nonstop flight. But do you know which is world's longest scheduled nonstop flight of a passenger aircraft? This record keeps changing. The current record is held by Singapore Airlines in a flight that is from Singapore to New York, as shown in the green sketch, which lasts around 18 and a half hours.

But depending on the wind conditions, it may also become as long as 22 hours in some cases. So that is really long.

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But then when we look at high altitude long endurance aircraft, the endurance records are really very challenging. For example, the Virgin Atlantic global flyer designed by Burt Rutan it holds the record for nonstop unrefueled circumnavigation fastest, okay. It is 67 hours and 1 minute. Now this record was recently broken by a Gulfstream challenger aircraft I think which went this distance in much lower time.

But there it went for refueling. This one is unrefueled circumnavigation. So that is really a long 67 hours and 1 minute nonstop flight across the world.

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So let us look at the key mission features of HALE UAVs. And the best example of a HALE UAV that we can think of is the Global Hawk that you see on your screen. HALE UAVs flies above problems. What do I mean by this? They fly above the weather. They

fly above the interception altitudes. They fly above the commercial flight altitude of around 10 to 12 kilometers.

So they have an unrestricted flying regime available to them. They carry payloads which can cover a large area of the Earth at a time. They may use search and rescue radar or and they also use satellite communication for carrying out their tasks.

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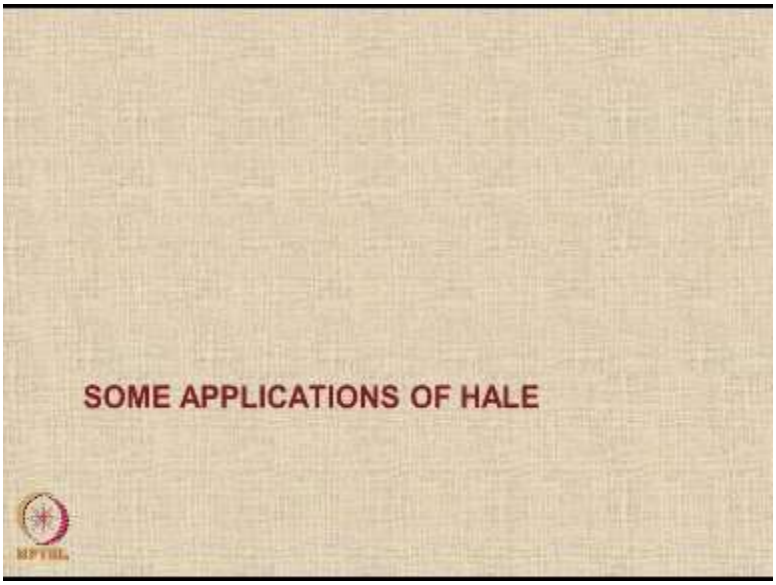

Let us look at some applications of these aircraft.

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One of the most common application of a HALE UAV is aerial surveillance. This surveillance could be for a military purpose or it could also be for nonmilitary purposes.

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Then we use them for some experiments on Earth Sciences. For example, here we see a HALE UAV, the same Global Hawk which is used by the defense services. It is used by the Aurora Atmospheric Sciences Research Institute to fly over hurricanes and to gather the data.

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Similarly, very novel configurations are being proposed these days to allow HALE UAVs or HALE aircraft to be pseudo satellites. These are low altitude satellites, which maintain the station and hence are able to hover or stay at a place for a long time.

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Let us look at the Legacy Hale Aircraft the Lockheed U-2. In true sense, this was the first high altitude long endurance aircraft which was operated by US. **(Video Starts: 05:40) (Video Ends: 08:44).**

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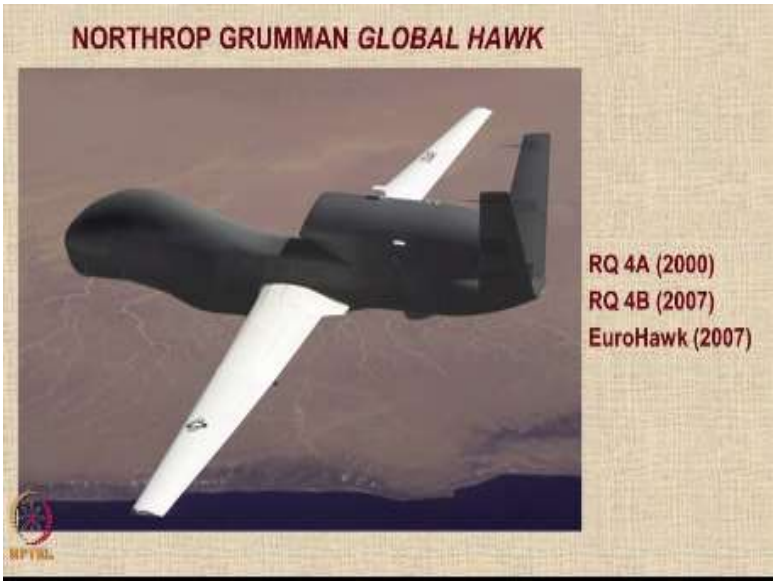

But the big daddy and the most famous aircraft in this category is the Northrop Grumman Global Hawk. This project was launched in 1998. And in 2000, the RQ 4A was launched, followed by RQ 4B in 2007, followed by the EuroHawk in the same year. **(Video Starts: 09:07) (Video Ends: 11:44)**.

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Here are the specifications of RQ-4B Global Hawk aircraft. Notice that it has an endurance of 32 hours and this has also been further extended, range of around 16,000 kilometers. It can fly up to 60,000 feet, which is far above the operating altitude of other aircraft. And it flies at a leisurely speed of Mach 0.6. It is an unmanned aircraft. So therefore, it uses remote pilots.

The duration of the flight is so large that you cannot expect one pilot to continuously monitor. So therefore you look at three pilots. It has a very large wingspan of 40 meters and a length of 15 meters. It is powered by a Rolls Royce RR-100 turbofan engine. The gross takeoff weight is around 15,000 kilograms of which around 9% is the payload 45% is the fuel weight and 46% is the empty weight. And the wing and the tail airfoils are LRN 1015.

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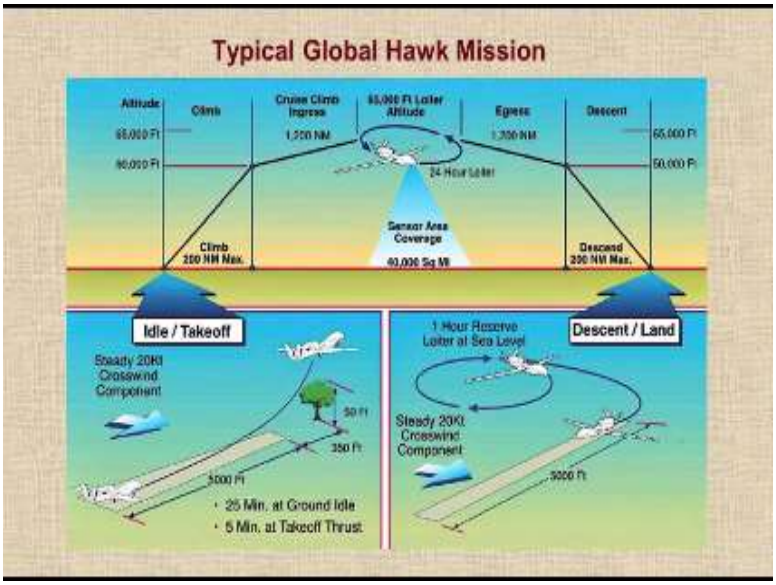

Here is a typical Global Hawk mission profile. So it takes off and then climbs slowly to a height of 50,000 feet and then travels around 1200 nautical miles, which is approximately 2500 kilometers. And then it can loiter for 24 hours at a particular location. Then it can travel back the same distance of around 2500 kilometers and then slowly come and descend.

It can operate from a standard airfield which has 5000 feet of available runway length both for takeoff and landing. And apart from the 12, 24 hour endurance it has it can also while coming in loiter for about an hour reserve fuel. And the aircraft can take off and land in a steady crosswind of up to 20 knots.

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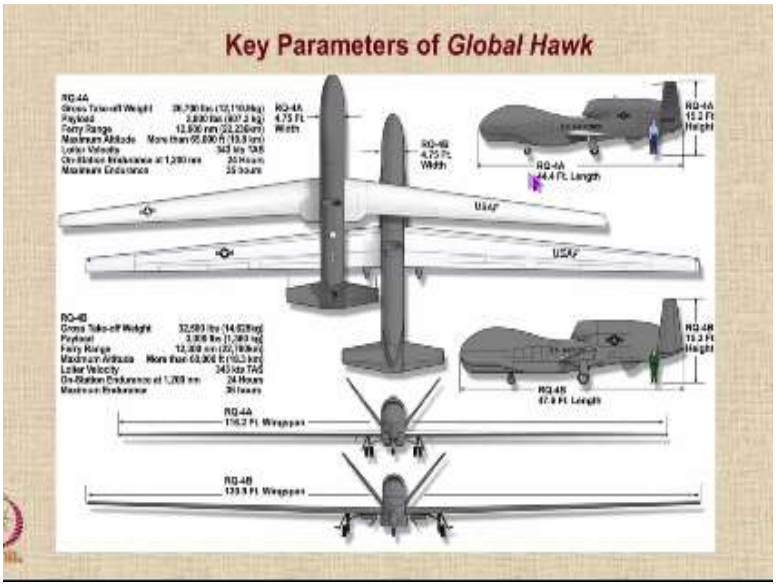

Let us look at some key parameters of Global Hawk. As you can see, here there is a picture that shows a typical human being and to show in the silhouette you can get an idea about how high it is, how large is the size of it. You can notice there are certain peculiar features very slender and long wings and you have this very unique kind of a shape for the fuselage and the engine, the single engine is mounted above and behind on the backside and you also see that the tail are having this V or butterfly tail configuration.

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So as I mentioned, this aircraft has got very high aspect ratio unswept wings and the reason for that is very simple that if you have a high aspect ratio, then your induced drag term reduces and induced drag is the largest component of drag in a cruising flight. So therefore in a low speed cruising flight, it flies only at Mach point 6.

This term is going to be the larger of the two terms and by large aspect ratio we not only get better aerodynamic efficiency in terms of the Oswald efficiency e, but also we get a lower value of induced drag.

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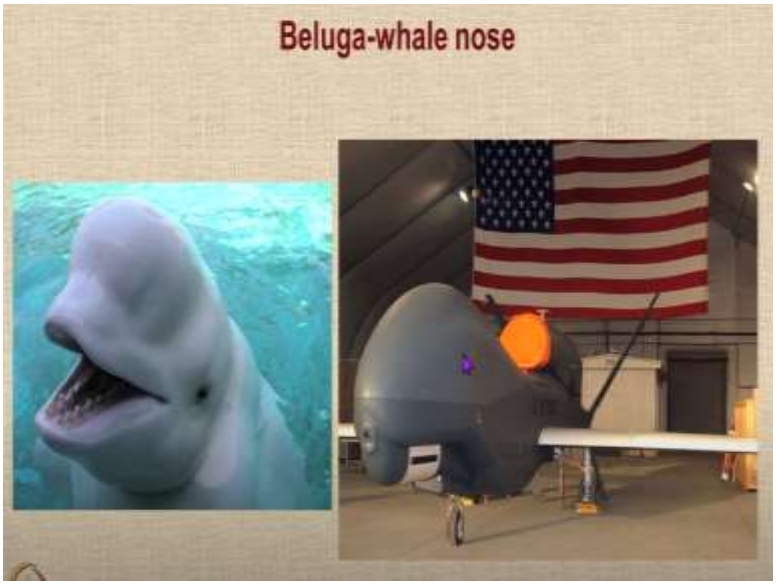

The second interesting feature is its unique nose shape. This particular nose shape is inspired by the Beluga whale. And this particular shape is actually a covering for its radar dish which is inside. And it gives them smooth aerodynamic shape. And behind that is the intake of the engine.

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Here is a look inside. So as I mentioned to you, there is this dish radar which rotates 360 degrees. So therefore, we need to have a covering over it and that is why we had this Beluga nose whale type Beluga whale type shape. Notice how the engine is mounted just above the fuselage with a specially designed intake. So the air is coming in from the top of the fuselage and getting inside the engine.

And then you have this V type butterfly tail. And you can see the structure details inside.

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Although it may be an unmanned aircraft, it needs a large amount of support on the ground to be operated. Here is a photograph of the Global Hawk operation center. Now what are so many people doing? Not all of them are flying the aircraft. In fact, I can tell you that most of them the ones especially which are having this image on their screen, are the ones who are actually monitoring the payload.

So as I mentioned, there might be only one person or maybe two who are piloting the aircraft. But there are a large number of people on the ground who are monitoring the sensors and the payloads and hence making it fly more efficiently.

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Let us take a example of the benefits of unmanned aircraft over manned aircraft for surveillance purposes. Here is an example in Africa, where there is a place called Darfur, which is the conflict zone and let us say there is a requirement to do surveillance. So from Malta an aircraft can take off and travel 1900 nautical miles and come over this area and then do aerial surveillance.

If we do it using an aircraft like U-2 then 2% of the Darfur will be mapped in every mission, because the time on station is around three hours. So you can imagine there has to be 50 flights required to map the whole country, the whole location. On the other hand, if you operate using a Global Hawk, then with one mission, you can actually cover more than 58% of the area because you have a 20 hour time over the station.

So therefore in couple of flights, you can actually cover the entire surveillance area. So compared to 3 hours, 20 hours compared to 2%, 58% that is the advantage of unmanned aircraft over manned aircraft for aerial surveillance.

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To increase the range of the aircraft further, it is possible to go for air to air refueling. So here is an interesting video that shows. **(Video Starts: 18:21) (Video Ends: 19:23)**.

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Moving on let us look at a few modern HALE aircraft designs. We have already seen Global Hawk. It was launched in 1998. One year later, NASA came up with a project called as Helios in 1999. And they contracted a company called AeroVironment to build this very unique aircraft, which is nothing but distributed propulsion, distributed payload and a flying wing configuration with a very high slenderness ratio.

Around nine years later the Zephyr project was launched by kinetic in 2008. And in 2013, it was taken over by Airbus. So now it is called as Airbus Zephyr. This is also a very slender, unique wing with distributed payload. Then AeroVironment launched a project called Global Observer in the two years later in 2010. This is also a very unique aircraft and again, you see distributed propulsion.

In 2012, Boeing launched a program called Phantom Eye, which is also a high altitude long endurance UAV. And recently, Aurora, with the help of Boeing has launched the project called Odysseus, in which the wing can actually bend at these locations so that the solar panels can be made to align with the in the optimal angle to get maximum power from the sun throughout the day. So let us have a quick look at each of these projects.

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Comparison of 5 HALE UAVs

	NASA *Helios*	Airbus *Zephyr*	AeroVironment *Global Observer*	Boeing *Phantom Eye*	Aurora *Odysseus*
First Flight	Sep 8, 1999	Aug 24 2008	Aug 5, 2010	June 1, 2012	Not Yet Flown
No. built	1	4	2	1	2
Wing span (m)	75	22.50	53	46	74.1
Payload (kg)	329	2.5	180	205	25
Endurance	~24 hrs	14 days	5-7 days	4 days	~24 hrs
Altitude (km)	20	21.5	17-20	20	20
Engine	Solar Powered Electric engines	Solar powered Synchronous motors	Liquid H_2 IC engine	Liquid H_2 IC engine	Solar powered, GaAs cells
Battery	Li	Li-Na	NIL	NIL	Li-Po

So let us first compare these 5 UAVs. The NASA Helios as I said, only one aircraft was built. And this aircraft uses lithium battery, and it has solar powered electrical engines, which fly at 20 kilometers for about a day. And the payload they can carry is around 329 or the payload they could carry is around 329 kg. This one aircraft which was built has been lost in an accident.

The Airbus Zephyr, four of them have been built. This one has a much smaller wingspan, much smaller payload. And also but the endurance is very high. It is 14 days. In fact, it held a record at one time for the highest endurance of a UAV. It flies at around the same altitude with solar powered solar panels all over with synchronous motors, and it has lithium sodium batteries.

The AeroVironment Global Observer was launched in 2010. The first flight was in 2010. Two of them have been built. It has a 53 meter wingspan and can carry 180 kgs for about 5 to 7 days. And it operates in the stratospheric altitudes. The first flight was held with battery powered engines, but now the propulsion system is converted to liquid hydrogen based IC engine and there is no battery onboard.

The Boeing Phantom Eye launched two years later in 2012 the first flight, only one has been built and now it is in a museum. It has a wingspan of 46 meters. It can carry around 200 kg payload for four days. Again, 20 kilometers again liquid helium IC engines without any battery. And finally, the Aurora Odysseus, which was supposed to fly in April 2019. But there has been an indefinite delay in its flight.

And we are still awaiting its first flight. Two of them have been built with a wingspan of 74 meters and it can carry 25 kilograms of payload for about one full day at 20 kilometer altitude. This is powered by gallium arsenide solar cells and uses lithium polymer battery.

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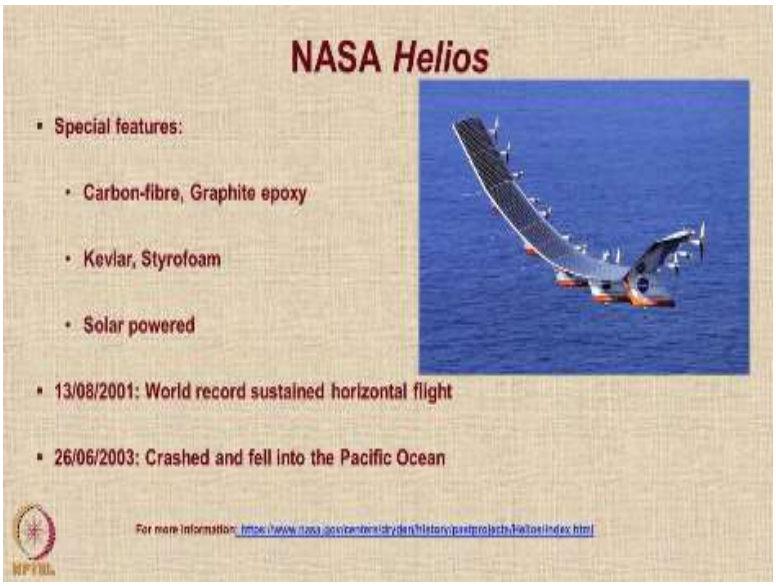

Let us look at all of these UAVs one by one. This is a NASA Helios. Let us watch a short video about this aircraft. **(Video Starts: 23:24) (Video Ends: 27:22)**. There are some special features of NASA Helios. It is a carbon fiber, graphite epoxy based construction but it also has Kevlar and Styrofoam. It is very unique structure. It is solar powered. As you can see there are so many solar cells mounted on it.

In August 2001, it had a world record for sustained horizontal flight. But in 2003 because of gusts which it encountered during the flight, which were beyond its design condition, its wing flexed a lot and there was a complete structural failure and it fell in the Pacific Ocean. There is a very interesting and detailed accident report available online for this particular aircraft, which you can search and study.

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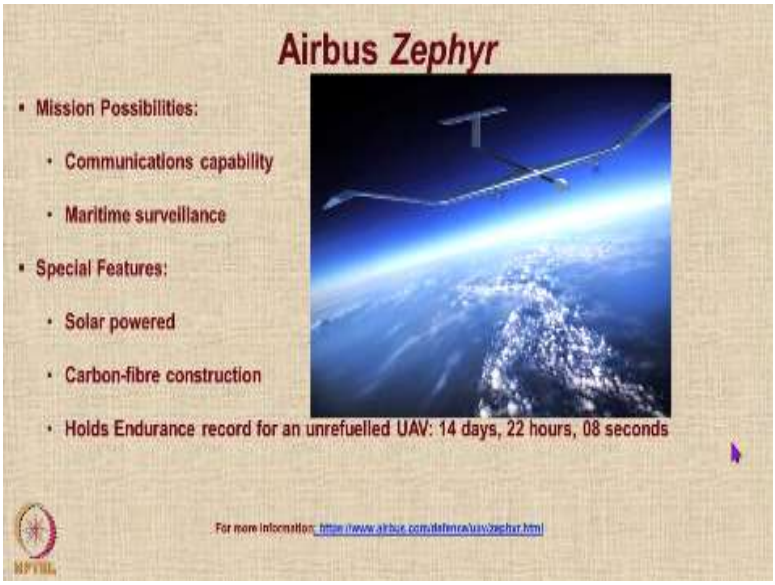

The Airbus Zephyr as I mentioned started with a as a program from Kinetic in 2008 and then 2013 taken over by Airbus. The main purpose of this particular aircraft is to act as a communications platform. And also it can be used for maritime surveillance. Very slender, very lightweight aircraft, which is solar powered with carbon-fiber construction. And it holds the record for endurance.

It flew for 14 days, 22 hours and 8 seconds nonstop. For further information on this unique aircraft you can have a look at the website below. Let us have a look at the video of this very unique aircraft. **(Video Starts: 28:56) (Video Ends: 30:13)**.

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Next we move on to the AeroVironment Global Observer. AeroVironment is a company which is very well known for bringing out very unique UAVs such as the

Black Widow. This aircraft is essentially meant to be a high altitude communications relay. It has a distributed payload system as you can see. There are this eight engines mounted on the wing.

And also it can be used for disaster response maritime surveillance. Unfortunately, it crashed in April 2011. And after that one year later, the contract was cancelled. Let us have a look at this aircraft. **(Video Starts: 30:50) (Video Ends: 31:59).**

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The Boeing aircraft company also has come up with a product called Phantom Eye. This aircraft is also meant to be a communications relay with provision for continuous long range communications. It was launched in 2012 or first flew in 2012. But disassembled in 2016, and now it is displayed in the Air Force flight testing museum. Let us have a look at a video of this unique aircraft. **(Video Starts: 32:26) (Video Ends: 34:56)**.

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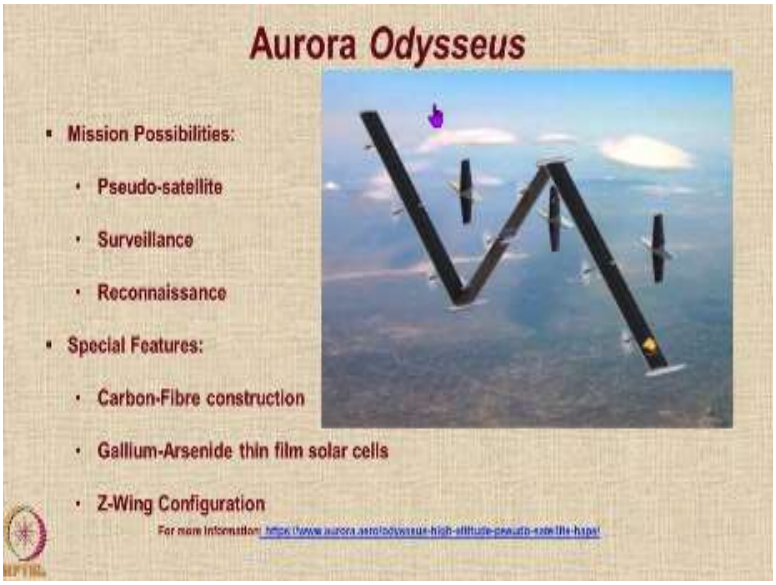

And finally, let us look at the Aurora Odysseus, which has been built with the support of Boeing again. This aircraft is supposed to be a pseudo-satellite. It is a low altitude satellite. You can see there are three fuselages with distributed propulsion. And also for surveillance obviously. Anything that can fly at a high altitude for long endurance automatically becomes a candidate for surveillance and reconnaissance.

There are a few special features. It is a carbon-fiber construction. And the solar cells are gallium arsenide, very thin film, very lightweight solar cells. The unique thing about this aircraft is its ability to convert its configuration from a conventional aircraft to a Z-Wing configuration as shown here. Let us have a look at the video of this unique aircraft. **(Video Starts: 35:48) (Video Ends: 38:36)**.

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In the recent past, there have been emergence of, I would say reemergence of lighter than air systems or airships for high altitude long endurance aerial platforms or HALEAPs. One very interesting project was the Lockheed Martin HALE-D, as you can see in the photograph here, which flew in 2008 for the first time, but there was an accident and so it was, you know, it just came down and after that it has not yet been taken up.

In the recent past there are studies from Thales Alenia Space for an airship called as Stratobus. So these platforms seem to have a promise for long endurance high altitude applications. And there are several challenges, the technological challenges are there and airships are making a very strong comeback. So watch this space for more information.

This is something that is definitely going to be the future of high altitude long endurance aircraft, very promising, but still not realized.

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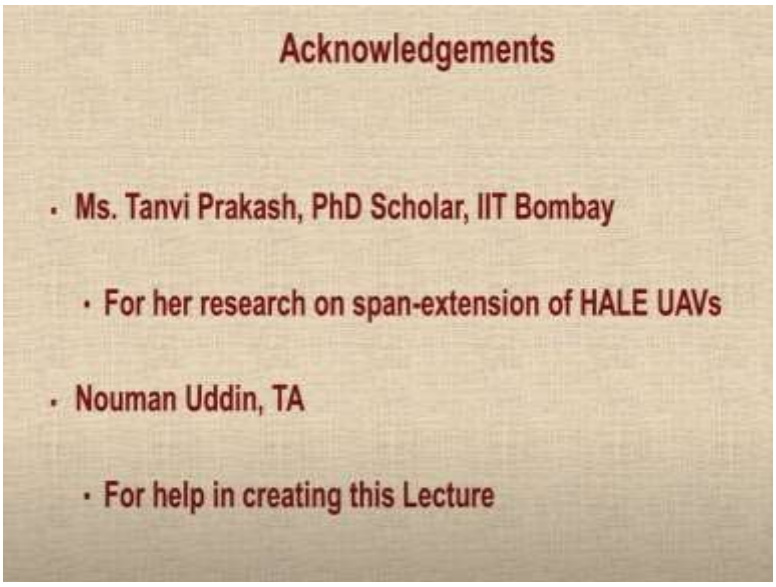

Before I close, I would like to acknowledge the contribution of Ms. Tanvi Prakash, PhD scholar at IIT Bombay, for her research on the span extension of high altitude long endurance UAVs. And it is with her help I have got the information and the data regarding so many UAVs, especially the Global Hawk, which is her baseline UAV. And my teaching assistant Nouman Uddin for help in creating this lecture. Thank you so much.