Introduction to Flight
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Lecture 11.1 - Range

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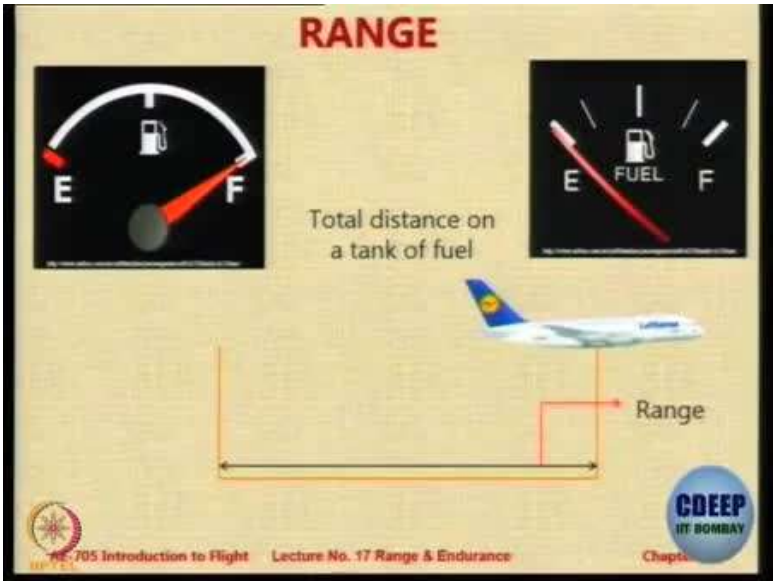

Professor: What are the three reasons, you just tell one reason, okay?

Student: There may be a leak in the….

Professor: That is never a reason. If there is a leak then nothing will stay, the fuel also will go. Reserve fuel will not remain, reserve fuel if there is a leak. So you never fly if there is a leak. Okay so you either have to keep flying at a particular height which is called as hold, because the runway is not free for some time, or you may have to divert to an airport nearby because the runway is not accessible.

So reserve fuel one of the reasons for reserve fuel is diversion and holding. So in the next lecture on take-off and landing we will cover this in slightly more detail. That is one reason, any other reason? Yes.

Student: Indicator might be wrong.

Professor: So therefore?

Student: So we might be thinking…

Professor: So you have a very low view about aircraft maintenance, engineers and pilots. Somebody thinks that the fuel can leak, somebody thinks that the instruments are not working. If this is the case then the aircraft will not be clear to operate. And reserve fuel will not help because then you do not know how much fuel you have. So I am sorry to say that your opinion about us is very bad. We are not so, in fact we are far more systematic than this. Yes, any other reason?

Student: It may happen that the weather will be will drastically change and the drag will increase, that is why we will need more fuel.

Professor: How does drag increase because of the weather?

Student: Because weather conditions….

Professor: So does the drag increase? Okay, fine. So, if the wind increases, now we will see today if you have tail wind actually it is beneficial, it is only if there is a head wind then the range will be less. So I understand what you can say is that on route weather conditions may become bad so you may have to divert. I was travelling from once Calcutta to Mumbai and the pilot said that we are diverting because there is heavy weather over Ranchi. So they took a circuitous path not the path which is normally taken. So that added 15-20 minutes to the flight so we need fuel for that.

So that is right. One reason is that you need fuel for weather diversions, you need fuel for at the end of the journey you may have to hold or divert. Any other reason? There is one more reason, other than this? There could be navigation errors that means you thing you are going on that route which the ATC has given you but actually when you come to know you are slightly off, so you come back. This is the part of, so en-route weather and navigation and holding and diversion. Any other reason? There is one more reason.

So those of you who have a vehicle with you, are you able to use the entire fuel in the fuel tank or there is some fuel which is not available. So there is some fuel which is always trapped in the pipelines. You will be surprised to know that this fuel can be almost half percent of the fuel supply. So the power plant is mounted on the wings and the fuel tanks are also on the wings. There is a piping in some cases the fuel tank is in the wing but the power plants are on the back. That is the pipeline which carries the fuel.

And we do not keep flying or we do not plan to fly till the pipeline fuel also is consumed because you want to maintain a continuous supply of fuel in the engines. So there is some amount of fuel which is kept, so it is unavailable fuel it is there but it is not useful to you for your consumption because it is blocked in the pipelines. So these are the three main reasons due of which we do not fly like this up to empty, okay so total distance on a given tank of fuel is defined as range.

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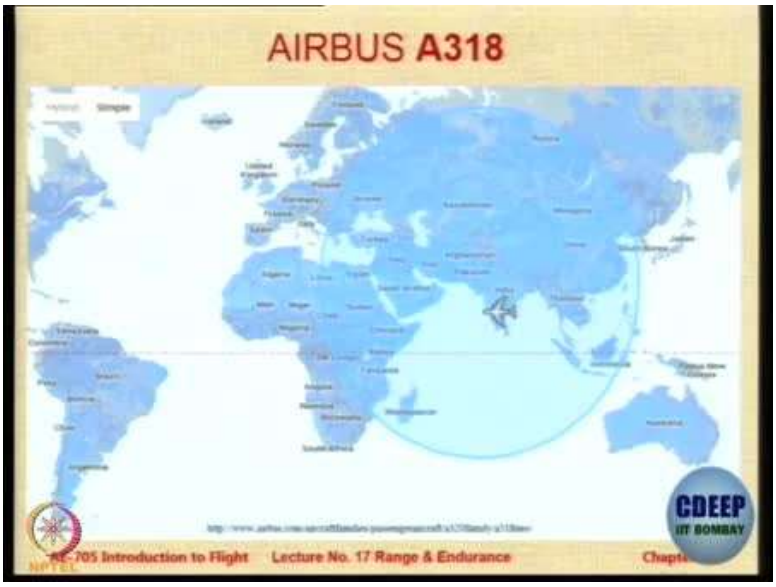

So let us look at the range some typical aircraft with which we are familiar and this particular series of pictures tell you the range of some standard aircraft from Mumbai. So if you travel on Airbus A318 you can cover literally up to Libya and Chad on this side and you can meet Kim Jong Ill if you are interested and go up to Korea. So this is Airbus 318.

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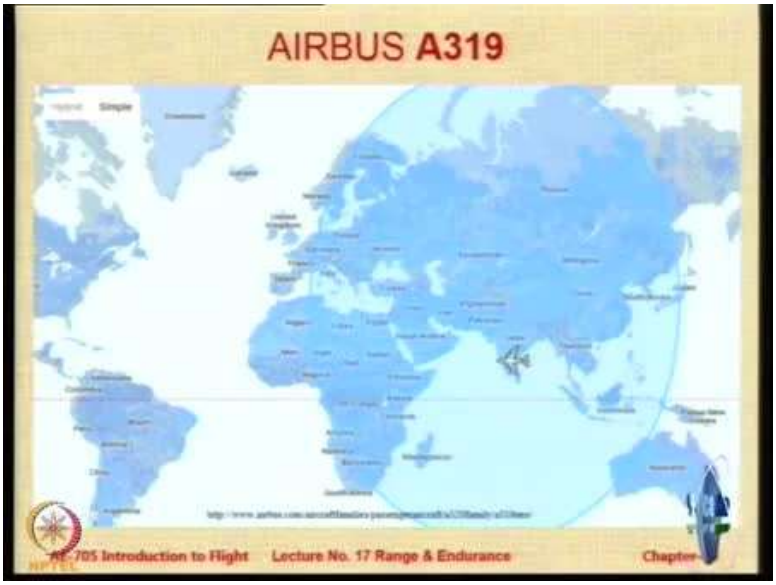

319 goes slightly further by less number of passengers. So it can cover, but you cannot go to Norway.

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320 is less than 321 because they are designed for a different market. I will show you the range and capacity very soon.

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This is 321 you can see it starts touching Australia now.

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And this is Airbus A380 this information was given by the Airbus people when they came and gave a talk, so I borrowed the slide from them. So you can see that almost every part of Africa, Europe, Asia, Australia, New Zealand all that is covered, including North America. What is not covered is Chile, Paraguay and South Africa that is out of range and also Mexico. Yes. Any other? So basically what it means is that the area on the right of this line and the left of this line is not covered. So Sau Paulo is covered, Rio is covered because that comes in Brazil which comes somewhere here.

So it is not that they have designed it like this, it is just that this aircraft with 555 passengers can travel around 15,100 kilometres non-stop. So do you think that it is a very big range? 15,100 kilometres non-stop, do you think it is a very big range? Now let me show you some numbers for really big ranges.

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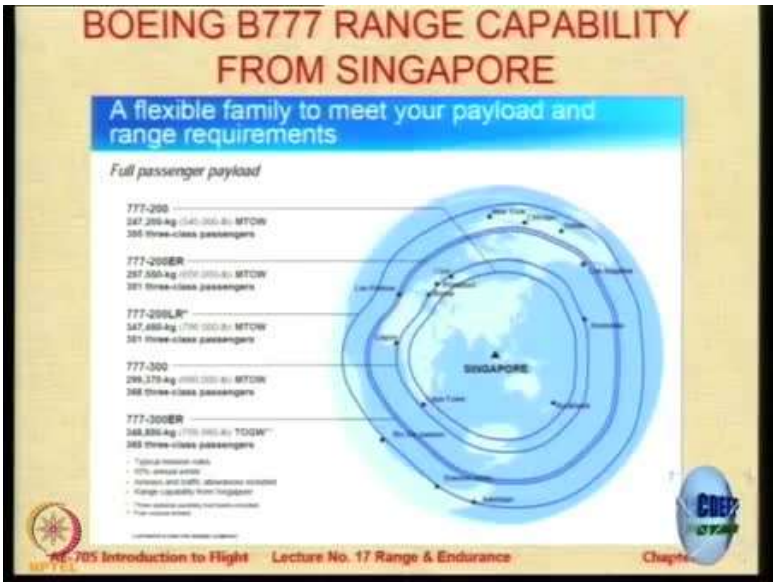

So since I spent a year in Singapore there I collected some data regarding Boeing 777 from Singapore where it goes. So you can see that Boeing 777-200 from Singapore can cover 9,700 kilometres okay then we have 300 which can cover 11,400. Then, we have 200 extended range or ER that is 14,320 and then we have 777 300 ER which is 300 with extended range that is 147 of course you cannot carry the same number of passengers in all these routes.

There is a diagram called as payload diagram which tells you the trade-off, and then you have 777 200 Long Range more than extended range which can cover 17,600 kilometres but even this is not the longest.

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Now for every aircraft in the Airbus table there is normally a competition in the Boeing's table, so they always fight neck to neck and they say if you want this why not take this. If you have that why not take this. So they keep on making such charts. This chart is made by Air France where they tried to compare Airbus with Boeing, so once the PPT is uploaded you can see this at leisure and get an idea about this.

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Okay let us look at the world's longest non-stop flight. This was done by Singapore Airlines, as you can see the date is mentioned there, the first landing of this aircraft at Newark airport in New York EWR. It was in June 2004 and you can see that the aircraft is been welcomed by water cannon from both sides. This is a typical thing they do in aviation. Whenever there is a

new activity, a new aircraft comes they have this system of welcoming the aircraft by on both sides they fire a water cannon okay.

So this is 16600 kilometres more than 18.5 hours non-stop and look at the phenomenal amount of fuel consumed per flight. So it was launched in great fanfare by Singapore Airlines in 2004. At that time it was the longest flight, not no longer. There are longer flights than this. But it held the record for good amount of years approximately 9 years, in 2013 this flight was, the aircraft that they used was Airbus A340-500 which is also considered to be one of the world's longest aircraft but they discontinued it.

Do you have any idea why they discontinued this flight? No idea, can you guess? If an airline launches lot of fanfare of flight which is a world record they would like to keep it, is not it? Because that gives them some distinction. Yeah, so you can guess what is the reason?

Student: So number of passengers could not be sufficient to meet the economy of margin for the….

Professor: Yeah, that is the reason but there is a slight twist to that. So when they launched this flight they were flying with 181 passengers. But then they realised that this is a very exclusive thing so they made it all business class. And about 101 or 102 seats it was successful for a long time but then it became difficult to sustain. To get 100 business class passengers for a flight of this distance they had to do lot of expenditure in maintaining that, finally they said give up, we cannot do it.

But interestingly, before that also the record was also by another Singapore Airlines aircraft that was from Singapore to Los Angeles. And that was 14.5 odd kilometres around 16 hours but the world record for the longest flight non-stop is held by Air India.

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Okay and that is Delhi San Francisco flight which took place in 2016. Now if you notice there are dates mentioned there. And if you also notice on 13th October last year 2016, they flew a polar route that means they flew over the poles which normally we do not fly. You can notice that the distance is only 3959 as compared to 15142. Also notice that the time taken is more for the polar route, 16 hours and 44 minutes as compared to the 14 hours 30 minutes for the Pacific route.

So the flight went around the world literally, it went from Delhi to San Francisco and then back from San Francisco to Delhi. So now the distance on the earth is the same or is it not the same? Why does it take more time more distance to go this way than that way? And why does it take more time on a shorter route? Okay so look at the numbers.

This is the aircraft Boeing 777 200 ER which was used okay, so flying westward you get what is called as the headwind that means wind coming from the front. Is that desirable? No, it is not desirable for range. It gives you better relative velocity but it gives you poor ground speed. Theoretically speaking, if the air speed is equal to the headwind the ground speed is zero, the aircraft is stationary in the air. So whenever you look at some aircraft flying and if you are travelling on a car at a particular angle it seems stationary, is not sometimes?

Sometimes you feel it is just right there and you keep on travelling on the route and you think it is not or you see it travelling very slowly okay so that is the thing. So ground speed basically so when you fly eastward then you encounter the jet streams behind you. So they are literally pushing you and pushing you not at a slow speed, pushing you at 138 kilometres per hour. That

is the speed at which the air in atmosphere travels in the jet streams and this is what Google loomed us.

They want to take their balloons in the jet stream and then free of cost they are travelling some distance and then they come down. They are riding the wind literally, so similarly the aircraft is riding the wind and you can see the ground speed is 936 kilometres per hour that is why there is 2 hour reduction in flight time if you fly eastwards okay. So that is the difference. And these 2 hours eastwards results in 13 tons savings in fuel.

You can make out how much is the benefit of travelling. Time is saved for the passengers so you take off at 4 a.m. and land at 6.30 a.m. on the same day because 12 hours is the time difference it is like a Mumbai-Delhi Flight typically you take off at 4 a.m. and land at 6.30 a.m. on the same day. And this record is also going to be broken soon now, I do not have any confirmation but there was a proposal that Singapore Airlines again that ROK Airline they want to now fly 19 hours non-stop from Singapore to New York. But as per the available information this flight has not yet taken place, so I do not know.

So it is up to you now to confirm this. So this is a Moodle question, people are very silent on Moodle, nobody is taking part of Moodle except for giving their comments on the examination type after the last date is over. People are now very quiet on Moodle, so please use the Moodle page, tell me if there is a record broken. Find out and tell me if really there is any other flight which is more than this distance and more than this time.

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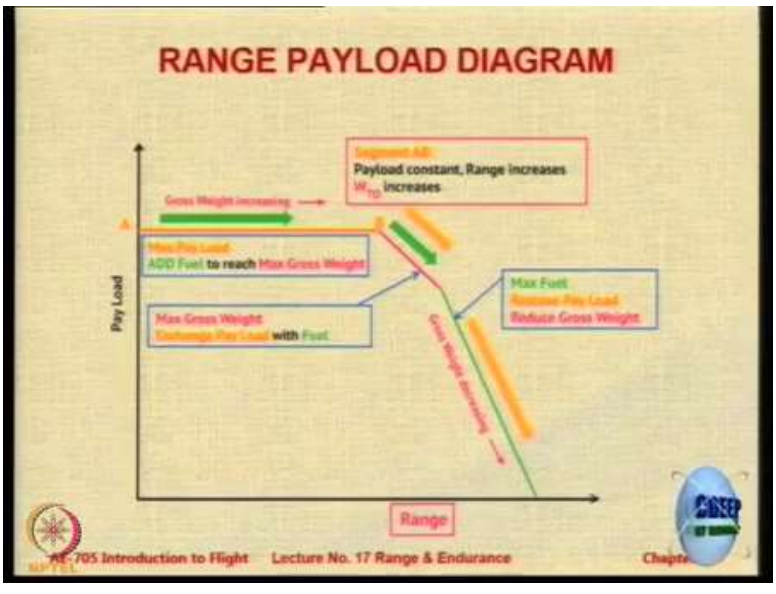

So this is the range payload diagram which actually tells you how far an aircraft can travel with the given amount of payload. The payload of an aircraft consists of passengers, their baggage and cargo okay. So this diagram has got very interesting feature, there is one line which is line A to B on the top you can see there is a line this A to B. This line is called as the Maximum Payload Line. This line represents the distance that you can travel with maximum amount of payload with different amount of fuel.

So if you do not carry any fuel you only have only reserve fuel and zero mission fuel then you are at point number A. That means that the aircraft is fully loaded there is no more capacity of carrying payload. Remember one thing the payload of the aircraft can be limited by either weight or by volume or both, because payload is kept in a particular area the payload carrying bay and that area has got a structural limitation.

If you load that area more than a particular mass it can lead to structural damage. Or the volume available in that payload carrying bay it could be filled up before reaching the maximum weight limit. So either it is volume limited or it is payload limited. So if you are carrying lead you will probably hit the weight limitation first if you are carrying cotton you will hit the volume limitation first.

Whatever be the case there is the maximum payload you can carry in kilograms or in the weight units. So any point from A to B corresponds to one particular flight in which the aircraft is filled with maximum payload then you add some fuel, the mission fuel and on that fuel you travel some distance. Now you cannot go beyond point B with full payload because at point B you have now hit the maximum take-off weight capacity limit.

At point number B two things are happening: the payload is maximum and the total weight is also maximum take-off weight. So do you think the fuel tank is full at point number B? You have reached the limit of maximum take-off weight and you have reached the limit of maximum payload carrying capacity. So at point number B what is the fuel weight, is it equal to the maximum fuel weight possible?

No, that is not the case, you have space in the fuel tank but you cannot carry fuel, the reason is you have hit the maximum take-off weight limit. If you put more fuel then the load on the landing gear with exceed the load for which it is designed for safe operation, so not permitted. But let us say you want to travel further, so the trade-off is remove some payload and that much fuel to hit the max take-off weight limit.

So along line B and there should be another point here called C this point here this point could be called as point number C. Up to point number C from B you travel. Now understand one thing this is not a graph that shows how you are travelling. It just shows you the operational point, so any flight is only a point in this diagram. So there could an operating regime in which when you go from B to C so what is constant for all operating point between B to C? Just like for all operating point between A to B the only thing, what is common between A to B?

The payload is maximum okay, from point B to C? The take-off weight is equal to max take-off weight. So at point number B you have both the things its intersection. At point number B you have payload maximum and take-off weight maximum. So that point is a very important point from the airline point of view. What is the farthest we can go without compromising on payload? So the range below B is called as the harmonic range, harmonic range is a real measure of two aircraft if they have to compete from the capacity and payload range and payload point of view.

You should compare the harmonic range. How much can you travel with full payload? How much can you travel? So if he can travel more better aircraft from the airline point of view. But airlines do not travel only on one route, the same aircraft is used for Mumbai to Pune and from Mumbai to Delhi. Okay so therefore it may be required that you go beyond the maximum possible go beyond point number B, so the only option for that is to trade between fuel and payload.

So you take out some payload, add fuel till you hit maximum take-off weight, that will be from point number B to point number C. Now at this point you hit one more limit. Now your fuel tank is full so at this point which I will mark as C when I load this presentation the fuel tank is full. So now you cannot put more fuel. Okay and obviously to travel this distance you cannot carry maximum payload you can see the payload is lower. The payload value is somewhere here. So from point B to point C we have the max take-off line.

At point C we hit the maximum fuel limit, now I want to still travel further. Now what is the option? Remove some payload but why will it travel more? Because the gross weight is lower. So it will consume less fuel per nautical mile hence its range will be better. But this particular line normally it is not so prominent. In many cases it is a straight line, in many cases it is just a small inclination it comes somewhere here.

But from the point of view of description we can say there is a line. So what is common along that line? What is common along that line? Fuel tank is full. So these three lines are called limiting lines, this is the max payload line this is the max take-off weight line, this is the max fuel line and the intersection points are max take-off and maximum payload, max take-off and max payload. Yes.

Student: Sir, in the maximum payload line from A to B is it because of the volume constraints that we cannot add payload?

Professor: No, it could be volume it could be weight, whatever be the case I cannot carry more than so many kilograms of payload. So you stuff the aircraft with payload till you hit either the maximum weight carrying capacity of the payload bay payload bay or the maximum volume carrying capacity of payload bay more than that I cannot carry because I cannot stuff payload in the passenger cabin. I cannot say each passenger will carry one more suitcase because we have to carry more payload.

So take some letters some courier letters please, on your lap you keep a bag with letters for courier then you cannot do that. It is unsafe. Okay, so this is a very important program diagram which is used by all airlines in planning so you can see now if you want to check so these are graphs for Boeing 777 under various conditions.

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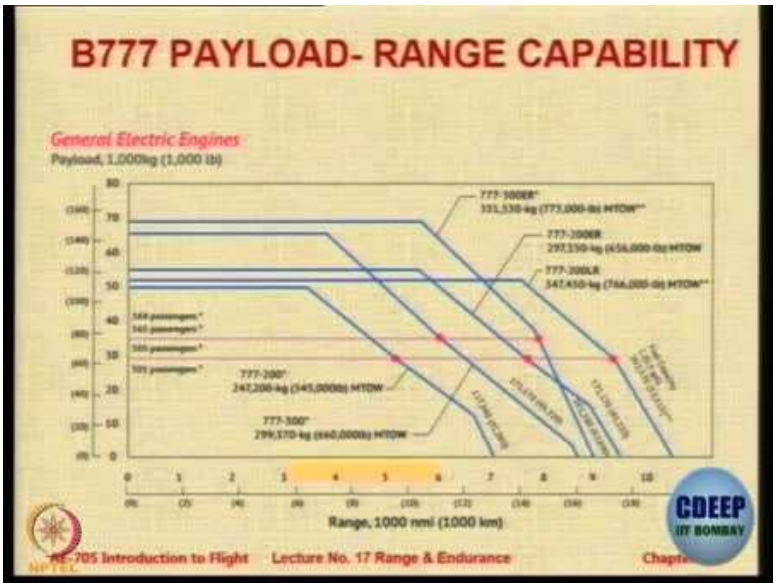

So you can see that the same aircraft 777 300 ER, 777 200 ER, 777 200 LR all of them they have different maximum payloads and hence there are different ranges. Now in this if I superimpose the aircraft of the Airbus company then you can make out which aircraft is fighting with which aircraft in the market roughly.

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Alright, so let us look at world records in aircraft range we will see this very soon. The world record is held by Steve Fossett on a Global Flyer 41,467 kilometres non-stop. And before that many years ago Burt Rutan designed an aircraft we will see a video of that hopefully in 1986 which travelled almost 40000. So both of them went around the globe. The first one was the voyager and the last one recently was the Global Flyer but these are not passenger aircraft. These are aircraft designed for these special missions.

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So let us look at Global Flyer. Yeah?

Student: Do we include gliders also in the that.

Professor: Gliders can be included but see gliders are not typically for gliders you cannot classify as range, this one is an aircraft which has got a power plant.

Student: Like Global Flyer, does it mean that at 41,000 the fuel was zero?

Professor: Not zero, they had reserve fuel remaining.

Student: So we can fly if the fuel is also zero, it can turn off and it can…..

Professor: Yes, but that is not considered. See, glider is not considered to be a candidate for aircraft world record, so yeah technically speaking yes once the fuel runs out you can keep gliding, if you are lucky you can get 7 more hours, 8 more hours. No, this one is on fuel but there is a difference. So let me see let me show you the clip if the clip works.

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Virgin
CDEEP
IIT BOMBAY


Virgin
GLOBALFLYER
CDEEP
IIT BOMBAY


CDEEP
IIT BOMBAY


CDEEP
IIT BOMBAY

So you can see that the Global Flyer consists of basically three fuselages. There are many aircraft that has got three engines and one fuselage, this is a unique one which has three fuselages and one engine. A single engine mounted on the middle, on the top.

So can you tell me why is it not going on a straight path? Why is it going this way then down then up then down? Yeah, anybody? Yes, what do you think?

Student: Sir, maybe to circumvent areas of bad weather and also restrictions in the airspace or something.

Professor: That is one restriction of airspace, for example Libya did not permit them to fly but the main reason is not only airspace the main reason is as they mentioned the route was planned to ensure that the circumference of the earth is covered at the tropics, because you could cheat by going around the earth at the northern latitudes or the southern latitudes, so they said for the world record you should cover more than the earth circumference at the tropical.

And secondly they always wanted to have heavy tailwind behind them, so the success of Global Flyer is a success of weather prediction technology in equal measure there was a ground based weather station which was predicting the wind, so they were changing altitude changing direction in real time ensuring that they get the maximum support from atmosphere by a tailwind. That is why they had to go for such a circuitous path. So this was in 2005 and 2006.

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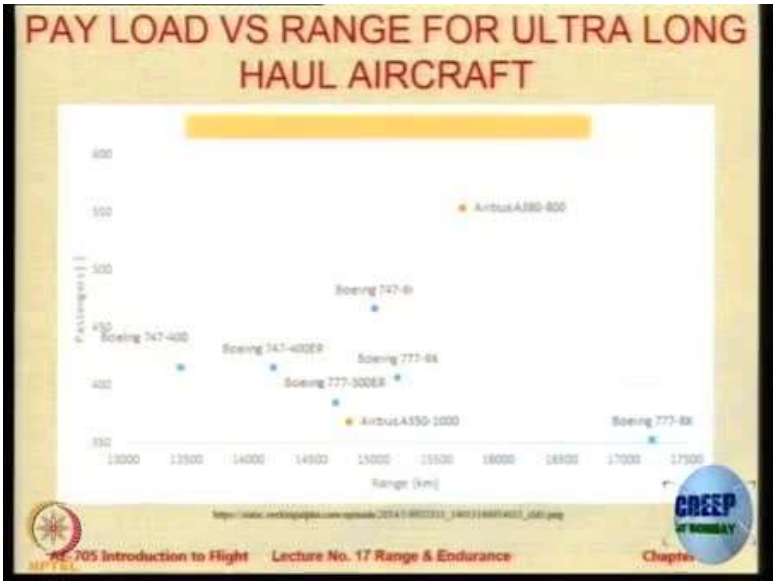

So you can see now there are some ultra long aircraft. So there is this Boeing 777-8X which is made into Boeing 777-9 you can see the range is 17,250. So many aircrafts are available who can fly but the payload is the lowest, it is just 350 passengers and Airbus 380 is here it can travel around 15,500 and more but it can carry 555 passengers.