Introduction to Aircraft Design
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Lecture - 76
Range Payload Diagram- Part-02

Okay, with this we have to now start looking at definition of range.

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There is one range called as the harmonic range, which is just the range that we observed without compromising on the maximum possible payload carrying capacity, how much can you travel with the given amount of fuel tank okay, keeping some fuel for reserve. That is called as the harmonic range and this particular range is most important for an airline to know.

Because this particular value tells the airline how far you can travel, which markets can you cover without compromising on your payload carrying capacity. We also have something called as a ferry range which is used only very sparingly in the aircraft life. This is essentially the range of the aircraft with no payload and if you assume that all the fuel including reserve fuel is consumed in transporting the aircraft.

So the ferry range is of importance when for example, if the aircraft is purchased from a manufacturer and how far can you travel to deliver the aircraft. Or if the aircraft has gone back to the manufacturer for any maintenance or any major overhaul, then you know when it comes back to you, even that time also ferry range is important. An important point to note is that by convention, we include reserve fuel also as a mission fuel in the calculation of ferry range.

This is only a convention, okay. And then you have another definition of a range which is actually quite theoretical in nature that is called as a gross still air range. So this is just to take out the fuel consumed in warm up, taxi-out, takeoff, climb and descent approach and land into the consideration. So what we assume here is that you have some mission fuel available and if the entire fuel is used by the aircraft only in range, then how far can the aircraft go?

That is called as a gross still air range and because it says still air, it is assumed that there is no en-route headwind or tailwind. So it is like a theoretical number. So by some magic, you lift the aircraft from the ground to a cruising altitude and throw it at the cruising speed and now you start consuming the fuel and the place where the complete fuel will run out that much distance is the gross still air range.

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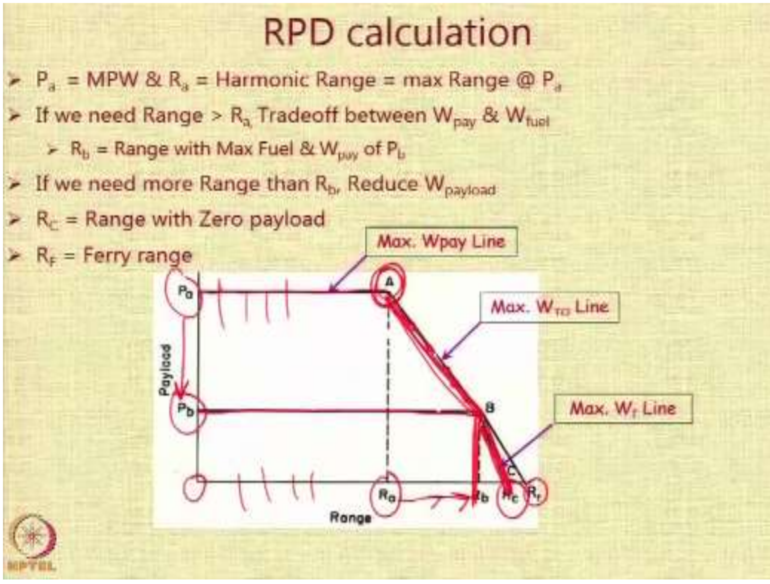

So the RPD calculation or the range payload diagram calculation thus is in terms of these three or four important points. The first point of importance to us is the point P_a okay. Now P_a basically stands for the payload that you know is the maximum payload and a is the harmonic point and range R_a is the harmonic range. So P_a basically stands for maximum payload weight.

And R_a stands for the harmonic range, which is the range that you can get at maximum payload. The next important consideration is that if you want range more than R_a okay then you have to reduce the payload. So any operating point along this line will correspond to tradeoff between payload and fuel, removing payload and adding fuel okay, removing the payload and adding the fuel.

But you cannot go endlessly, you will hit a point b very soon. At point b now your fuel tank is full. So at this point b we have a payload P_b. This P_b corresponds to the payload that you can carry with your fuel tanks full okay. After that, you will not be able to travel unless you either carry more fuel somehow okay. So therefore, R_b is the range which you can achieve with lower payload P_a reduces to P_b but R_a increases to R_b, right.

Now if we need more range than R_b, then we reduce even W payload further and now we assume that but you know in many cases this point is a straight line because you really cannot do much further. And you know the effect of the aircraft being lighter is you know not really going to be too much manifested. R_c is a theoretical point which corresponds to the ferry range.

So in ferry range, what you have done is you have included the entire reserve fuel also as mission fuel and you have just traveled some distance. Your payload is zero, your range is R_c because all the fuel including the mission and the reserve fuel has been consumed in traveling okay. So R_f is the ferry range point.

So this particular line on which range is increased by carrying more and more fuel till you hit the maximum takeoff weight point that is called as a maximum payload line. Along this line, the payload is reducing and the fuel is increasing, but the max takeoff weight is constant. So this is called as the or the takeoff weight is equal to max takeoff weight. But this is called as the max takeoff weight line.

And then we have a third line, this line. In this line the fuel tank is full. So this is the maximum fuel weight line and the W takeoff and W payload are going to reduce accordingly.

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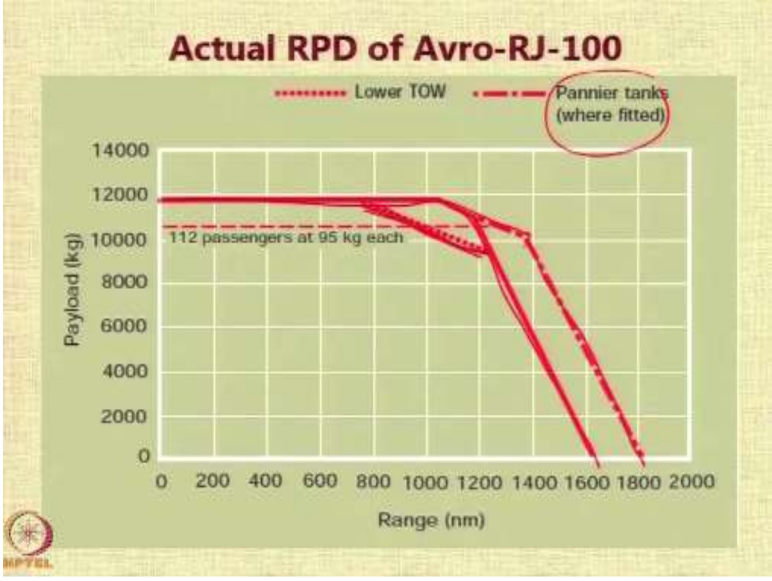

So let us see the actual payload diagram of an Avro-RJ-100. So this is the basic diagram, the dark red one. And when you install some additional fuel tanks called as the Pannier tanks, then you can increase the range by some amount, but still you then very soon you will hit the limit on the Pannier fuel tank also and then you can only travel further by reducing the payload, okay.

And this particular line corresponds to the range payload diagram where there is a constraint on the lower takeoff weight on this particular aircraft.

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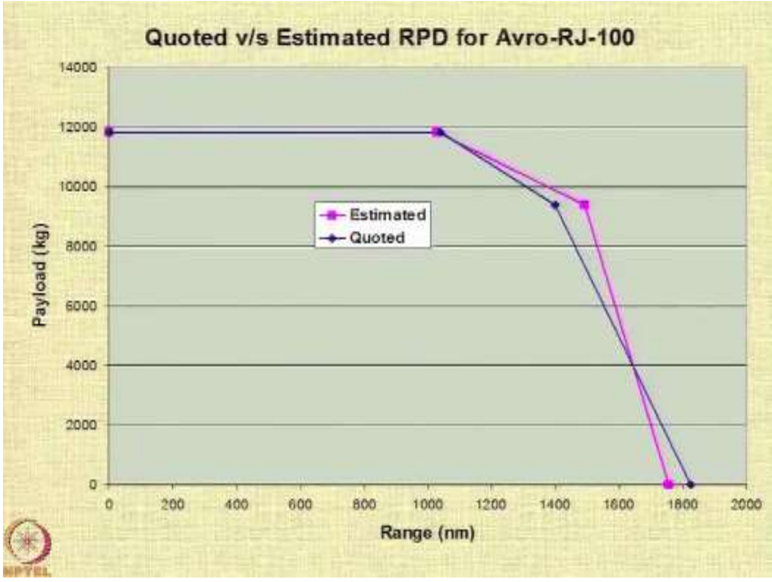

So we have shown a procedure for calculating the range payload diagram and if you plot using the calculations that are discussed, you will find that the error in the range payload diagram between the actual value and the estimated value is not very different.

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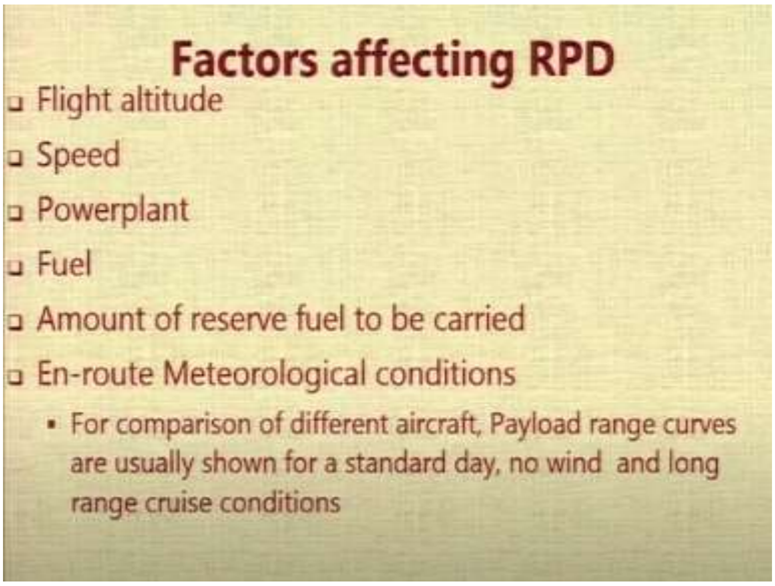

We are going to look at a detailed tutorial in which the calculations will be explained. Let us have a look now at some of the factors that affect the range payload diagram. The first factor that affects the range payload diagram is the flight altitude because at different altitudes the aircraft has a different specific range, okay. Then the speed. There is one speed at which the fuel consumption is minimum.

And then there is also another speed at which the time taken by the aircraft is less. So depending on at what speed you fly there is going to be a difference in the range that you can travel. The type of powerplant. Sometimes the same aircraft can have different versions of powerplants or different companies can provide powerplant which can be fitted on the same aircraft.

Depending on the functioning of the power plant and its efficiency, the range payload diagram of the aircraft can change. Type of fuel can also matter a lot. Then the amount of reserve fuel to be carried depends upon the company policy and sometimes the regulatory issues. So even that will affect. So what we do is we have to also worry about the en-route metrological conditions like do you have a headwind, do we have a tailwind etc.

So if you want to compare the range payload diagram of two aircraft, then you have to have a set of common assumptions. So for different aircraft, the payload range curves are usually shown for a standard day that is under the ISA conditions with no winds that means no en-route winds. And we assume that the speed at which the aircraft flies is the long range cruise condition at which the fuel consumption is minimum.

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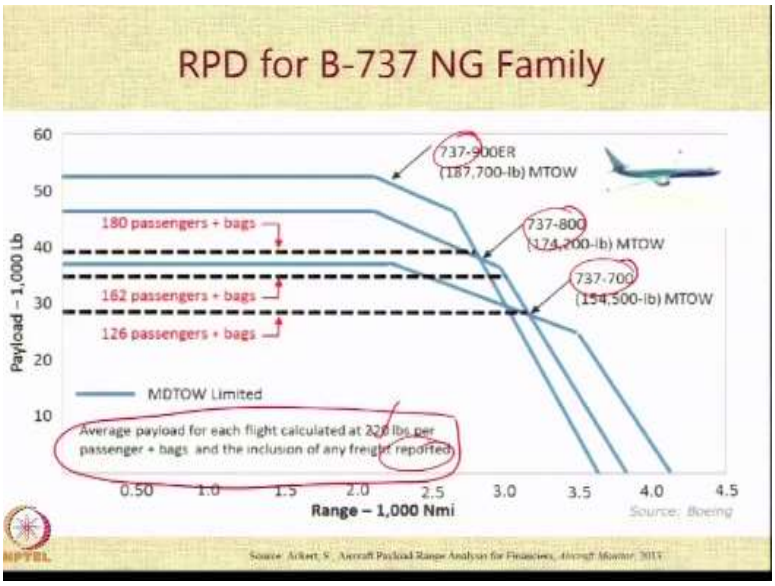

So keep in mind that when you compare the two aircraft's RPDs they have to be at some common ground. And whenever you see a graph like this, which shows the RPD for various aircraft, there is always some kind of a note on the bottom which says what are the assumptions? So here they say that the average payload is 220 pounds for passengers and inclusion of any freight that can be possible.

So you notice here that the same aircraft 737 has these three, the newer versions have these three models and with the same aircraft you can actually try to address different markets okay.

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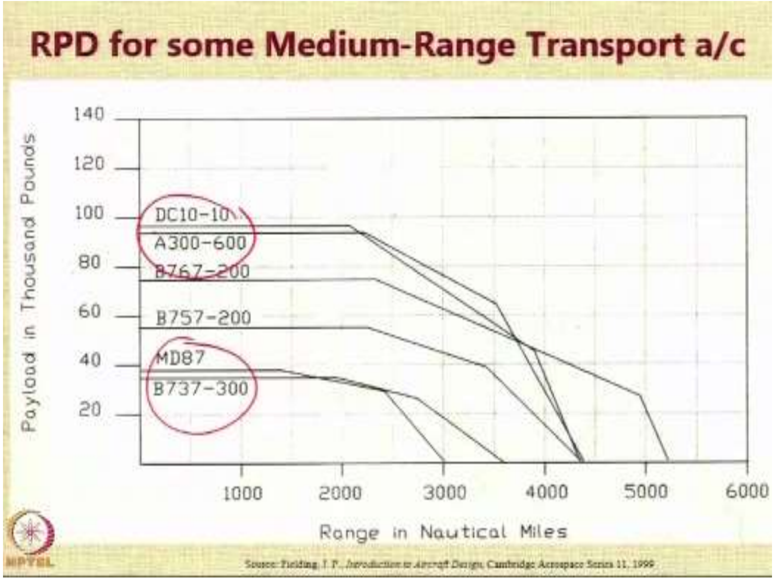

Similarly, if you want to compare two aircraft you can see DC10 and A300 are competing in the market for very similar capabilities, because their range payload diagrams are also quite similar. Similarly, MD87 and Boeing 737 at one point before McDonnell Douglas was acquired by Boeing, they were competing again for a very similar market.

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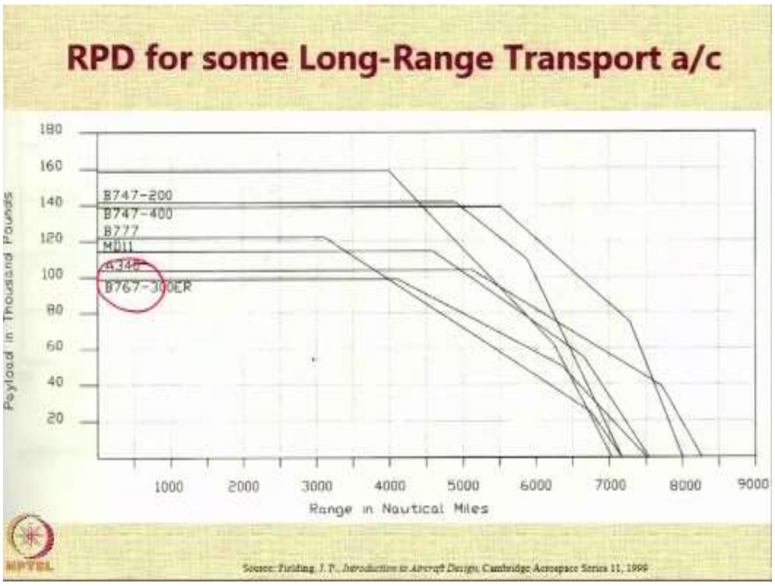

This is the RPD for some long range transport aircraft. You know, there you can see Boeing 777 and MD11. And you can also see A340 and Boeing 767. They are also two aircraft. Now the you know, these are how in the market people plot the diagrams over the computer diagram and try to show that there is the superior.

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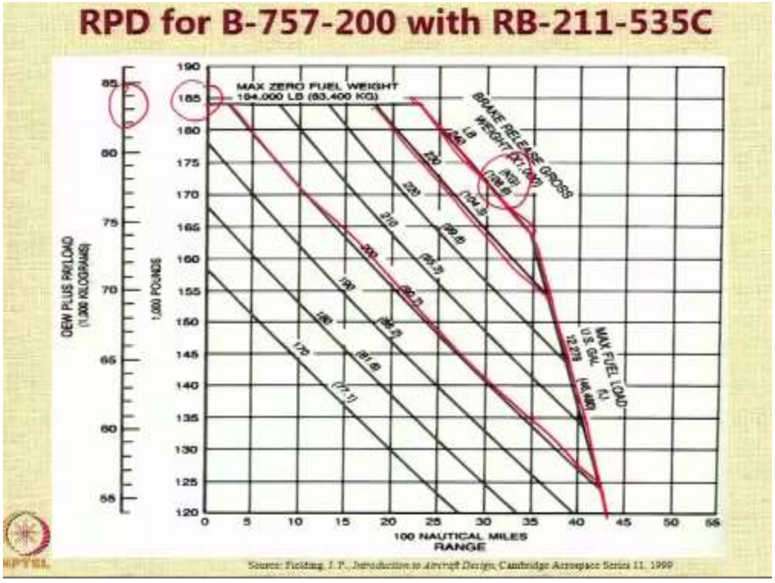

Here is a diagram that shows the effect of the limit on the takeoff weight. So there is a boundary diagram, there is the load diagram where you have the maximum zero fuel weight and there is a corresponding payload for it. Then this is the gross weight. Now in this particular line, the gross weight is 108.9 thousand kilograms, okay. And this is the maximum fuel line.

But suppose there is a restriction on the aircraft on the maximum takeoff weight, then you have these inner lines which are applicable. So for example, for the same aircraft if the maximum takeoff weight permitted is 108.9 tons you have this line, but if you have only 90 tons then you get this particular line as the range payload diagram. So this graph shows how for a given aircraft with a given engine the diagram can also change.

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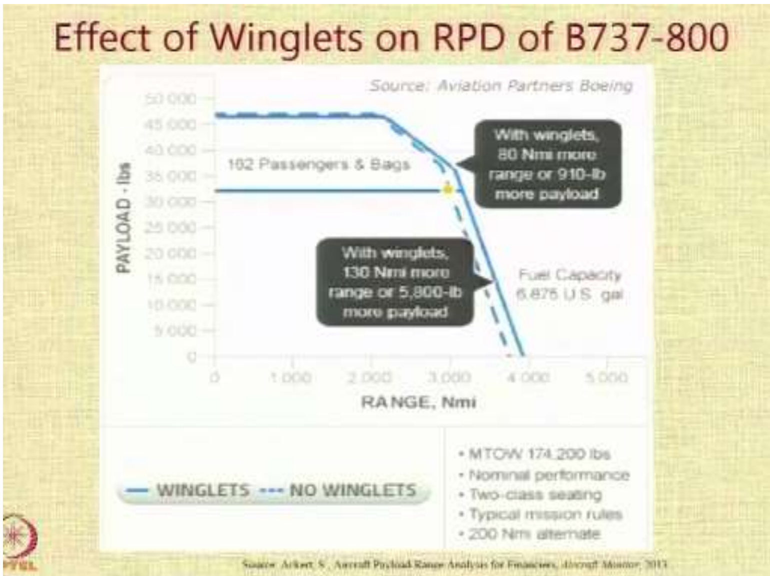

Let us see the effect of winglets on the range payload diagram of this Boeing 737-800 aircraft. Many companies are many airlines are installing winglets on the aircraft to try and improve its fuel consumption. So as this particular graph shows, if you install winglets, you get 80 nautical miles more range or you can carry around 910 pounds of higher payload for the same aircraft. And that happens in this particular regime.

And with winglets, you can travel 130 nautical miles more or you can carry 5800 pounds more payload in this particular region, okay. So installation of winglets can lead to a substantial improvement in its operational performance.

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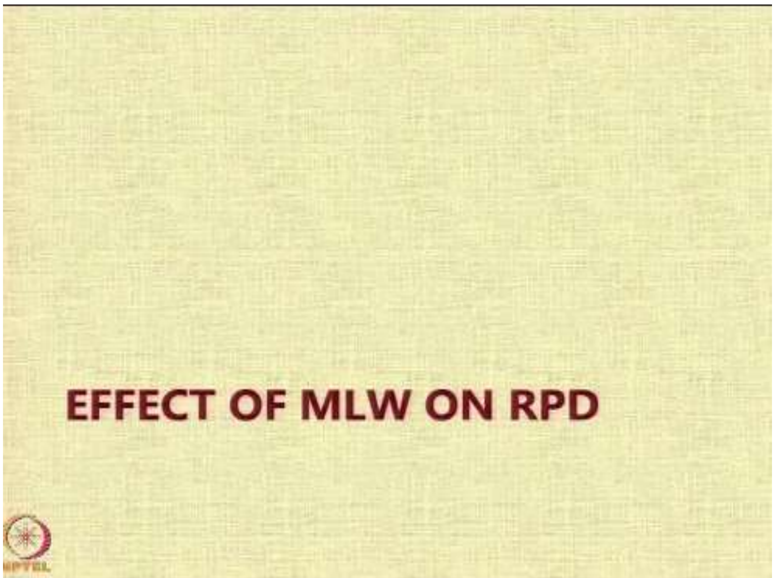

Let us look at the effect of maximum landing weight on the range payload diagram. The effect of this is similar to that due to the lower max takeoff weight. You will have a line which is parallel to the tradeoff line for the range and payload, but inside the range payload diagram.

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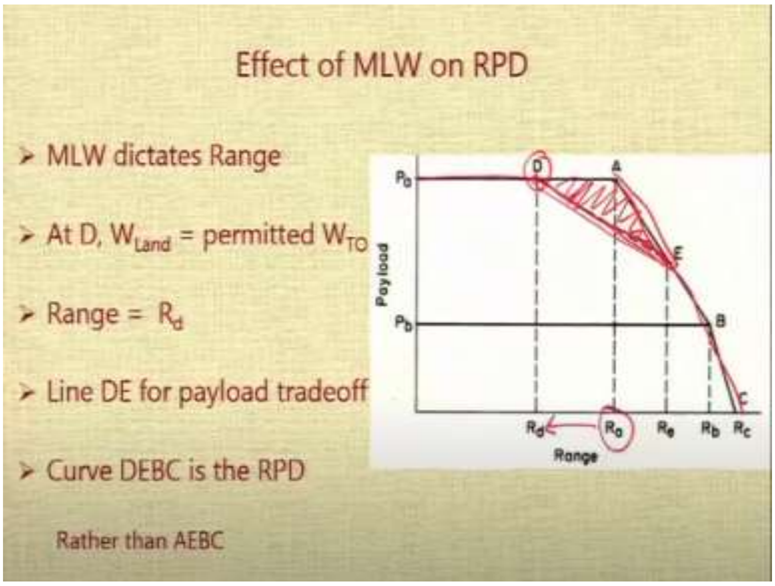

So you know, the maximum landing weight will dictate the range of the aircraft because when you come into land, you are not allowed to land at a weight more than a particular number. Therefore, you have to carry less amount of payload or less amount of fuel to be able to manage. Now if you do not want to compromise on the range, then the only option you have is to make the aircraft lighter by carrying a lower amount of payload.

So at point number D in this range payload diagram, you hit a condition that from this point, if you proceed further, you are going to hit the limit on the maximum landing weight. If you carry more payload, if you know if you travel more distance you will not be able to meet this requirement. So the tradeoff which started at this particular point, now starts at this particular point itself.

So the range that you can travel will be only R_d. So the if you have a maximum landing weight limit on the range payload diagram, the effect is that the harmonic range reduces from R_a to R_d, okay. And the line DE is for the payload tradeoff just like the line AE was for the payload tradeoff in case there were no limits. So the curve you know, this curve becomes a range payload diagram.

And this much area is not available to you for operation if there is a limit on the maximum landing weight.

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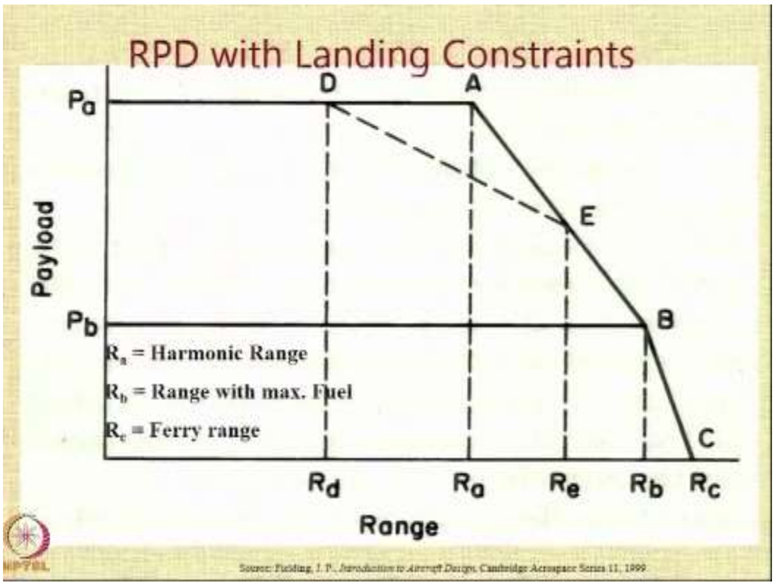

So this is what will be the range payload diagram with constraints on the landing weight.

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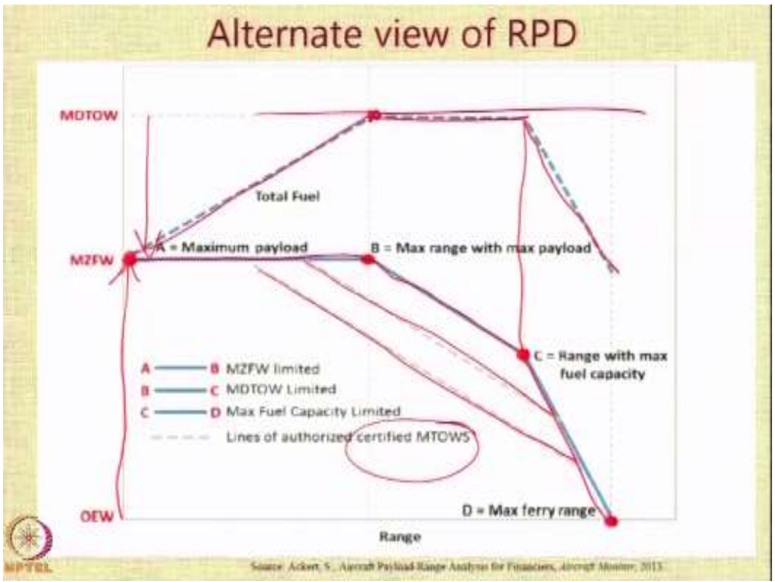

There is another way of looking at the range payload diagram which is if you plot on the x axis not just the payload, but the various weight terms, okay. So you see for example, that from the operating empty weight you include the payload and that then you hit the maximum zero fuel weight. So this is the limit on the maximum takeoff weight.

So when you are at this particular operating point when you have maximum payload and actually zero fuel because range is zero, your takeoff weight is much lower than the maximum takeoff weight. So as you take any of this operating point you are increasing your max takeoff weight to condition and when you come to this particular point, this particular point you have now hit the line where you have got the maximum design takeoff weight.

So during this entire tradeoff line the maximum takeoff weight remains constant till you hit the line where you have hit the maximum fuel tank. After that when you proceed along this line you are actually again reducing the takeoff weight of the aircraft okay. And as you can see, these are the lines which indicate how the range payload diagram gets compressed if you have limits on the certified max takeoff weight lines, okay.

So this is another way of looking at the range payload diagram. Thanks for your attention. We will now move to the next section.