Introduction to Aircraft Design
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Lecture - 75
Range Payload Diagram- Part-01

Let us have a look at range payload diagram which is one of the important constructs in aircraft conceptual design. The material for this presentation has been taken mainly from three sources. The first is the book by Professor John Fielding. The second is a textbook by Horonjeff McKelvey and others on Airport Planning and Design.

And the third is a note by Ackert on the Range Payload Diagram for Financiers. Before we start, it is important to look at some definitions.

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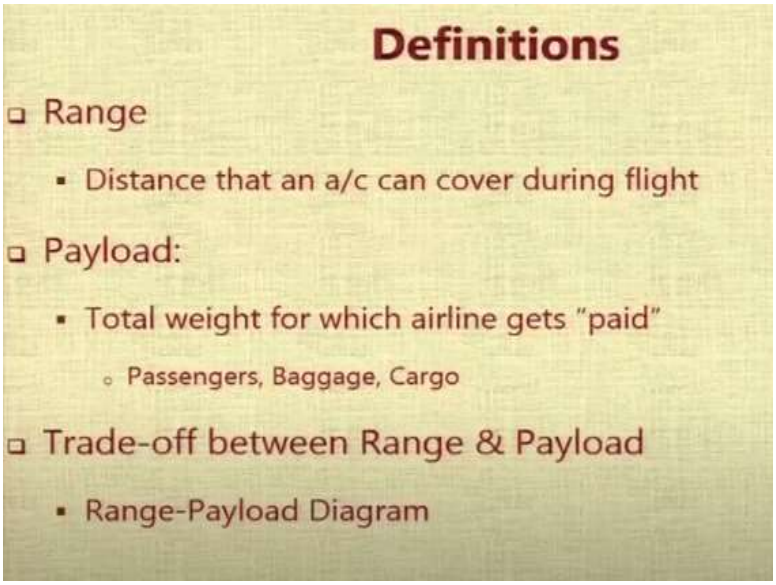

Range is defined as the distance that an aircraft can cover during its flight. And there are different types of ranges as per the definition, which we will see in a little bit from now. Payload is the total weight for which the airline gets paid. This consists of the passengers, the baggage and the cargo. The trade-off between range and payload is basically the range payload diagram.

Sometimes it is also called as the payload range diagram, because the payload is on the y axis and the range is on the x axis.

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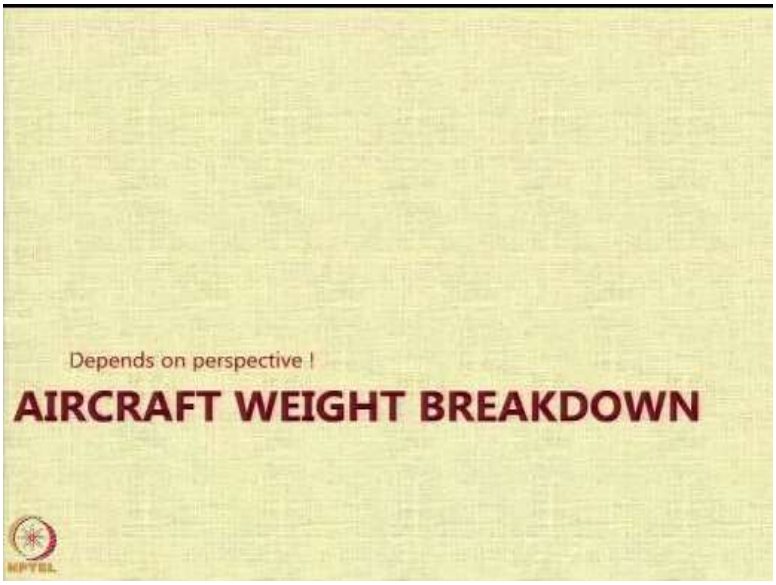

Let us look at a typical breakdown of an aircraft weight. And when we discussed about weight breakdown, it depends on the perspective who is talking about weight breakdown? Is it the airline or is it the aircraft designer.

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From the manufacturer's perspective, you have the largest possible weight of an aircraft is the maximum ramp weight, which is the weight of the aircraft for which the landing gear is designed and which is the one that the maximum it can withstand. The maximum ramp weight if you take out the fuel that is required for warm up taxi-out and take off, then you have the maximum takeoff weight.

This is the weight which the aircraft is expected to be able to lift off. And then you have a maximum landing weight. This is the weight for which the landing gear is designed

to take the impact at landing, the expected impact at landing. Then you have maximum zero fuel weight, which as the name suggests, is everything except the fuel. And then you have important consideration of the authorized limit versus the structural limit.

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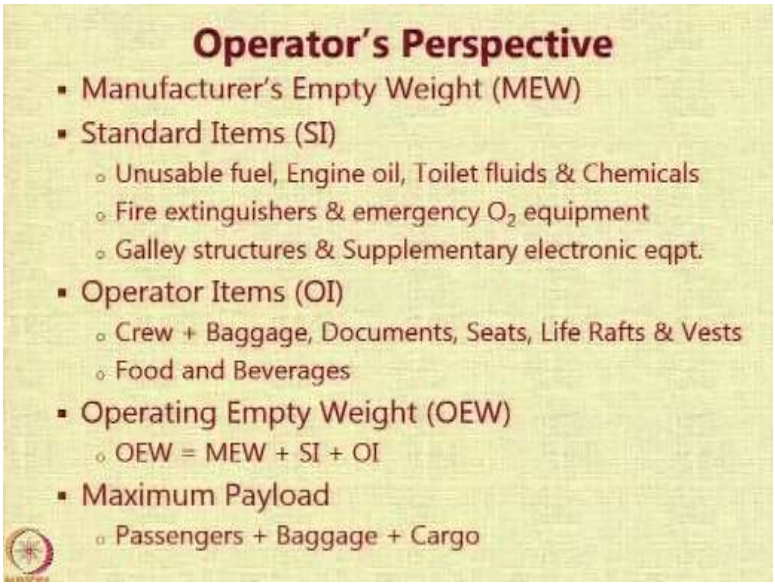

There might be some constraints in operating an aircraft and therefore the authorized limit of weight may be less than what the structure can withstand. If we look at the operator's perspective or the airline's perspective, you have manufacturer's empty weight, which is the weight of the aircraft as supplied by the manufacturer.

And then on that we install some standard items, the unusable fuel, the engine oil, the toilet fluids and chemicals and other safety equipment, the structures and supplementary equipment. With this you get the standard items have to be included into the manufacturer's empty weight to meet the requirements and to ensure comfort and safety. And then there are operator items.

Items which the airline adds such as the crew and baggage, the documentation, the seats, life raft, vests etc., food and beverages. Together we get the operating empty weight, OEW which is the manufacturer's empty weight plus the standard items installed plus the operating items installed. So for an airline, this is the minimum weight with which the aircraft can operate.

Without this the aircraft cannot operate, okay. Above this you will have only the payload. So the maximum payload that you can carry would be a combination of the passengers, their baggage and the cargo, okay.

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So let us take an example of Boeing 737 – 800, one of the most popular transport aircraft. The certified weight for this particular aircraft are as mentioned. There is operational maximum limit and then there is a structural maximum limit. So the airline has to operate within the operational maximum limit. So this aircraft for example has a maximum ramp weight of 156.2 thousand pounds.

Whereas the max takeoff weight is only 155.5 thousand pounds. The maximum landing weight is 144 thousand pounds and the maximum zero fuel weight is 136 thousand pounds.

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So let us see how the weight is built up. So the ramp weight is going to be the weight of the fuel required for warm up for taxi and the takeoff run plus the takeoff weight. The takeoff weight is going to consist of the payload plus the fuel plus operating empty weight. The operating empty weight is going to consist of the structure, the crew and the operational items.

The operational items are going to be the weight of the food and beverages, the weight of magazines and weight of all other items which an airline provides for its operation. The fuel weight is going to be in two parts, the mission fuel and the reserve fuel. The reserve fuel you are not supposed to touch for the mission.

The reserve fuel is meant for safety margin towards things like diversions, holding, weather issue, weather related changes in the itinerary and some errors that can happen during flight. The payload is the combination of the weight of passenger's baggage and cargo. Now there are limitations on payload. Either it can be volume limited. That means when you stuff the payload bay with all the items, very soon you might run out of volume.

So the total weight maybe not that much large, but the volume is not available now to stuff more items. Or it could be a function of the structural strength of the cargo bay. You may have volume, but you are loading a very heavy item, high density item and before you hit the limit on volume, you may hit the limit on the structural strength. So as an example, if an aircraft is carrying cotton as a cargo.

Now cotton is fluffy and light in weight per unit volume. So if you start stuffing the passenger the payload bay, if you start stuffing the payload bay with the cotton bales, very soon you will hit the volume limit constraint before you hit the weight constraint. Similarly, if you are carrying lead as the payload in the payload bay, you will hit the structural strength limit of the cargo bay before you hit the volume limit.

So either volume limited or weight limited that is the limitation on how much payload you can carry.

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Let us look at an example of a weight built up of another very popular aircraft called as the Avro-RJ Whisperjet, which is the regional jet transport aircraft.

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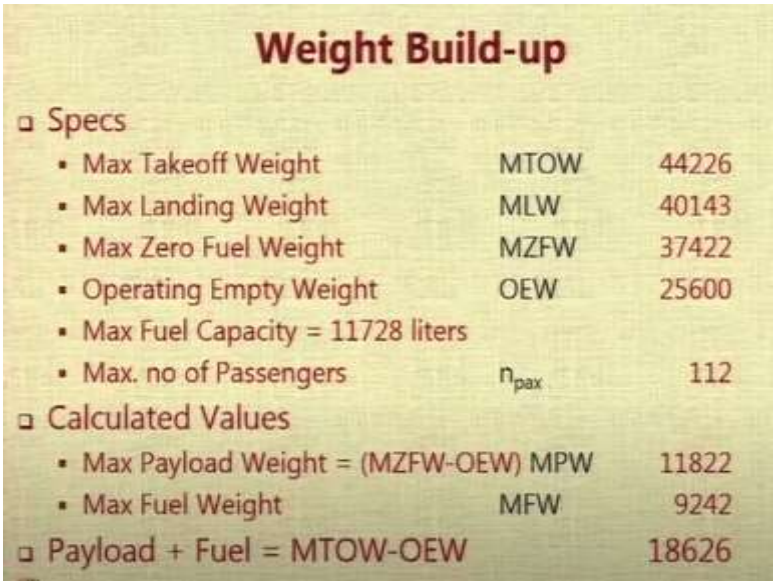

Let us see the way it built up. So in this case, the max takeoff weight is 44226. In this particular calculation all the weights are in kilograms, okay. So the max landing weight is 40143. Zero fuel weight as mentioned, operating empty weight also as mentioned. The fuel capacity is 11728 liters and the maximum number of passengers it can carry is 112.

So therefore, the payload weight is going to be the difference between the maximum zero fuel weight and the operating empty weight because above that is going to be only the payload. So the total payload you can carry in this aircraft is only 11822 kilograms. And if you convert the fuel capacity of 11728 liters into weight, you get 9242 kilograms assuming a density of approximately 0.8 kg per liter.

So if you add the total maximum payload of 11822 and the total maximum fuel of 9242 you get 18626 which is more than the payload capacity of the aircraft, okay.

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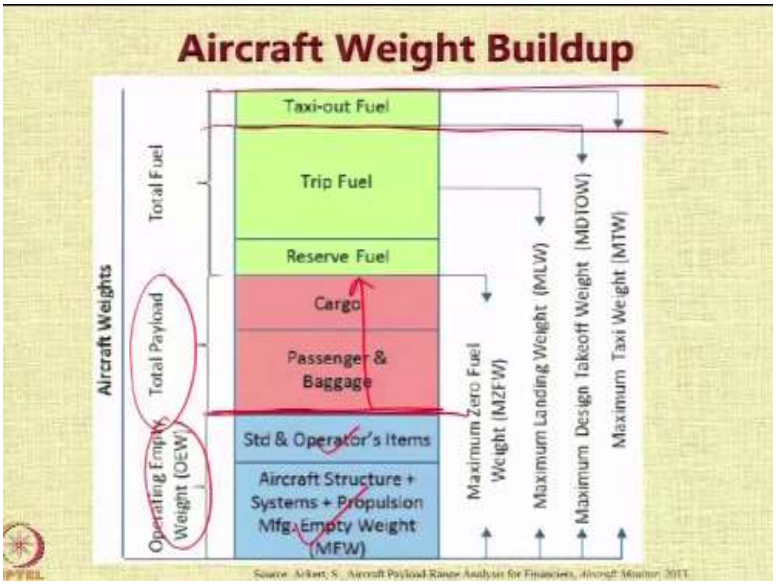

So in other words, it is not possible for us to carry the entire payload that is possible and the entire fuel that is possible. This figure shows you the built up of the weight. So you can see that the operating empty weight is basically the summation of what the airline receives as the basic structure and also inclusion of the standard and operating items. On that you add the passenger baggage and cargo.

So you get the maximum zero fuel weight. So the operating empty weight plus total possible payload is going to be the maximum zero fuel weight because above that, you can only add fuel, okay. And fuel also will consist of various components okay, the taxi-out fuel, the trip fuel and the reserve fuel. So if you exclude the taxi fuel you get the maximum design takeoff weight and here it will become the maximum ramp weight, okay.

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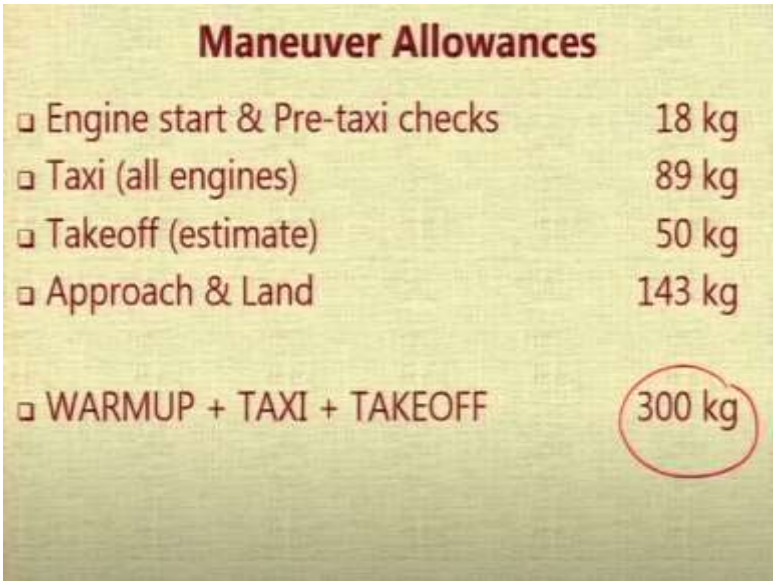

Now let us see, there is something called as the maneuver allowance. So in this particular aircraft, here is the indication about how much the fuel is consumed in the starting of the engine and pre-taxi checks. Then taxing with all engines working. An approximate value for the fuel consumed during takeoff and have an approximate value for the fuel consumed in approach and land. If you add all of that it comes to around 300 kilograms.

So in other words 300 kilograms of fuel is gone or has to be provisioned for the basic takeoff and landing activity. So together we call this as a maneuver allowance, okay.

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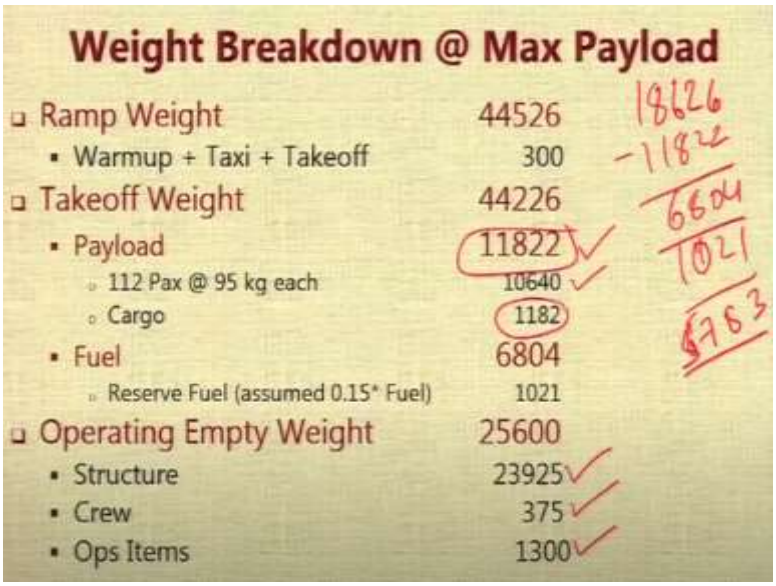

Let us look at the weight breakdown at maximum payload. So here we assume that we are carrying the maximum permitted payload plus fuel value of 18626 kg. So let us

keep a note of that, 18626. This is the combination of the payload consisting of the actual payload and fuel. So the ramp weight is 44526 kg, which is a maximum load that the aircraft can carry on its wheels.

So from that we subtract 300 kilograms, which is the fuel required for the maneuver allowance, which that we get the maximum takeoff weight of 44226 kg. Now since the total payload plus fuel is 18626 kg and we want to carry full payload, so if you do a subtraction of 11822 okay, you get 6804. So that much fuel can be carried which is put here. So what we have done is we have kept this number constant because we want to carry maximum payload.

And for this particular payload, the first thing we do is calculate what would be the weight of the passengers with their baggage. So that would be 112 passengers maximum into 95 kg each for their baggage plus their weight. So you get 10640 kg. So therefore, if you subtract this number from this number you get how much cargo you can carry. So in this case, since the total of payload and fuel has to be 18626 and we want to carry a full payload, we are able to carry only 6804 kg of fuel.

And on that 15% of that approximately is the reserved fuel. So the usable fuel that we will get will be only it will be -1021 which would be 3875. So 5783 would be the fuel that you can carry, okay. So with 5783 kilograms of fuel you will be completing your mission, okay. The operating empty weight is 25600 kg, which for information consists of the structure which is the major part minus the crew which is 375 and operating items which is 1300 kg.

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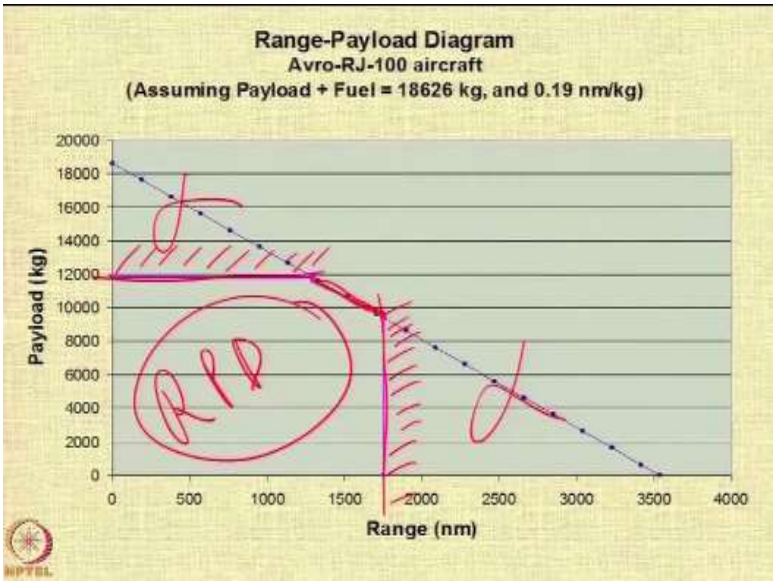

So with 5783 kgs of fuel now what we can do is, we can get this particular blue line. Now this particular point corresponds to the maximum payload. So with the maximum payload and 5783 kg of fuel available, if we assume and this data is available from the performance of the aircraft, if we assume that the aircraft can travel approximately 0.19 nautical miles per kilograms, you will get an idea about how much would be the range that you can carry that you can travel with the maximum amount of permitted fuel ensuring that payload is not compromised.

But, what you could also do is you could say okay, I am going to reduce the fuel. I want to sorry, I am going to reduce the payload, replace that with the fuel and I can get this kind of a trend line. So assuming the fuel available to be 5783 kilograms, you can trade off fuel and payload and you can get this blue line but there are limitations.

This limitation comes from the maximum capacity of the fuel tank and this limit comes from the maximum capacity of the payload carrying bay, either volume or weight limited. So you cannot have any operation above this line and you cannot have any operation actually also beyond this line. So this is the only effective region in which you can do the tradeoff.

These are not possible because either they violate the fuel capacity constraint or they violate the payload capacity constraint. So this area becomes the range payload diagram operatable area and that is what is the range payload diagram.

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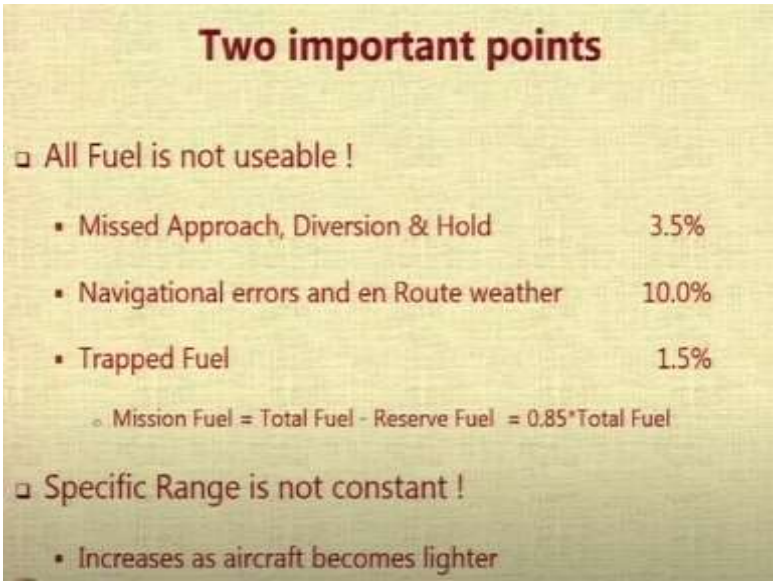

Let us look at two important points. One is that the entire fuel that we have is not usable. We have already seen that the mission fuel is going to be limited by the reserve fuel. And the second thing is that this specific range 0.19 nautical miles per kilogram that we assume is not actually constant because as the aircraft flies further and further, it becomes lighter and a lighter aircraft actually consumes less amount of fuel and hence travels more distance per kilogram.

But in the simplistic analysis, we are going to assume that to be constant. Thanks for your attention. We will now move to the next section.