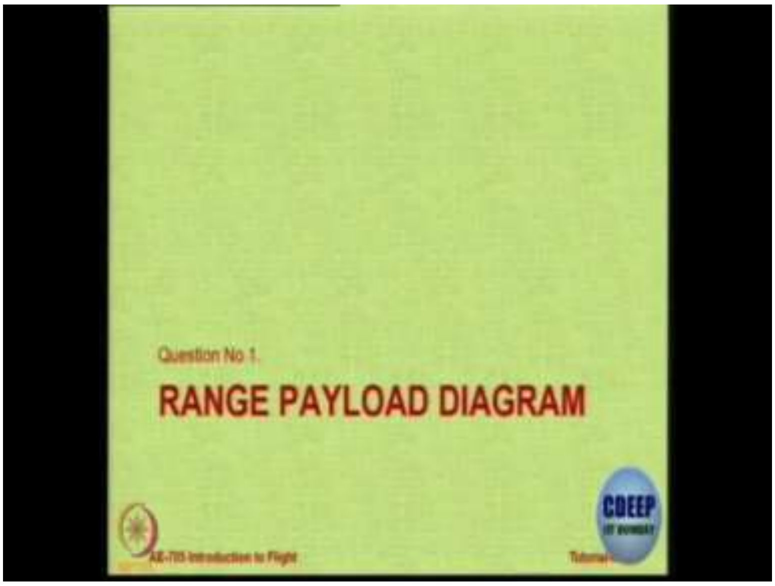
Introduction to Flight
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology, Bombay
Lecture No. 11.7
Tutorial on Range Payload Diagram

So we have reached the end of capsule number 9 today we will look at three questions as a tutorial and the first one of them is on the range payload diagram. So I will spend little bit more time on range followed diagram and then we will take up two questions regarding the performance I have not put any questions regarding takeoff and landing. I have only put questions regarding the cruise and endurance.

(Refer Slide Time: 00:47)



So the first question that you will solve is on the range payload diagram this I have discussed briefly in the class but today I want to take a live example and to show you how this diagram is constructed. So you are going to consider the diagram with me. I hope all of you have calculators with you okay. So take them out

We will look at the example of a very interesting aircraft a small jet engine aircraft which has got four jet engines okay.

(Refer Slide Time: 01:21)

So let us have a look this is the aircraft when it is on approach at an airport. Wind 330 42 knots that is what the ATCO has told.

(Refer Slide Time: 1:43)

So everything looks normal everything looks ordinary okay the plane is going from your left to the right hand side. But interestingly the video has been shot from the runway where it is supposed to land okay. So the aircraft is on a worse called as right hand circuit to come into land. Where you can see now it starts banking and starts meeting the trajectory for the arrival. It is a very unique aircraft when it comes into land I want you to look at some interesting features and I will point them out to you one by one okay.

(Refer Slide Time: 2:26)

So there you go now the aircraft is almost pointing towards us. Notice a small aircraft but four engines okay. So one question I want you to answer is and also notice only light is working starboard wing. So the aircraft is in its final approach now. Flaps are in the landing configuration or the approach configuration .The aircraft has a T tail. Four small engines.

(Refer Slide Time: 3:00)

And look at the rear of the fuselage you will find an interesting thing those are the airbrakes, which have been deployed and then there are spoilers deployed just after touchdown.

(Refer Slide Time: 3:17)

We will roll it back slightly at this point you do not see spoiler deployed.

(Refer Slide Time: 3:24)

See they are up they are down rather, flap is fully down. Just after touchdown you will notice the spoilers have come on.

(Refer Slide Time: 3:39)

And those airbrakes were also in the approach condition okay right. So one question I have which I do not want you to answer right now but I want you to look up and answer is why is it so that such a small jet engine aircraft with approximately 100-110 seats why does it have four engines? From the airline point of view operational point of view obviously if you need four engines that means you must have four serviceable engines available to you, it is a maintenance problem it is expensive okay.

But then why they have gone for an design is not driven by power requirements because you can easily meet these requirements with two engines I can understand that more than one engine is required from safety point of view, but you could do it with three engines you could do with four you could do with five etc etc, but what is a need for four engines.

So this is something that I would request people to study about this aircraft and answer on Moodle. Let us look at the weight build up now the numbers that you see are the actual numbers for this particular aircraft okay.

(Refer Slide Time: 04:52)

So the max takeoff weight MTOW is around 44 tons, landing weight is 4 tons less 40 tons. So in case the aircraft has to land immediately after takeoff from safety and from the structural strength point of view you will be required to dump around 4 tons of fuel okay.

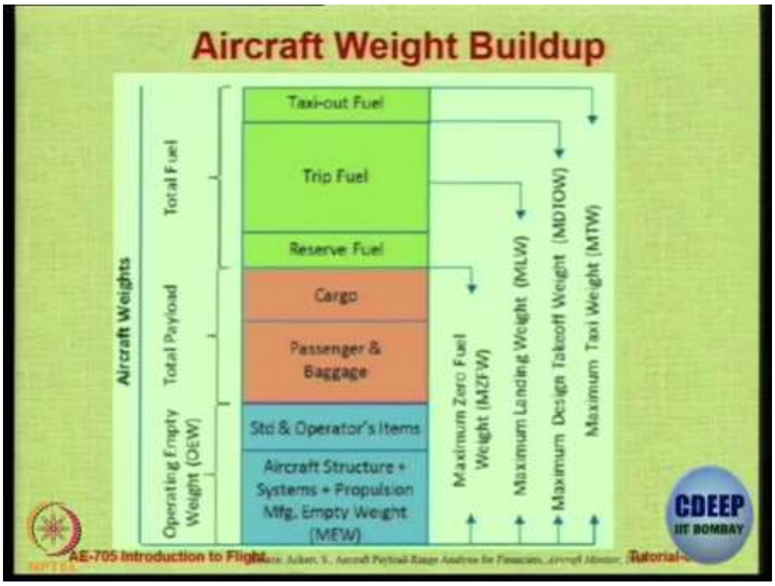
Then you have maximum zero fuel weight this is a very interesting term in aircraft operations the maximum zero fuel weight means everything else accept fuel okay. So what is there above maximum zero fuel weight to get maximum takeoff weight? You have the payload which consists of passengers, their baggage and cargo and crew, operating items okay so maximum zero fuel weight means the only thing you can add to this to hit maximum takeoff weight is fuel.

Operating empty weight stands for the aircraft structure, aircraft systems. No passengers, no cargo but the pilot, copilot and the crew are all there and so are the operating items, the beverages the food the newspaper everything is there, it is operating empty okay, fuel is not there payload is not there so you add those two items this aircraft has a maximum fuel capacity of 11000 liters and maximum number of passengers it can carry 112 okay. No need to copy anything because when you do the question you will get these number there again.

So the maximum payload weight that you can carry would be the maximum zero fuel weight minus the operating empty weight because the difference can only be payload right. So the maximum payload weight is 11822 kg and the maximum fuel weight is just a multiplication of the liters of fuel with the density of fuel okay. So therefore the summation of two quantities payload and fuel can be only the maximum takeoff weight that you can carry minus the minimum operating empty weight that you need to have as I said on the operating empty weight you just add payload and fuel to hit maximum takeoff weight.

So the total of payload and fuel is going to be 18626 kg this is what the airline can play with, but remember entire fuel is not available to you there is some reserve fuel which you cannot touch from safety regulatory requirements. So there will be some amount of fuel which is the mission fuel and payload okay.

(Refer Slide Time: 07:57)

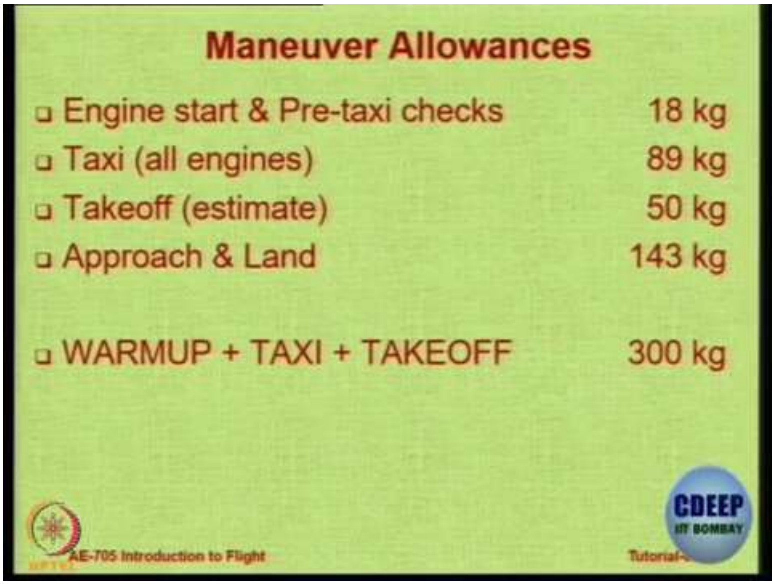


So therefore if you now see the buildup of weight graphically this is just for you understanding you have the aircraft weight consisting of structure propulsion manufacturing empty weight, etc, all the item. The manufacturer does not always make engines okay they normally buy the engines from the engine manufacturer, they also buy the seats they also buy the other equipment.

So operating empty weight will consist of what the aircraft company makes plus what are the standard and operating items which are to be put on the aircraft without that you will not be allowed to operate okay. But there is no fuel there is no payload now you add passenger plus baggage and you add cargo total of that is a payload. After that you add fuel so first compulsory reserve fuel then you have a trip fuel, trip basically here in this definition trip only means the flight from airport to the other and taxi out fuel is a small amount which they have added, normally we put taxi out fuel and trip fuel together as mission fuel we do not do this distinction okay.

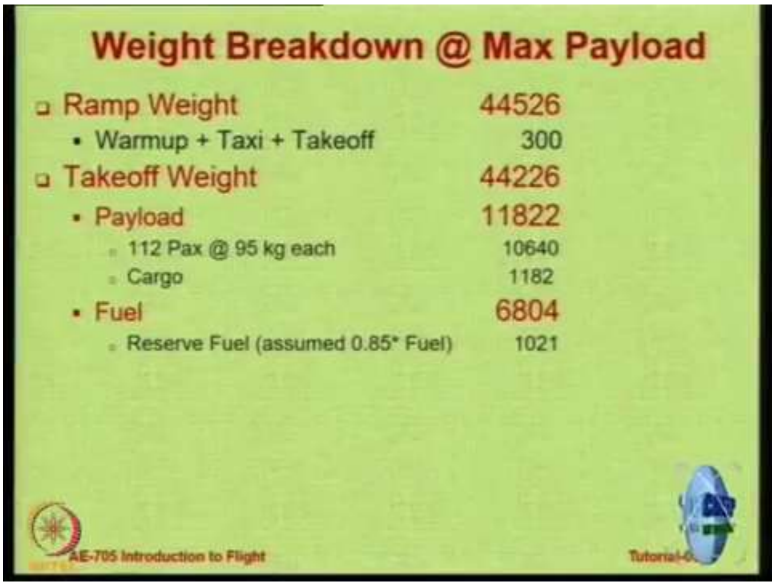
This is how the aircraft weight is built up okay. So now you have something called as maneuver allowance this is a slightly misleading term because people think this is the fuel required for doing maneuvers, etc, no this is basically the fuel required for doing other than the cruise, climb and cruise. So before every flight the aircraft undergoes some pre taxi checks during that time the engine is normally switched ON because you are ready for takeoff so there is some fuel for engines starting and pre taxi this aircraft consumes around 18 kilograms, then taxi all engines that means you are going from the terminal to the beginning of the runway you will consume around 89 kg of fuel. Then takeoff you will lose 50 kg of fuel and when you come to approach and coming to land and then taxi in all that will be around 143 kg.

(Refer Slide Time: 10:13)



So this aircraft incidentally consumes around 300 kilograms fuel in other then climb cruise and descent okay, this number is as high as 650-700 kg per 747 alright.

(Refer Slide Time: 10:29)

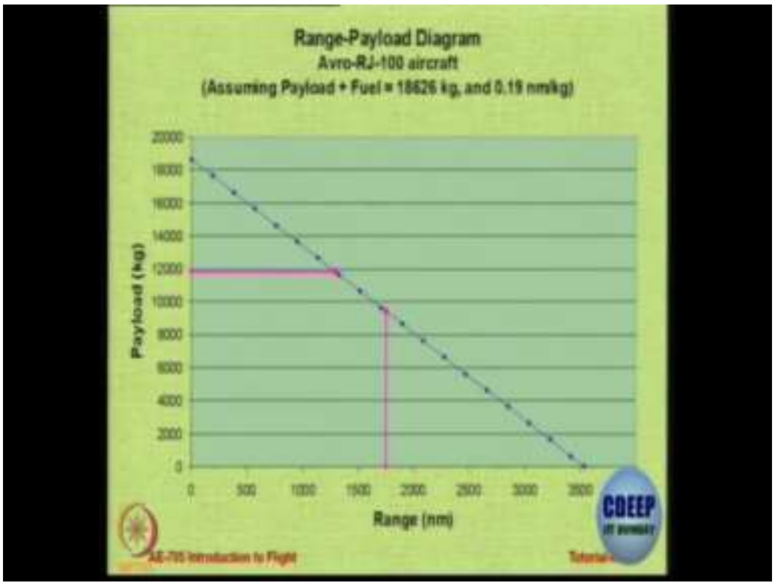


So let us look at the weight breakdown, now we are assuming that the airlines wants to flight with maximum possible payload so there is something called as Ramp weight now Ramp weight is maximum takeoff weight plus fuel required for the taxing, etc and warmup and take off. So if you want to be very particular you can say the maximum takeoff weight is the maximum permitted weight when the aircraft wheels leaves the ground or when they clear the obstacle height ok, but all the fuel before that when you add to the max takeoff weight you get what is called as a Ramp weight that is a maximum weight that the aircraft actually can have.

So it is nothing basically you just remove the 300 kg odd in this case okay so the take weight is 44226 then in this case as I mentioned there are 112 passengers so there are certain standard norms for how much weight to assume for a typical passenger plus baggage, so 95 kg is the industry norm some of them take 100 kg etc okay.

So since the maximum payload in this case is 11822 kgs you can carry 10640 and then there is some place for cargo. So fuel I am assuming that reserve fuel is 15 percent so total fuel I have just taken 15 percent of that. So therefore the fuel weight available will be 6804 the operating empty weight as given by the manufacturer is 25600 which consists of just for your information some structures some crew and some operating items okay. So this is the actual weight breakup of this aircraft in its typical operation right.

(Refer Slide Time: 12:22)



So the blue line that you see is the tradeoff between range and payload and these two purple lines or cyan lines the horizontal one is the cut because of the limitation on the maximum structural weight and the vertical one is the cut because of the maximum fuel capacity of the aircraft and the inclined line in between is the permitted operational tradeoff between range and fuel.

So in this case the range payload diagram is a horizontal line inclined line and a vertical line. This diagram was obtained assuming some numbers, one number that you need is what is the specific range of the aircraft that means how many nautical miles per kilogram fuel the aircraft can travel, this number as you know will not remain constant because as the aircraft becomes lighter it will travel more distance from the same amount of fuel but for assumption purposes we have assumed that there is a constant value of 0.19 nautical miles per kg so that is how this diagram was drawn. Now there are two important points you already know this point that all the fuel is not usable you have to keep it for various items and secondly we also know that the specific range also does not remain constant correct.

So moving ahead keeping in mind the range payload diagram and the operation there are three types of ranges which are defined, we have only studied one range in our lecture but here I want to clarify there are actually three types of ranges, the first one I mentioned is called harmonic range.

(Refer Slide Time: 14:17)

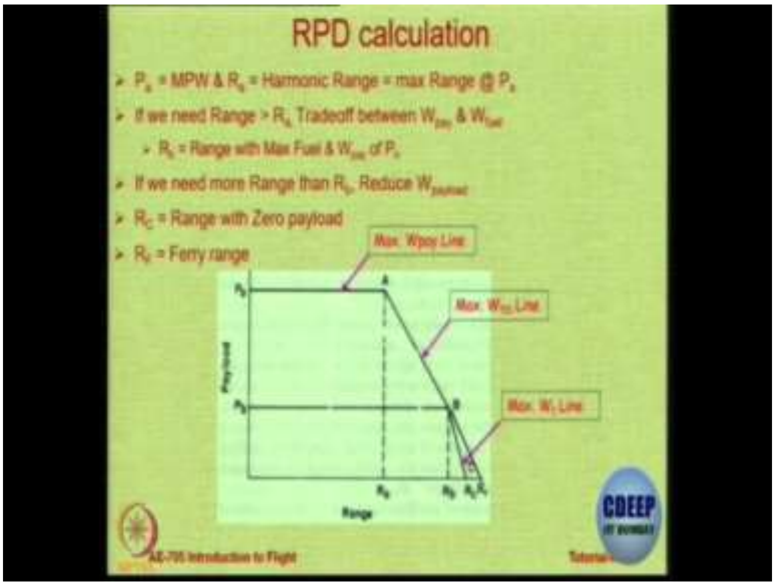
That is how far you can go without compromising on maximum payload because an airline wants to make money and to make money they want to carry maximum possible payload, it could be cargo, more cargo less passengers, more passengers less cargo, does not matter the total payload capacity they want to utilize without compromising on that they want to go as far as possible. So that range which corresponds to point number A in the Range payload diagram is the harmonic range. Then you have ferry range, in ferry range the aircraft has is now to be transported to a supplier to an airline.

So let us say Airbus constructs an aircraft and they want to deliver it how far can you go without refueling. So in this case what you do is, you assume that you will consume the entire fuel including reserve fuel okay. This is not a normal operation this does not happen every day. So these activity are very very carefully planned so the entire whether map is very carefully studied, there are no passengers on the aircraft okay. In some cases they also install some temporary fuel tanks inside the aircraft to increase the range but we will not take that case we will assume that there are no fuel tanks inside the aircraft, there are no passengers, aircraft is empty there is no payload.

Now the entire fuel is being used to travel so that distance is called as a ferry range. It is the largest distance that is theoretically possible without refueling, and in between or just a theoretical definition is called as a gross still air range. Now this is a very peculiar quantity okay so I want you to imagine something before you understand what it is, imagine that you have some kind of a magical crane which can lift the aircraft to the cruising altitude and throw it at the cruising speed.

So you have somehow by magic reached the cruising altitude and you have achieved the cruising speed, now how far can you travel with the full fuel with no on route winds that is called as the gross still air range. Still air means no head wind, no tail wind gross means really gross value, no fuel consumed in takeoff warmup, taxi, climb, descent, the entire fuel is used only in cruise at the cruising altitude at the cruising speed that is the gross still air this is just a theoretical number okay but it is still there.

(Refer Slide Time: 17:10)

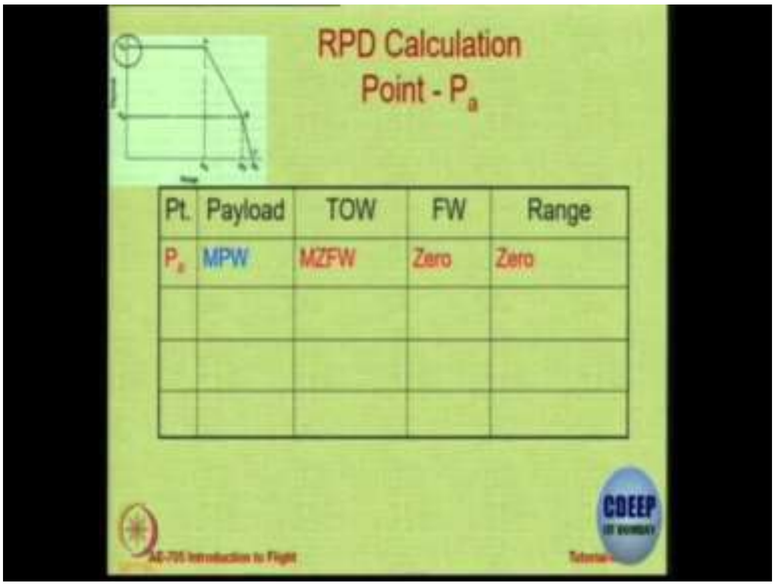


So this is the range payload diagram and this is what we are going to calculate now okay. So point A corresponds to harmonic range and point C corresponds to the ferry range and point B has to be determined. So basically if you look at how to draw the diagram, the first thing is you will draw a vertical line representing payload and the horizontal line representing range then the first point you will mark will be this point called P A. This is a theoretical point this is like aircraft is completely ready, pilots are there everybody is there okay payload is also loaded up but there is no fuel. So now you add some fuel and you will travel some distance add more fuel you will travel more distance so that is the theoretical point which is zero range point, max payload zero range.

Any line on this operating point from PA to A corresponds to more and more fuel being added hence more and more distance being travelled till you hit a point A where you will have maximum takeoff weight. Now you cannot add more fuel because you cannot, sorry you cannot add more fuel simply because you have space in the fuel tank but you have already hit the maximum takeoff weight, if you want to travel further you have to reduce some payload.

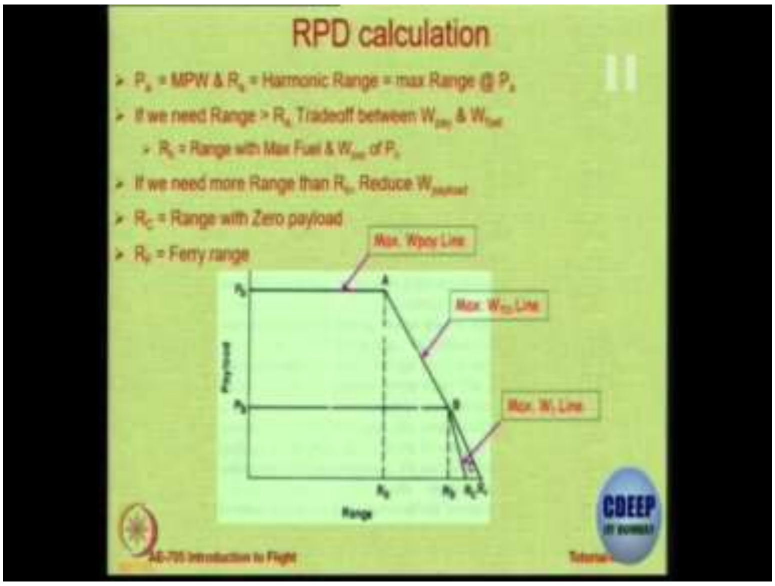
So then you go along line A to B, you are trading off payload for fuel, payload for fuel till you hit a point B, at point B the fuel tank is fuel. So payload range is not full but fuel tank is full and you have hit the maximum takeoff weight. Now you cannot add more fuel after that you normally will go only along line B to RB normally. Now some people say no no it is possible to travel more distance because aircraft is lighter so lighter aircraft will travel more distance so you reduce the payload further and because it is lighter it will travel more distance so some people assume there is a line, but normally we assume this line to be vertical and point C is a theoretical point which is the ferry range okay. I think it is clear to everybody alright. So max payload line, max takeoff weight line and max fuel line okay.

(Refer Slide Time: 19:48)



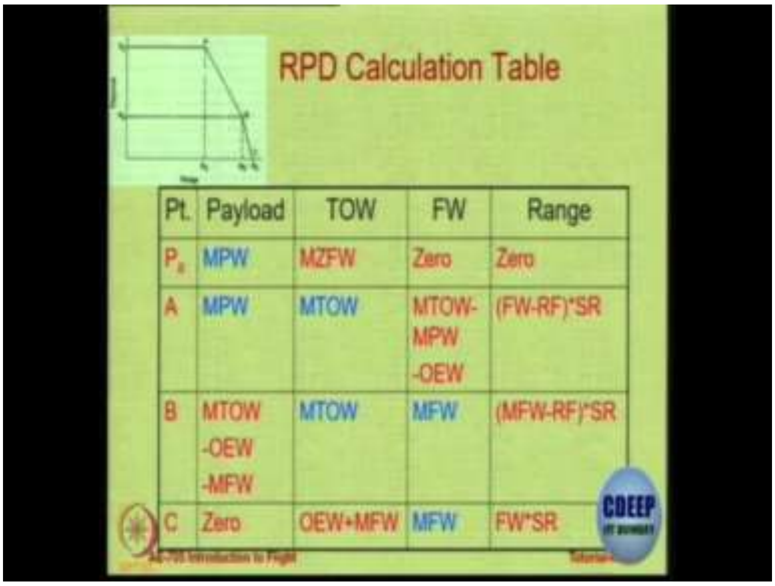
So let us see how we calculate these points. First point is very straight forward, so this table later on you will make for your aircraft okay. yeah it is not RC, the name I have given RF is because I want to distinguish between RF and RC.

(Refer Slide Time: 20:18)



RC is the range which you can get more than RB because the aircraft is lighter, but RF is a theoretical point the line is misleading RF is a theoretical point which corresponds to reserve fuel also consumed for range. Along RC you do not consume reserve fuel so when you go from B to RC you are travelling more distance by reducing payload but reserve fuel is untouched but when you go from B to RF actually you do not go from B to RF, RF is a very special point. This line actually should be removed, RF is just one theoretical point which is how far can you go with all fuel plus reserve fuel consumption. Yes, the definition of ferry range is complete fuel consumed including reserve fuel for distance alright.

(Refer Slide Time: 21:15)



So if you want to calculate this point, it is very straight forward in the payload column you put maximum payload weight, in the fuel weight column you put 0 hence range will be 0 okay and in the takeoff weight column you will put maximum zero fuel weight because what does it contain? It contains operating empty weight plus maximum payload, 0 fuel so this is maximum zero fuel weight. For point number A, what you should do is since it is on the inclined line the takeoff weight is maximum takeoff weight, since it is on the horizontal line payload weight is equal to the maximum payload weight.

So to get the fuel weight you just subtract from the maximum takeoff weight take out the payload weight, right and takeout the operating empty weight, remaining is only fuel so that fuel is available to you for the mission and for the reserve. So if you subtract from that the reserve fuel you get the mission fuel multiply this by the specific range you get the range you get the range can be travelled clear, you are going to do this now so you better understand what it is okay. Point number B, you can fill up the column for maximum takeoff weight and the maximum fuel weight because for point B intersection of two lines fuel weight is maximum fuel weight, takeoff weight is maximum takeoff weight.

So therefore the payload will be what you can carry maximum that is max takeoff weight minus operating empty weight which is minimum minus the fuel weight, remaining is payload it will be less then maximum payload. And from the maximum since your fuel tank is full so maximum fuel weight minus reserve fuel that is available for the mission into the specific range gives you the range. Point number C, payload is 0, takeoff weight is going to be operating empty weight plus maximum fuel weight payload is 0 fuel weight column you can fill in advance and the range now this is not C actually this is actually F this is F because we are saying range is equal to the total fuel into specific range so this is actually F point correct.

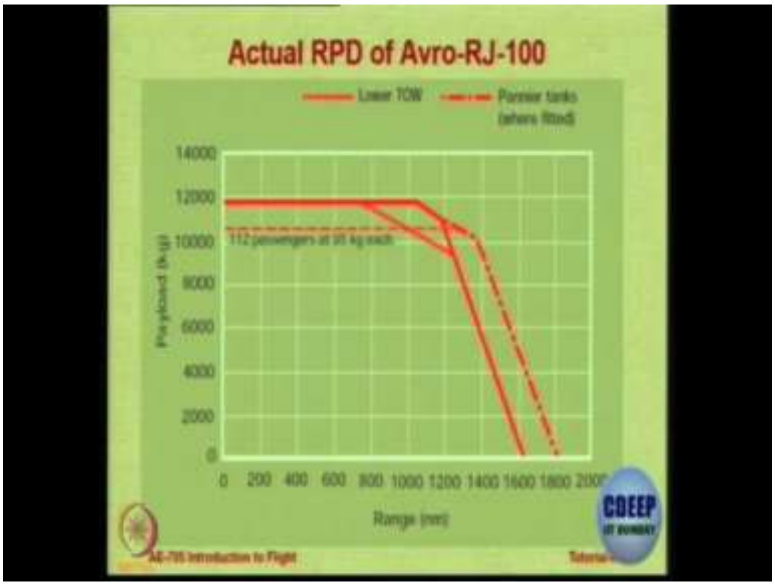
Now the point C actually yeah so the point C is changed with point F right, so this is the summary. Now I want you to spend just 1 minute looking at this and if you have any doubts you can ask me you should be able to appreciate this table. So the best way of doing this is whatever things you know the blue ones by definition you fill them first and other things you calculate okay. Point A is on the two line so therefore both of them are maximum payload and takeoff weight, point B is on two lines takeoff weight and fuel point C is on the fuel line maximum fuel and calculate the other things alright, right.

(Refer Slide Time: 24:53)

Now let us look at Avro RJ-100. So first assumption is specific range and these numbers are given okay these numbers we fix, we fill in because we know them you can check, you can check from the table above and see if you are okay with these definitions. So from PA to A you will have maximum payload, from A to B you have maximum takeoff weight from B to C you have maximum fuels so therefore those columns get filled up now you have to fill the remaining so this is your job now. Now you make this table and fill in the blanks there are just seven calculation you have to do seven numbers you have to calculate. So when you finish calculating all the seven quantities just raise your hand so I know that you are through.

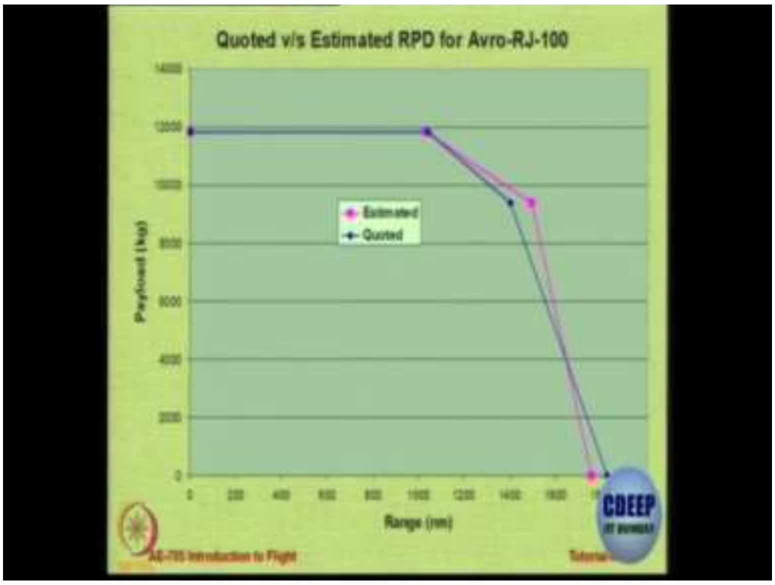
All the weights are in kgs and the range I want in nautical miles, done all seven okay. Okay so here is the table which is filled in now you can check your numbers all correct? Shall we go ahead? Okay.

(Refer Slide Time: 27:16)



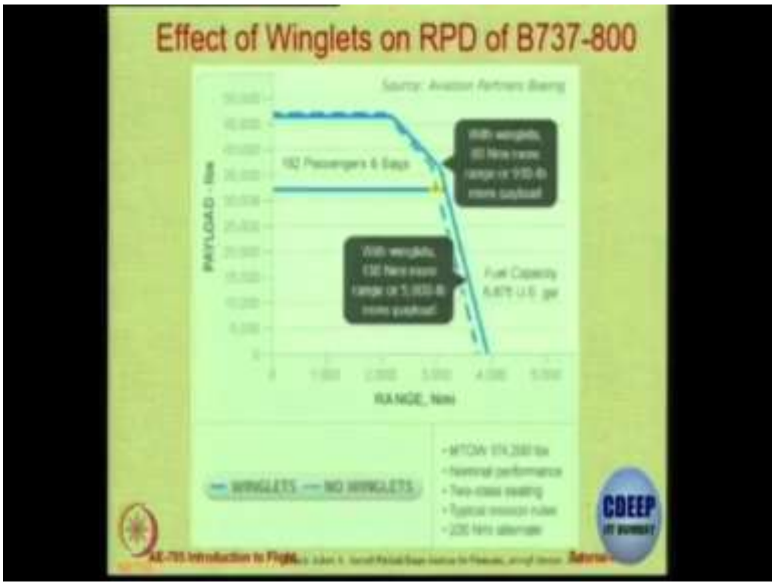
So this is the actual range payload diagram of this air craft from the operating manual from the aircraft manual and these pannier tanks basically are those additional fuel tanks that you can fit inside the aircraft for delivery purposes. So you can see that with 112 passengers at 95 kg each this is your range payload diagram, there is no line it is just increasing.

(Refer Slide Time: 27:52)



So you see this is estimated versus quoted, so whatever number we do in the class they are very similar to what are actual numbers

(Refer Slide Time: 28:05)



Just one more figure I want to show you, effect of winglets on the range payload diagram. This is a very interesting report which has come from and economist, there is a magazine called as aircraft monitor which is a magazine of aviation economists. So one aviation economists has done some calculation and he has shown what is the effect of putting winglets on a 737-800 right. So it just tells it concludes that if you put winglets you get 130 nautical miles more range or 5800 pounds more payload. So the airline has to weigh this against the cost of getting the winglet installed.

It would not be free of cost, the manufacturer or the company there are some companies also who do it, there are third party companies who make winglets for an aircraft. So you do not have to go to Boeing or Airbus only, you can go to some other company okay. One of our alumnus is working in such a company.