Introduction to Aircraft Design
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Lecture - 77
Tutorial on Range Payload Diagram of Transport Aircraft

Hello, let us look at how we can estimate the values of range payload diagram for a long range transport aircraft.

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We have taken Boeing 787 Dreamliner as our baseline aircraft for this tutorial. But the same method is applicable to any transport aircraft or for that matter any aircraft. Before you go ahead, I would like to remind you that you should do the tutorial only after you watch the video lectures regarding the procedure for the range payload diagram.

Because here we do not explain anything, we assume that you have already seen the tutorial, so we straightaway proceed with the calculations.

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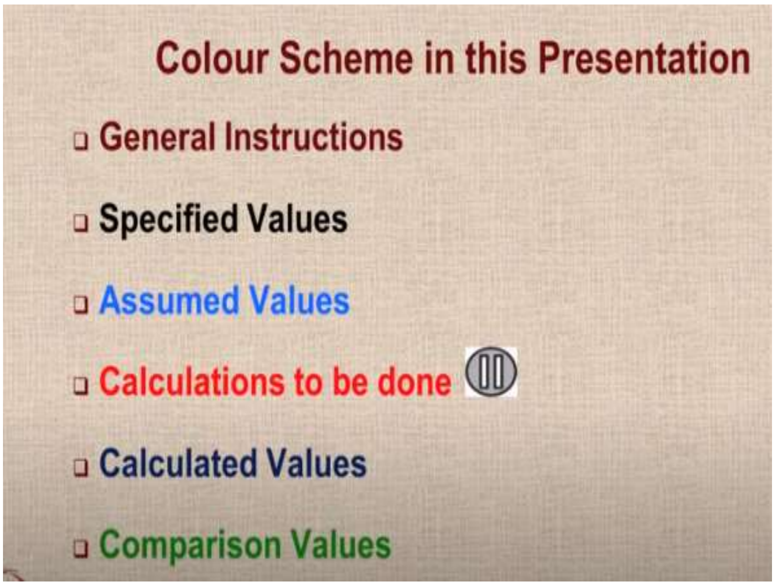

Once again, let us look at the color scheme in this presentation. The general instructions would be given in brown color. The values specified by any specifications of the aircraft will be shown in the black color, which are very few in this particular tutorial. The values which are assumed from sources that are considered as our basic information sources are shown in the blue color.

The calculations to be carried out would be highlighted by the red color with this pause symbol. So wherever you see this symbol, you are required to pause the video, do the calculations and then only move forward. Otherwise, you will not be able to practice. Remember, aircraft design is best learned by doing things and by calculations, not by just listening.

So it is very important that you do these tutorials along with the video as we go. The values which are calculated, are going to be shown in this dark blue colored font. And towards the end, we will do a comparison with the values quoted in an online source which is going to be used as a baseline source for us. Those values will be shown in the green color.

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Weight Build-up

		LB	KG
Max. Ramp Weight	MRW	478000	216820
Max. Takeoff Weight	MTOW	476000	215910
Max. Landing Weight	MLW	365000	165560
Max. Zero Fuel Weight	MZFW	340000	154220
Operating Empty Weight	OEW	239200	108500
No. of Passengers (standard)	n_{pax}	224	
Weight per passenger		210	95.2
Max. Fuel Capacity		32940 US gal	124691.5 lit

Source: Simos, D., B787-8 Sample Analysis (2005), *PIANO*, www.piano.aero

Moving ahead, let us first have a quick look at the typical weight build-up of an aircraft. And I am going to give you the values in pounds and kilograms. But I am going to use the values in pounds to do the calculation towards the end. Normally we work in the SI system, but we are going to make an exception in this tutorial. The reason is that the numerical values for this aircraft are given as whole numbers in pound.

So it is easier to remember and easier to do the calculations rather than converting them into kilograms. But for your appreciation, I am going to show you the data in both the units. However, when we proceed with the calculations, we will do the calculations only with pounds. So the first important parameter that we need to know is the maximum ramp weight MRW, which is 478000 pounds for this aircraft.

And then you have the maximum takeoff weight which is 2000 pounds less because 2000 pounds is the fuel that is earmarked for engine startup and warm up. And the maximum landing weight specified is 365000 pounds. The maximum zero fuel weight is 340000 pounds. The operating empty weight or the weight of the aircraft with the basic structure with the crew members and with the operational items is the operating empty weight 239200 pounds.

The aircraft cannot be operated with the weight below this. Above this weight you have to add payload and fuel till you can maximum hit the max takeoff weight limit or if you are counting in the fuel consumed during the warm up and engine out you can also load up the fuel up to the maximum ramp weight. The number of passengers which is standard in this aircraft is 224 although it can carry more passengers.

But for a standard analysis it is 224 and the weight per passenger as specified in the standard documentation is 210 pounds. This includes the weight of the passenger plus the permitted baggage. Total weight of the passenger plus their baggage is 210 pounds. And the maximum fuel capacity of these aircraft as mentioned in the source is 32940 US gallons. If you convert US gallons into liters the number that you get is 124691.5 liters.

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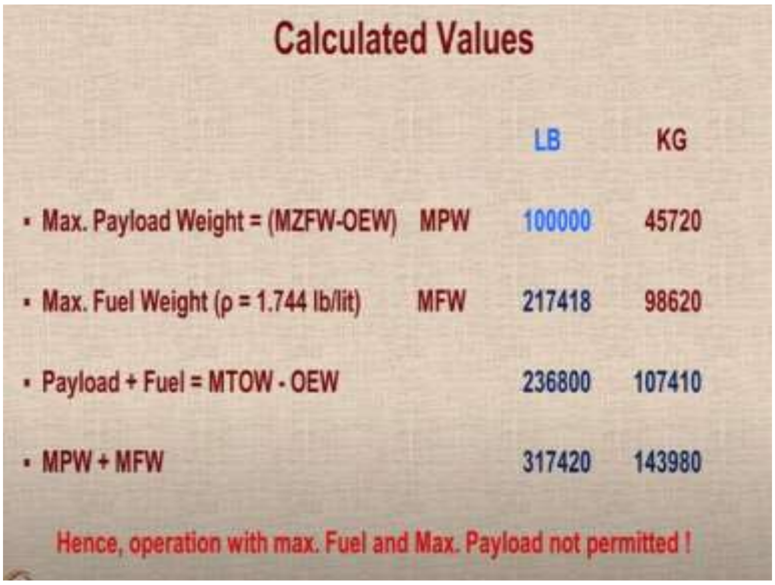

Let us look at some calculated values. So based on the values which I have just flashed, you would be able to now do some basic calculations to get the values. So the maximum payload weight will be the maximum zero fuel weight minus the operating empty weight. It is called as MPW and in this case it is also specified as 100,000 pounds. The maximum fuel weight is estimated by multiplying the capacity of the fuel in liters with a standard density value.

So the maximum fuel weight comes out to be 217418 pounds. This is a number that we need to remember because we will be using this number in the future. The payload weight plus fuel weight that means the combination of payload and fuel that you can carry is only up to maximum takeoff weight is what you are permitted minus operating empty weight, which is the minimum.

So the difference between these two is the summation of payload and fuel that you can carry and that for this aircraft is 236,800 pounds. Now if you add the maximum payload weight of 100,000 pounds and the maximum fuel weight of 217418 pounds, the number that you get is approximately 317420. So it is clear that you will not be able to operate at maximum payload and maximum fuel weight together and that is why we need to have a tradeoff. That is why we need to draw this range payload diagram.

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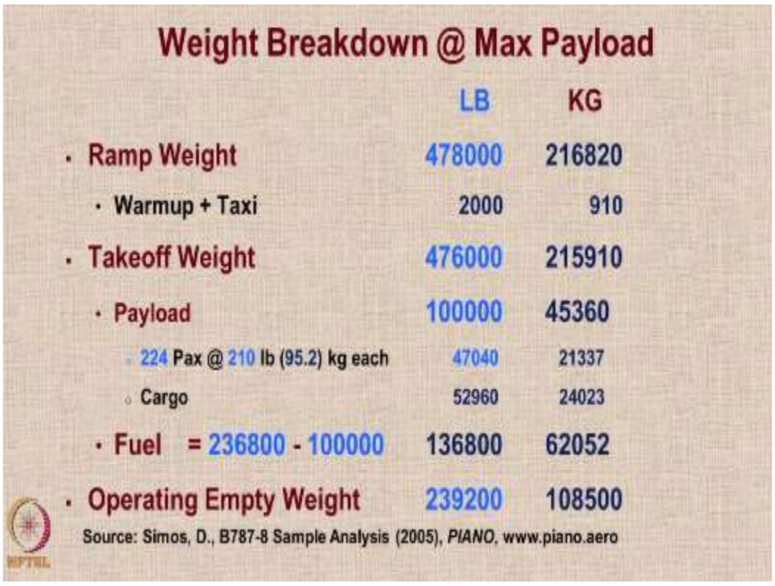

Now let us look at the weight breakdown of the aircraft when it is carrying the maximum payload. This is a very important operating requirement. An airline would like to never compromise on payload, because payload is what gives it profit. So they would like to know the breakdown at maximum payload. Once again we will look in two units. The ramp weight is already known, 478000.

Now the fuel which is consumed in warm up and taxi is specified as 2000 pounds and therefore the takeoff weight, that means the weight at the end of warm up and taxi is the weight which is allowed to be carried on the wheels that is 476000 pounds. In this the payload is 100000 pounds, which is 224 passengers at 210 pounds or 95.2 kgs each. 47040 another important number which we will use later for the max payload case.

So if you are carrying maximum payload with all passengers since you can carry 100000 pounds and the passengers and their baggage occupies only 47040 pounds. Therefore, you are able to carry cargo of 52960 pounds, which is to be carried in the belly of the aircraft.

Now the fuel that you can carry for this particular mission would be from the zero fuel weight you know you have to take out the maximum payload weight and you will get the value of the fuel that you can carry that is 136800 pounds. Now with so much fuel you would be able to move a particular distance which we will calculate and the operating empty weight as we all know is 239200 pounds.

The source of the data is the same as mentioned in the previous slide and also in the bottom of this particular slide.

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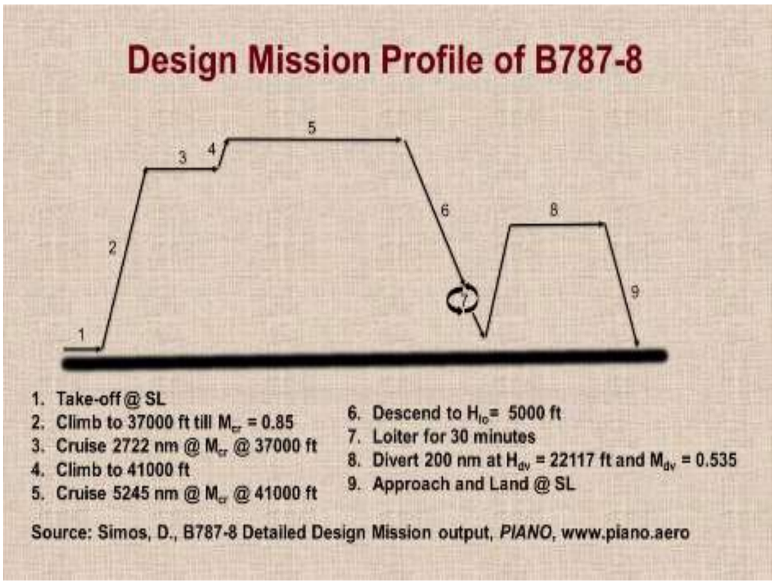

Let us look at the design mission profile of Boeing 787-8 for which this particular calculation was shown. So the first segment is the takeoff segment that occurs at sea level. We do not consider any credit for the distance traveled in this particular phase because you are at the same airport. The next segment of the mission is the climb which occur still height of 37000 feet where the Mach number is 0.85.

In reality this climb is actually in three or four separate phases. So takeoff ends when you reach the obstacle height of 35 feet and climb ends when you reach the cruising Mach number of 0.85. In between there is one level flight acceleration. Then there is a initial climb to 1500 feet. Then there is a climb to 10,000 feet. Then there is a climb to the cruising altitude and then there is an acceleration to the Mach number of 0.85.

All that we are combining together into this one climb just for simplicity. Once you reach the cruise Mach number of 0.85 at the specified cruising altitude of 37,000 feet, then you can do the first leg of the cruise which is 2722 nautical miles in a level flight. So you maintain the cruising altitude as 37,000 feet, okay and you cruise at a Mach number of 0.85 which is basically 488 knots true airspeed.

Then you do a small climb of around 4000 feet to from 37,000 feet you go to 41,000 feet. The reason for this is that the aircraft is now lighter, because it has consumed quite a good amount of fuel in segment number three, the first cruise segment. So the desired altitude or the optimum altitude for the cruise for the next cruise segment would be higher because the aircraft is lighter.

So you go to you climb up to 4000 feet. So there is a small climb segment. There will be some distance traveled and some fuel consumed also in this segment. And then you do the next cruise which is 5245 nautical miles at the same cruise Mach number of 0.85. But the altitude is 41,000 feet. And then actually you do not just do a level flight.

You also do a deceleration okay, but we are including that thing in one single cruise segment for simplicity. And then you actually go for a descent. In that descent you go from the cruising altitude of 41,000 feet to the holding altitude of 5000 feet. So then you need to have enough fuel for about half an hours of hold at 5000 feet near an airport waiting for the airport to be available.

So you need to you may not do this every time and sometimes you may do hold more than 30 minutes, but you need to have a provision for minimum 30 minutes of hold. And then there is a possibility that when you come into land, there is some issue maybe there is a visibility issue maybe there is some other issue. So you have to miss the approach and divert to a diversion destination, which is supposed to be located at around 200 nautical miles.

So you need to have enough fuel for a diversion to 200 nautical miles while flying at a Mach number of 0.535 at a height of 22,117 feet. These numbers have been obtained by the manufacturer based on their assessment of what would be the most optimal altitude and the Mach number for carrying out the hold under the standard ISA conditions. After this, you have the approach and land, okay. So this is the design mission profile of Boeing 787-8.

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Design Mission Breakdown for B-787-8

- Total Cruise Distance (nm)
- = 2722+56+5245 =?
- = 8023 nm
- Total Cruise Fuel (lb)
- =61772+1487+98329 = ?
- = 161588 lb
- Cruise Sp. Range. (nm/lb)
- = 8023/161588 = ?
- = 0.04965 nm/lb
- Non-Cruise Range (nm) = ?
- = 176+129 = 305 nm
- Non-Cruise Fuel (lb) =?
- = 458+9395+436+328+137 = 10754 lb

Segment	Time (min)	Distance (nm)	Fuel (lb)
Warmup &Taxi-out	10	0	2000
Take-off	1	0	458
Climb	27	176	9395
First Cruise	335	2722	61772
Step Climb	7	56	1487
Second Cruise	645	5245	98329
Descent	21	129	436
Approach	2	0	328
Landing &Taxi-in	1	0	137
Mission Fuel	1050	8328	172341
Diversion	39	200	5040
Holding	30	NA	3620
Reserve	NA	NA	8617

Now let us look at the detailed breakdown of weight consumed or fuel consumed, distance traveled and time taken in all these small segments. So the first one is the warm up taxi-out segment which as I mentioned, does not get any credit for distance. The fuel provision for this segment is 2000 pounds. This is above the maximum takeoff weight in this particular aircraft. So this only adds up to the ramp weight.

And the time given for that is approximately 10 minutes. The next segment is takeoff which happens in about one minute. Again, we do not worry about the distance traveled but we do have to consider good amount of fuel which is gone. So that fuel is approximately 458 pounds during takeoff. And then we have those multiple climb segments. Adding all of them together you reach a height of the cruising altitude of 37,000 feet in about 27 minutes.

But during this time you travel a distance of 176 nautical miles but you have also consumed, the aircraft also consumes 9395 pounds of fuel. Then you have the first cruise segment which lasts for about 335 minutes, okay. And in this particular segment, the distance traveled is 2722 nautical miles close to around 5000 kilometers and the fuel consumed is 61772 pounds.

Then you go in for a stepped climb which is approximately 7 minutes. You climb from 37,000 feet to 41,000 feet. During this climb you travel a distance of 56 nautical miles and you consume 1487 pounds of fuel. Then you do the second cruise which is a much larger cruise almost double of the previous cruise. This also lasts for almost double the time, 645 minutes okay.

And in this particular segment you cover 5245 nautical miles and the fuel consumed is 98,329 pounds. So a large amount of fuel is consumed in the first cruise and in the second cruise and also in the climb phase. Once you finish you reach the destination, now you do a descent. The descent segment takes around 21 minutes and the travel, the distance traveled is 129 nautical miles. The fuel consumed is 436 pounds.

Notice that the fuel consumed in descent was neglected in, it is neglected when you do the initial sizing because of the approximations in the procedure. But good amount of fuel is consumed in descent, almost as much as that you consume during takeoff. Once you do the descent you reach the low altitude and then you do an approach which goes for about two minutes.

During approach you are already actually almost at the airport. So we do not count the distance traveled, but fuel consumed is 328 pounds. And then finally, you have landing in and taxi, landing and taxi in. Fuel consumed during landing is actually neglected okay, so we do not worry about fuel consumed during landing. But in taxi of course, there is some amount of fuel consumed and the whole time taken is about one minute.

And no distance credit is to be given. So if you add all the numbers which are mentioned above as far as the except the first segment, except the warm up and taxi-out segment, which is not really counted. If you add all the other segments, you get a total mission fuel of 172341 pounds. Total distance traveled of 8328 nautical miles and total time taken of 1050 minutes for the mission okay.

Now remember that we need to have fuel for diversion. So for this aircraft, the diversion fuel is 5040 pounds. The diversion distance as I already mentioned, is 200 nautical miles and the time taken to divert is 39 minutes. Then you have 30 minutes of holding.

During holding you are circling over the airport, so you do not have any distance credit, but you do consume fuel.

And the half an hour of flight consumes 3620 pounds of fuel for this aircraft at approximately 5000 feet under ISA conditions at the landing weight. And finally, we have fuel as a reserve fuel which is meant for either the fuel which is blocked in the pipeline or the fuel that is to be made available for any navigational errors or any weather issues, okay. So for that, what we normally do is a certain percentage of the mission fuel is kept aside and never consumed, that is the reserve fuel.

8617 pounds in this case is the reserve fuel. So with this information, which has come from the document uploaded by Simos on the PIANO website let us do some observations now. So the total cruise distance that would be traveled would be in the first cruise, second cruise. And let us also include the distance traveled in the step climb as a distance in cruise. So that would be if you add the distances it would be 2722 + 56 + 5245.

So at this place, I would like you to pause and calculate this number. It is a simple addition. So with this you will know that the total distance traveled in the cruise is 8023 nautical miles, okay. Remember this is only cruise. To this we have to add the distance in the other non-cruise segments. Let us look at the total cruise fuel. Total cruise fuel would be the fuel consumed during the first cruise, during the step climb and the second cruise.

That number I would like you to pause the video and do the calculations to get this number. That number would turn out to be 161588 pounds. So much of fuel is available for you to do the mission. So now we know how much fuel is consumed in the cruise and we also know how much is the distance traveled in the cruise. So what we can do is we can get an approximate value of the specific range in nautical miles per pound during the cruise segment.

Remember we have included the step climb inside cruise. So we are not distinguishing between first cruise, second cruise and step climb. We combine them together into one big cruise. So this number would be the distance 8023 divided by the fuel in cruise

161588. Please pause the video, do this calculation. The number turns out to be 0.04965 nautical miles per pound.

So in this tutorial, we will assume henceforward that unless specified this particular value of the specific range would be used in the calculations. Now as I mentioned during other segments other than the cruise also some distance is traveled. So as far as the aircraft is concerned, it is a part of the range. So what would be the non-cruise range?

It would be the distance traveled in the climb, descent phases, okay. And that would be 176 + 129. That is 305 nautical miles. I hope you had paused the video and done this calculation. Whenever you see the symbol whenever you see this particular symbol, whether I say it or not, you are supposed to pause the video and then do the calculations, okay. Finally, let us look at what is the fuel consumed in the non-cruise segments.

That would be the fuel consumed in the takeoff, in the climb, in the descent, in the approach and the landing and taxi-in. That is a part of the non-cruise part of the mission. So that would be 458 + 9395 + 436 + 328 + 137 which would be 10754 pounds okay. So that much fuel is consumed in the non-cruise segment and the distance that is traveled is only 305 nautical miles.

So these numbers have to be remembered because we are going to keep these.

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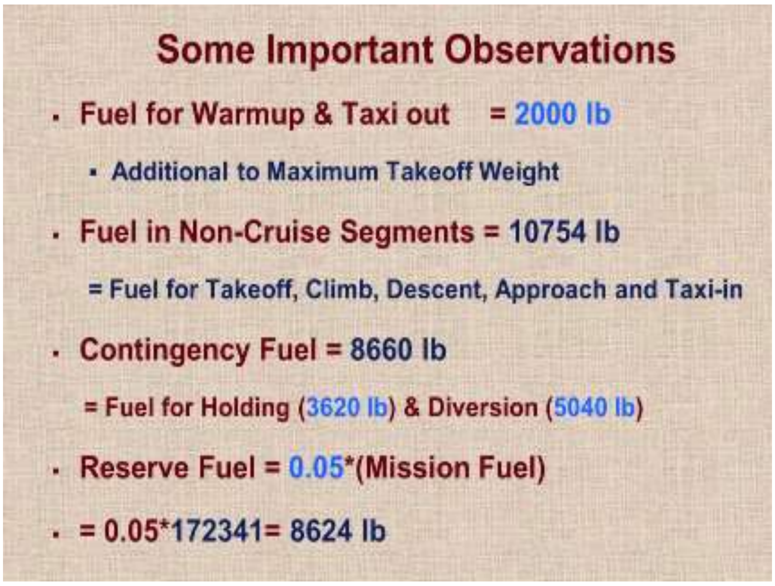

So there are some important observations. Fuel for warm up and taxi out is 2000 pounds, but remember this is out of our calculations, because this is additional to the maximum takeoff weight in this particular aircraft. This is the one that adds up from the maximum takeoff weight to the maximum ramp weight in our case. Fuel in the non-cruise segments is 10754 pounds as we just calculated.

I am writing this again so that you can remember. You can note down this and you can remember this number because we will use this number in the calculations that follow. The contingency fuel is the fuel for two contingencies, the holding and the diversion. So for hold it is 83620 pounds given in the document and diversion 5040. So if you add them together in every flight, you will have to carry a contingency fuel of 8660 pounds okay.

And the reserve fuel will be a given fraction, in this case 5% of the mission fuel. So in our case, it is actually 0.05 into 172341 which is our mission fuel weight for this particular design mission that turns out to be 8624 pounds. So this number will keep changing depending on the mission. For the design mission, this number is 8624 pounds. So my suggestion is that these numbers you have to note down.

What you could do is just take a picture of this slide and keep it next to you. So that when you do the calculations, this information is always handy with you.

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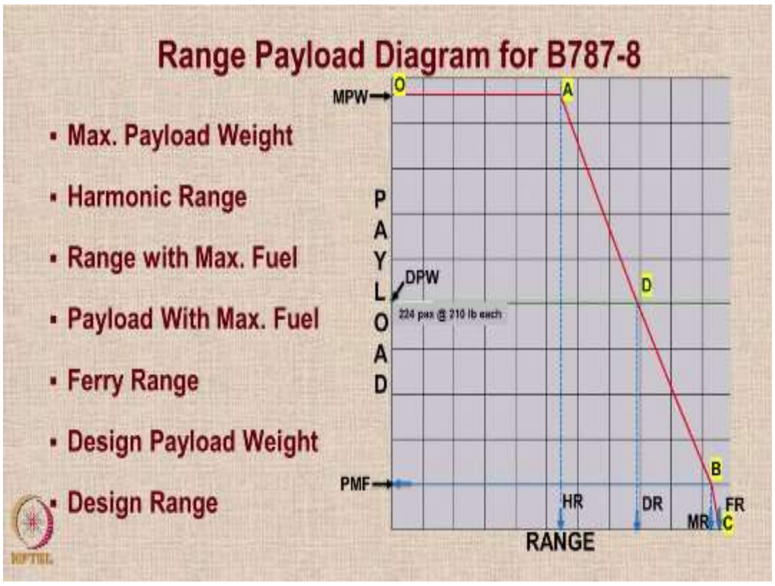

So this is the basic range payload diagram for a general aircraft okay and for 787 the design mission involves 224 passengers at 210 pounds each. So the green line in the screen represents the condition for the range with the payload equal to the design payload. So in this diagram, the x axis is the range and the y axis is the payload okay. So this is the diagram that we are going to draw for Boeing 787.

First let us understand the various components. So the first point which we need to look at is the point O. Now O is a very trivial point. It represents zero range and full payload. So here what you do is imagine that you have the aircraft with operating empty weight, and you have you put in the full payload that you can carry and then you just stay at the airport.

That is operating condition corresponding to point number O at which the payload weight is the maximum payload weight, okay. That is the only condition which is applicable for point number O. So the range will be zero. And also the aircraft weight will not be the max takeoff weight because you have not added all the fuel. You have added zero fuel actually, okay.

In fact, you have added the contingency fuel. You have added the reserve fuel, but you have added zero fuel for the mission and therefore, your range is zero. The next point is point A, which is a very important point as far as an airline is concerned. Airlines are very keen to know the value of this point A for any aircraft that they operate. In fact, when they compare two aircraft seldom their comparison is based on this particular point A.

They would like this point to be as high as possible. That means as up as possible and as far as possible, okay. So what is this point? This point corresponds to harmonic range. Harmonic range basically is the maximum range that an aircraft can travel with full payload and so much fuel that now you cannot add more fuel even though your fuel tank is not full. But you cannot add more fuel because you have hit the maximum takeoff line. That is the harmonic range.

The next point is point B, which corresponds to another inflection where B represents the point where your fuel tank is full okay and the aircraft weight is also able to match takeoff weight. So you just add enough amount of payload so that fuel weight plus payload weight becomes equal to the maximum permitted fuel and payload weight that can be carried by the aircraft. So this particular point corresponds to MR which is the range with maximum fuel.

And for point number B, you have one important input which is how much range it can travel because now you have reduced the payload. But you also need to know what is the payload for maximum fuel that is PMF. So the payload for maximum fuel is obtained directly from the range payload diagram. This is an important number that we need to calculate for our aircraft also.

The next important point is the ferry range or point number C, which is where the graph touches the x axis. The ferry range is used to ferry the aircraft from origin A to destination B. Some applications of ferry range are when you are sending the aircraft for maintenance or when the aircraft is being delivered. One option is that you can install some additional tanks they are called as Pannier tanks inside the fuselage to increase the range further.

But that involves expenditure that involves approvals etc. So suppose I would like to know how far my aircraft can travel with zero payload and full fuel then because such flights are done very rarely and under the very close supervision, then what we also permit as a special case is that we permit the reserve fuel to be consumed, because we do have contingency fuel.

So contingency fuel is to be carried, but reserve fuel can be merged with the mission fuel. So the mission fuel here will be equal to the total fuel capacity of the aircraft without any internal tax minus the fuel for contingencies. Remaining all fuel is available for the ferrying of the aircraft. This is permitted because ferry of the aircraft is done under very special approvals and permissions.

So it is allowed that it is assumed that you may not require any fuel for any other reserves. And then we have the point D, which corresponds to the design payload weight okay, which in this case is 224 passengers at 110 pounds each. And corresponding to that particular thing on the diagram, you also have a design range, okay.

So now what we are going to do is, we are actually going to calculate these points OADBC for Boeing 787-8 and then we will compare the values with those quoted in the literature.

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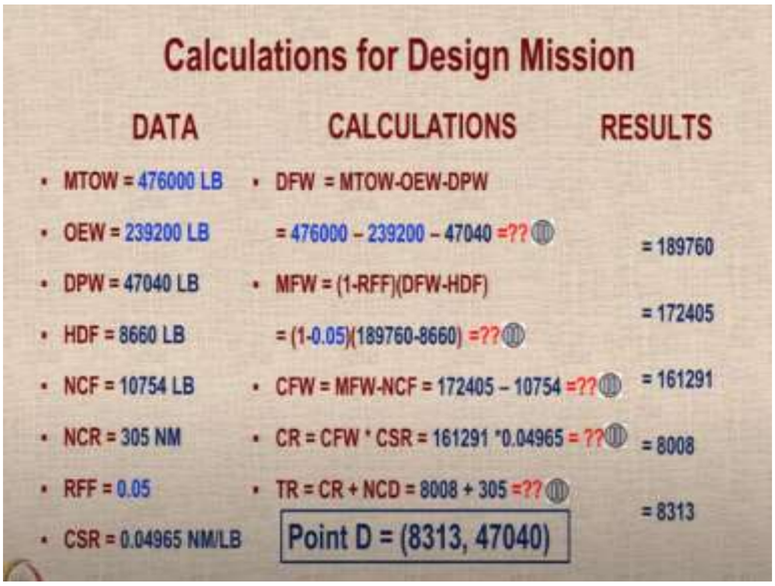

So let us first do the calculations for the design mission. So the information is going to be presented to you in three separate columns, the first representing data, which is the input information. The second calculations, which are numbers or procedures to be calculated. And finally, there will be another column which will contain the results of these calculations.

So I would request you to pause the video whenever you see the pause sign, and then calculate the result of that particular specific step and match it with the value that has been mentioned in the results column. So first, let us look at the data that we will need to calculate the range payload diagram for the design mission. This is remember point number D. So max takeoff weight 476000 pounds, operating empty weight 239000 pounds.

The design payload weight, which we calculated was 210 into 224, which is 47040 pounds. HDF stands for the handling and diversion fuel. This is not a standard designation, this is the number just I have given that. So do not quote me anywhere and say that what is the HDF of your aircraft? In our calculations, HDF stands for handling and descent fuel, which as you know is 8660 pounds.

So in each mission, so much fuel has to be kept aside from the total fuel available in the fuel tank for this particular this particular contingency. Then NCF is the non-cruise fuel. That means the fuel which is consumed in all the non-cruise segments, which as you know is 10754 pounds. NCR is the non-cruise range or the range of 10 in a non-cruise mission. That means the distance traveled in all other segments put together added together is NCR.

The reserve fuel fraction is given as 0.05. And we have also calculated in the previous slide the cruise specific range or CSR as 0.04965 nautical miles per pound. Let us do some calculations now. First we need to calculate what is the design fuel weight or fuel weight in the design mission. That number will be obtained from, from the maximum takeoff weight you take off the operating empty weight that would be consisting of fuel and payload.

And from there you subtract the design payload of 47040 you will get the value of the design fuel weight. So to do this calculation, I have put in the numbers for your convenience for the values of MTOW, OEW and DPW. Now you can pause the video and calculate what is the design fuel weight of this aircraft, okay. And that number turns out to be 189760. Now let us move ahead.

The mission fuel weight is going to be one minus reserve fuel fraction into the design fuel weight minus the handling and diversion fuel. So essentially 5% of the fuel is kept reserved for contingencies as I mentioned to you; navigation, fuel block in the pipeline and also for missed approach etc. So that number can be estimated by a simple calculation. Please pause the video and do the calculation.

It will be one minus reserve fuel fraction into the design fuel weight that we have just now obtained minus the fuel that is to be kept aside for holding and for diversion. So with that, this number is 172405 pounds. Now so once you have this value of the mission fuel weight, you can now estimate how much fuel is available for the cruise mission.

So cruise fuel weight will be the mission fuel weight minus the non-cruise fuel because from the mission fuel available to you 172405 you are going to do 10754 pounds of consumption in non-cruise phases. So therefore you know that for cruise you have 161291 pounds. Now since you know the average cruise you know the value of the average cruise specific range 0.4965.

So you just multiply how much is the fuel available for cruise with that number and you will get the value of the distance traveled. So the distance traveled in cruise is 8008 nautical miles. But remember that 305 nautical miles can be traveled in the climb and the descent phases itself. So that number we need to add. So finally what we get is that we get the total distance to be 8313 kilometers.

In other words, the coordinates of point number D are if you look at the first one is the value of the range and the second point is the value of the payload, okay. So x and y. So the point D has a coordinates of 8313 nautical miles and 47040 pounds of payload.

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Moving ahead, let us calculate for the harmonic range. As I mentioned harmonic range corresponds to the range with no compromise on payload that is the maximum payload, okay. So for this again we have three blocks the data, the calculations and the results. The data block is very much the same, except that there are certain new things. We know now that the maximum payload weight is 100,000 pounds.

Earlier it was 47040 but now the maximum payload weight is 100,000 pounds, because we are looking at harmonic range where the payload is the maximum payload weight. The handling and descent, holding and descent fuel remains the same. The non-cruise fuel remains the same. The non-cruise range remains the same and the reserve fuel factor also remains the same.

And we will also assume that the value of the cruise specification also is the same. So to do the calculations first we need to find out what is the fuel weight for this particular condition. Earlier we had calculated the design fuel weight for the design mission. Now we will calculate the fuel weight available for the harmonic range. Now that will be quite simply the maximum takeoff weight minus operating empty weight which corresponds to the total of payload and fuel.

So from there you remove the maximum payload weight of 100,000 pounds. You will get the fuel weight available. So I put the numbers for your convenience. I would request you to pause the video and do these calculations. The number comes out to be 136800 pounds, okay. Now once again we have the same formula for the mission fuel weight, which would be one minus reserve fuel fraction into the fuel weight minus the fuel for contingencies of holding and diversion.

So this the numbers inserted in the formulae are as shown on the screen. Please pause the video and do this calculation to get the value of the mission fuel weight for the harmonic range. The number turns out to be 121733 pounds, okay. So if we know the value of the mission fuel weight, you can calculate the cruise fuel weight which will be the mission fuel weight minus the fuel that is required by the non-cruise segments, okay so non-cruise fuel.

That will be 121733 - 107584. Once again pause the video and do this calculation. This number turns out to be 110909. So so much of fuel is available for cruise and each pound of fuel gives you 0.04965 nautical miles of range. So therefore, you can get the value of cruise range as the cruise fuel weight into the cruise specific range.

The answer is 5510 nautical miles. So therefore, the next thing is the total you know the total range in the harmonic range case or the harmonic range that would be the cruise range CR plus the distance traveled in the non-cruise segments. So it is 5510 during the cruise plus 305 during the non-cruise segments. So it comes to 5815.

In other words, the coordinates of this particular point which is point number A, they will be 5815 would be on the x axis that is the range and we know that 100,000 pounds is the coordinates on the y axis because that is the maximum payload.

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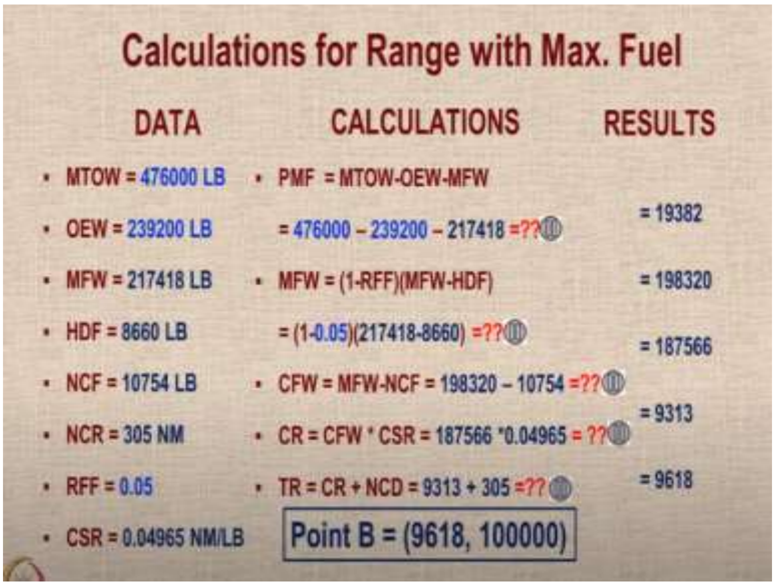

Moving ahead, we look at the calculations for range with maximum fuel. Once again we have data, calculation and results blocks. In the data the first numbers are the same, okay. Fuel weight now is the maximum fuel weight because this is the condition for range in the maximum fuel. Holding and descent fuel will remain the same. NCF will remain the same. NCR will remain the same. RFF also will remain the same.

And we assume that the cruise range also remains the same because even here the aircraft weight is equal to max takeoff weight. So therefore, whatever improvements you get in the fuel consumed during climb and descent that improvement will not be there because this is the max condition anyways. So let us look at what is the value of the payload with maximum fuel condition.

That would be the maximum takeoff weight minus operating empty weight okay minus the mission fuel weight which is actually the maximum fuel weight. So with that you will know how much payload you can carry. This number will be 476000 maximum takeoff weight minus 239200 that is operating empty weight. Remaining will be payload plus fuel. Payload is to be calculated. Fuel is 217418.

So therefore, pause here and calculate the value of PMF. It turns out that PMF is 19382 pounds. Now once again the mission fuel weight will be one minus RFF into MFW minus HDF. So what we have done here is we have just taken maximum fuel weight subtracted from that the fuel consumed during the descent and diversions sorry, holding and diversion segments, okay.

So you should pause now and you should do the calculations. The value comes out to be 198320. Moving ahead, the fuel available in the cruise segment in this case will be cruise fuel weight. That will be the maximum fuel weight minus the non-cruise fuel 10754, okay. We just consumed other phases. So let us calculate this number and get the answer for what is going to be the total fuel available for traveling a particular distance.

Turns out that that number is going to be 9313, okay. So 9313 is basically 187566, which is the total cruise fuel available into the specific range of 0.04965. So the total distance traveled would be the distance traveled in cruise that is 9313 plus distance traveled in non-cruise segments, which is 305. So that is 9618. So therefore, the coefficients for point number B would be 9618 on the x axis and 100,000 on the y axis.

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Finally, we look at the last calculation which is for the ferry range. So remember that again there are three columns. The first one is data. So here operating empty weight is known. Maximum fuel weight also is known. Now the payload for the fuel ferry range is zero because ferry range occurs with zero payload. And also the handling and diversion fuel is also available.

So we assume here that we do not keep any fuel for any holding or for diversion and also we do not carry any payload. So the entire fuel is available for the mission. The non-cruise fraction still remain the same and the non-cruise range also remains the same because we are assuming everything to happen at the same cruising altitude. The CSR value will be 0.04965 again.

So the takeoff weight is going to be operating empty weight plus maximum fuel weight which would be 239200 plus 217418. That comes to 456118. The fuel weight is maximum fuel weight which is 217418. So we do not have to do any calculations. The cruise fuel weight will be the fuel weight available totally minus the fuel consumed in the non-cruise segments. So that was 206664 pounds okay.

So therefore, if you assume the same value of the cruise specific range you just multiply that number with this particular fuel you will get the range as 10,261. Remember that some distance is also traveled in the non-cruise segments, okay. So that is the non-cruise distance NCD and that comes to 305 nautical miles, okay. So here we use NCD and NCR interchangeably. They are both the same. So point number C turns out to be 10566 and zero.

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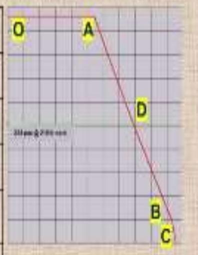
RPD calculation for B-787-8

SR_{cruise} = 0.04965 nm/lb

MTOW = 476000 MPW = 100000 OEW = 239200 MFW = 217418

Pt.	Payload	TOW	FW	Range
O	100000	339200	Zero	Zero
A	100000	476000	136800	5815
B	19382	476000	217418	9618
C	Zero	456118	217418	10566
D	47040	476000	189760	8313



So if you now create a table where you can draw the we can draw the range payload diagram of this aircraft. Some fixed numbers which we need to know are first mentioned on the top. Let us look at point number O which is a trivial point. It corresponds to maximum payload corresponds to zero range, okay. So the payload is 100,000 pounds. The fuel weight is zero hence range is zero.

The takeoff weight is basically the operating empty weight plus the maximum payload weight which is equal to the zero fuel weight 339200. Then going to point number A this corresponds to the harmonic range. So in harmonic range, the payload is maximum, payload 100,000 pounds. Takeoff weight is 476,000 pounds which is the maximum takeoff weight. The range is 5815 and the fuel weight is 136800.

Then we come to point number B, which is the point with the fuel tank full and maximum takeoff weight condition. So the numbers takeoff weight and fuel weight come automatically from the nature of the data. And then the range is 9618 as we just now calculated and the payload by calculation would be 19382 pounds. And finally we have the ferry range or the range which corresponds to zero payload, okay.

So you use the full fuel but you have zero payload, and the takeoff weight is actually around 2000 pounds lighter here. So therefore, it will travel little bit more distance. So it is 10566 nautical miles total distance traveled. And finally, we have point number D, which is our design point and for that we already know the value of payload. And we also know the value of the range, because we have just calculated this.

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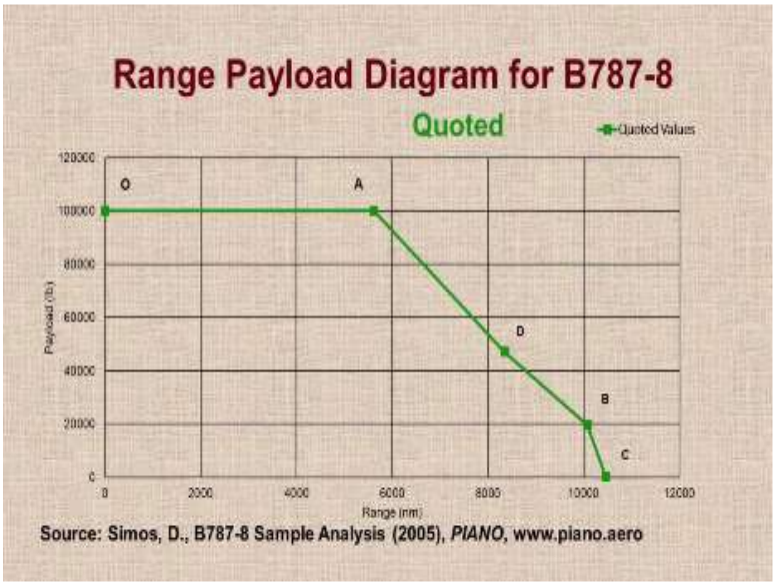

Let us see how our calculations compare with the quoted values. This graph is taken from the Boeing 787-8 sample analysis by Dmitri Simos using PIANO software, where the points OABC and D are marked in the green color.

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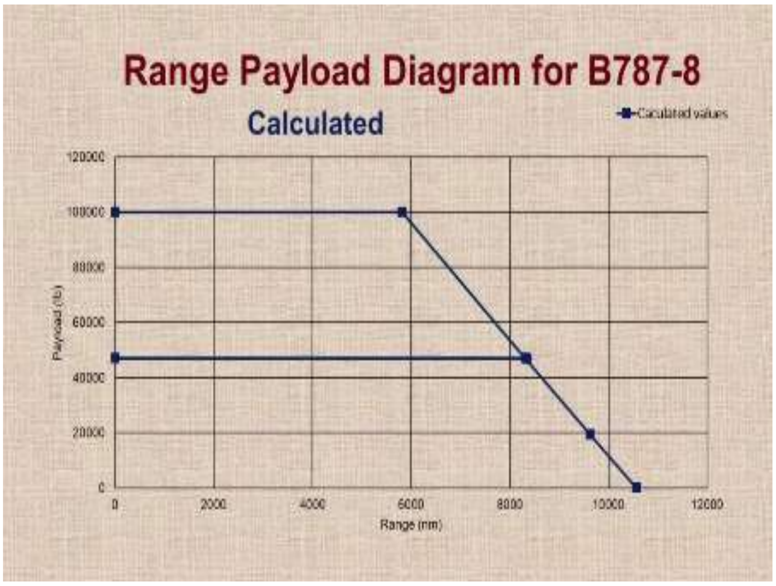

And here is the calculation that we did for the design payload range as well as for the other points. So now let us see how do they compare.

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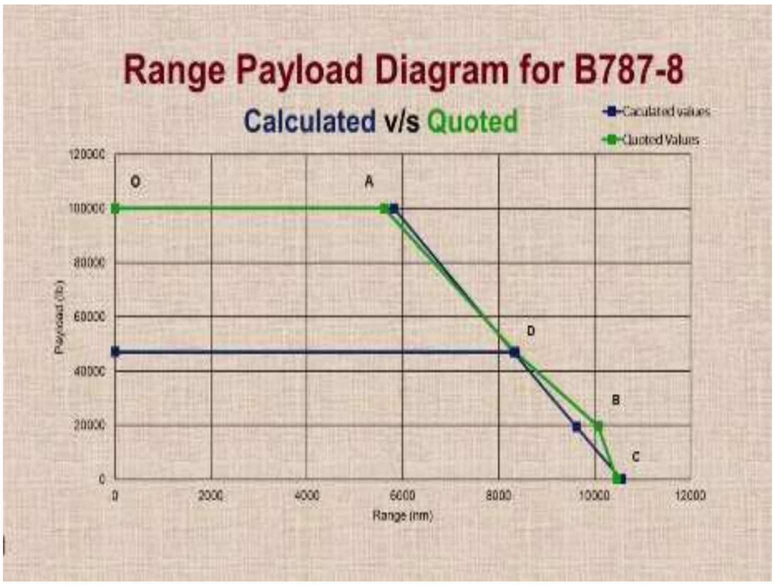

If you plot one over the other, you can see that there is a very good comparison, okay. There is a very good comparison.

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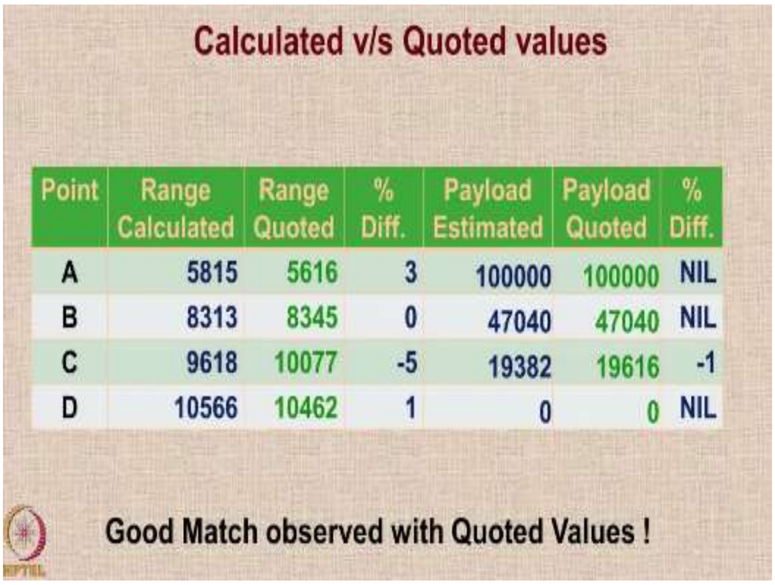

Calculated v/s Quoted values

Point	Range Calculated	Range Quoted	% Diff.	Payload Estimated	Payload Quoted	% Diff.
A	5815	5616	3	100000	100000	NIL
B	8313	8345	0	47040	47040	NIL
C	9618	10077	-5	19382	19616	-1
D	10566	10462	1	0	0	NIL

Good Match observed with Quoted Values !

So for point number A, the range that we calculated is 5815 and the range which is quoted is 5616. So we have around 3% difference. Payload is not actually calculated is known 100,000 pounds, so there is no error in that. For point number B, we know that the payload is nothing but total number of passengers 224 into weight of passenger plus baggage that is 210.

So there will be no error in the payload calculation, it is a trivial thing. But the range that you get is you know approximately so you can see it is less than a1% error. For the point number C, which is the ferry range, actually here there is some difference, about

5% difference in the value that we calculate and the value that we estimate and similarly, there is also a 1% difference in the payload.

And for point number D, we already know that the payload is zero. So there is no big achievement there. But the achievement is that you are able to get the design range within 1% within 1% accuracy, okay. So we conclude that there is a very good match observed with all the quoted values except for 5% variation in the case of point number C.

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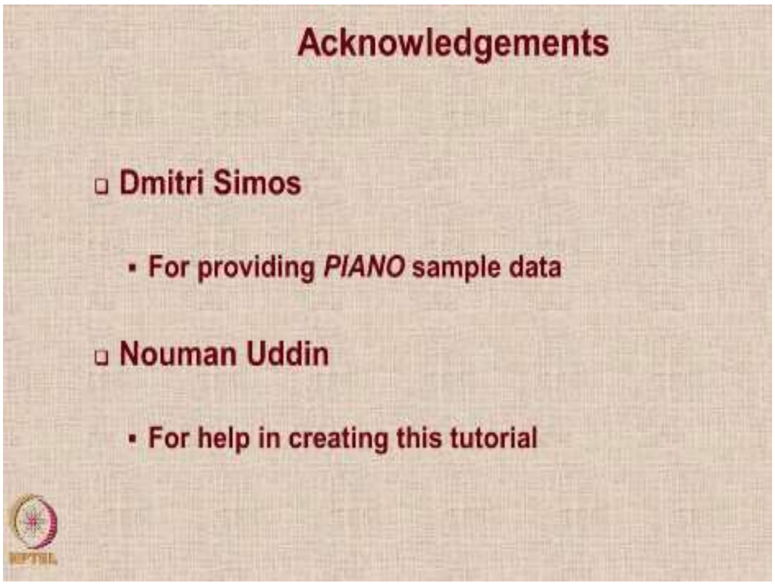

Now before I end, I would like to acknowledge two people who have been very instrumental and helpful in making this presentation. The first of course, is Dmitri Simos, who has provided the sample data for PIANO software online. But for this information, we would not be able to do the detailed calculations as we have done.

And secondly, I want to thank Nouman Uddin for helping me in creating the presentation, doing some calculations for me and also plotting the chart that you saw. Thanks for your attention.