Introduction to Aircraft Design
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Lecture -71
Tutorial on RDT and E and Production Cost Estimation of Transport Aircraft

Let us have a look at how we estimate the research development testing and engineering or RDT and E cost.

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And also the aircraft production cost for a given amount of production run. We have taken Boeing B 787-8 Dreamliner as our test case for this exercise.

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We are going to follow a color scheme in this presentation as always the general instructions are going to be given in this brown color. If there are some values which are specified in some sources we would show them in black color. The values which are assumed are shown in this light blue color. The places where you need to do some calculations will be shown in red color and they will be this symbol which represents a pause button.

Wherever you see this symbol you are expected to pause the video do those calculations and only then proceed further. I would like to reiterate that you will learn aircraft design only when you do calculations just by looking at the videos and nodding your head you really will not be able to appreciate and also get a first-hand feel for doing conceptual design calculations. The values which are calculated will be shown in this dark blue color and towards the end we will compare the value and the color green will be used to show the quoted values.

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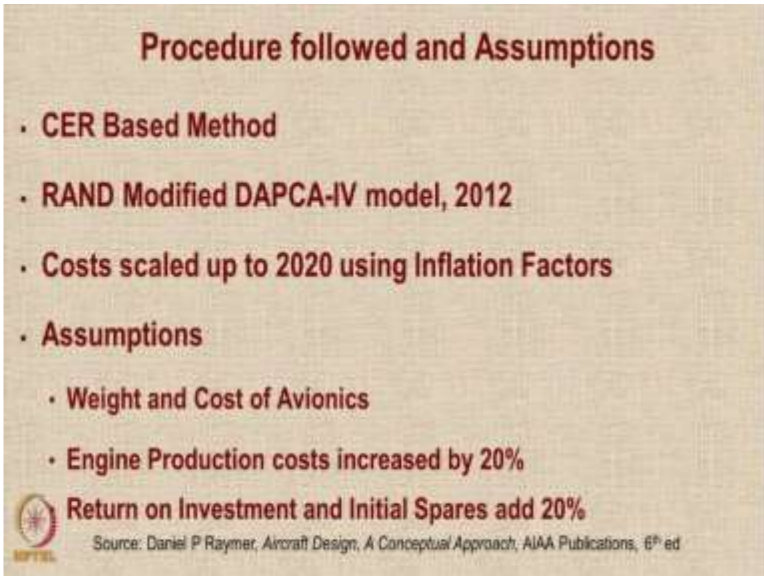

The procedure that we follow is based on the cost estimating relationships or CER's which are outlined by Daniel Raymer in his seminal textbook we have used the RAND modified DAPCA IV model of 2012 which has been mentioned by Raymer in the 6th edition of his textbook note that the values that this model predicts is for 2012. So therefore we have to scale up the cost from 2012 to today 2020 using some inflation factors.

And for inflation factors we have referred to an online source. There are also some assumptions which have been made while carrying out this analysis. The DAPCA IV model does not have any way of predicting the cost of avionics. So we need to assume some weight of avionics equipment onboard the aircraft and the cost per unit weight of those items. The engine used on Boeing 787 series is a very advanced engine.

It is a turbofan engine high bypass ratio and it has several features like Chevron etcetera which reduce the noise etcetera. So the DAPCA IV model gives you the estimation of costs based on the some parameters related to the engine such as the turbine inlet temperature and the maximum weight etcetera. But we have increased the values by around 20% as suggested by the raymer for a turbofan engine.

And finally there will be an assumption that 10% of the costs are going to be added towards the return on investment. And another 10% will be required for the initial spares which are supplied with every aircraft. So whatever cost we estimate it is going to be scaled up by a factor of 20%.

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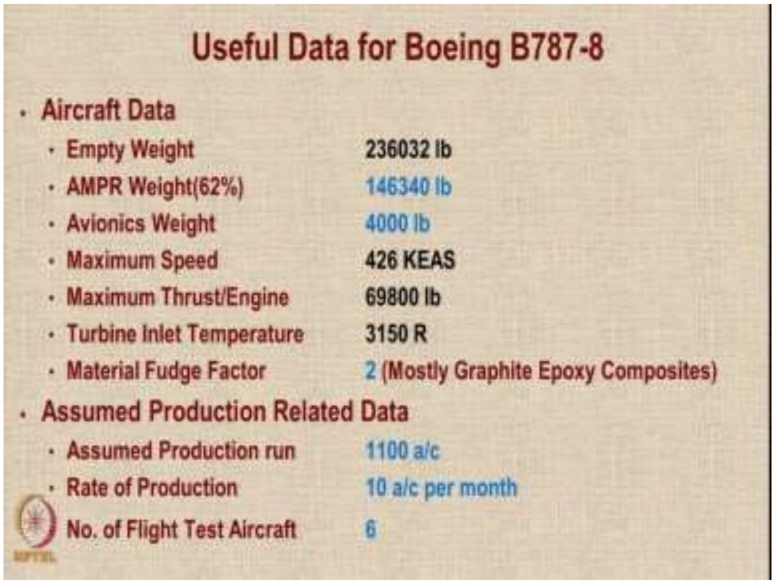

Let us look at some useful data for Boeing B 787 dash 8 aircraft, the aircraft data so empty weight is as mentioned 236032 pounds, the AMPR weight is the aviation manufacturers planning report this weight is assumed to be 62% of the empty weight. So it turns out to be 146340 pounds. This is an assumption because 62% is an assumption. The weight of the avionics items in the accurate is not known.

So we have taken a suggestion from Raymer we have taken the value so Raymer suggest the value to be between 2000 to 6000 pounds we have taken a medium value of 4000 pounds. The maximum speed of the aircraft as listed in the specifications is 426 knots equivalent airspeed hence it appears in black the maximum thrust per engine as mentioned in the Gen X engine bulletin is 69800 pounds, Gen X is one of the choices available for the engines for Boeing 787-8.

And in the same specification manual the turbine inlet temperature is mentioned as 3150 Rankine as far as the material is concerned Raymer suggests the value of up to 1.8 for the graphite epoxy composites but we have taken a slightly higher value of 2 because there is very aggressive use of composites in Boeing 787. As you know the most of the fuselage is consisting of composite material unlike other transport aircraft where the fuselage generally is aluminum alloy.

We have to also assume some production related data we have to assume the production run. So we have taken the number as 1100 aircraft This is based on some websites where they discuss about the plans of the company the rate of production of the aircraft is also assumed to be 10 per aircraft the same number is used in the RDT and E phase as well as in the production phase because in RDT and E any phase actually the fabrication of the aircraft is a kind of almost like a individual you know hand built prototype in some ways.

So therefore we have assumed that even the rate there is also 10 to bring in a little bit higher cost and we assume that there are 6 aircraft to be built during the RDT and E any phase or 6 of them are going to be subjected to flight testing and then maybe 1 or 2 of them will also be used in the structural testing some of them may actually be completely destroyed there may be destructive testing for example the wing of the aircraft is generally tested to destruction.

I think even the fuselage some areas are checked for ruptured loads during pressurization etcetera. But we assume here that all these 6 aircraft are to be costed in RDT and E phase and they will not be sold to any manufacturer they will be available with the manufacturer for any further exercises.

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The manhour rates specified by Raymer in his textbook are as shown for 2012. And these have been increased based on an inflation fraction from 2012 to 2020. Using an online inflation calculator called as usainflationcalculator.com as per that the inflation factor from 2012 to 2020 is 1.117. So all these costs are scaled up accordingly. The avionics cost as mentioned by Raymer is 6000 dollar per pound in 2012. This also has been scaled up using the same inflation factor as 6702 per pounds.

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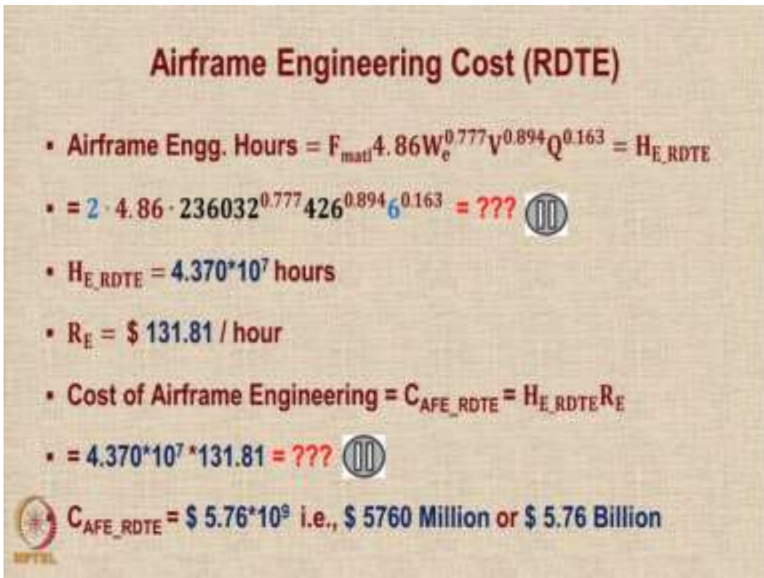

Let us look at the first and the most important component of the cost. That is the airframe engineering cost. In the RDT and E phase the hours required for airframe engineering can be estimated using this particular cost estimation relationship in which empty weight maximum speed and a production rate per month are the quantities to be used. So we are using F material is 2 because we are using graphite composites and more advanced versions.

So at this stage you should pause the video and do these calculation the number comes out to be $4.37 *10^7$ hours. This number is for the hours needed for the airframe engineering and the manhour rate for the airframe engineering is already mentioned in the previous slide is reproduced here. So the cost of airframe engineering in RDT and E phase would be a product of the hours required and the manhour rate. So please pause the video and do this calculation. The number comes out to be 5.76 into 10 power 9 which corresponds to 5760 million or 5.76 billion US dollars.

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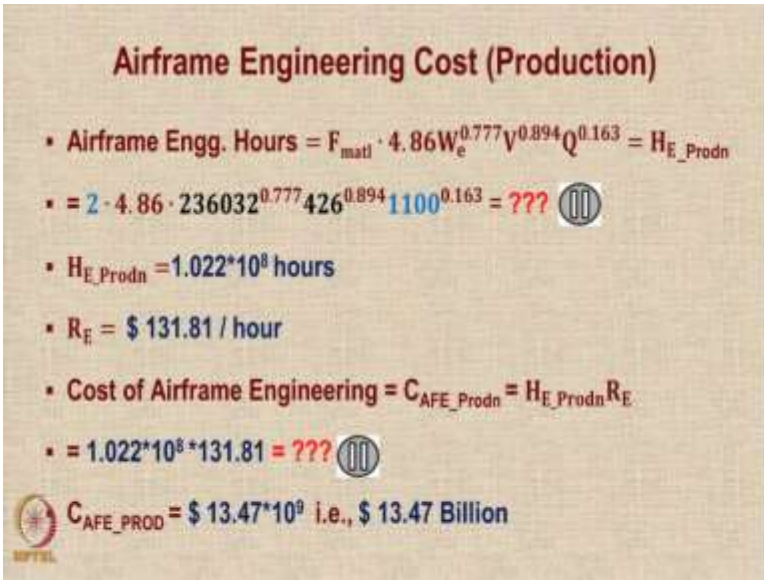

The airframe engineering cost for production is obtained by the same formula as shown here. So when we look at the production aircraft the number is 1100. So I think you need to have a look at this and pause the video and calculate this number. The number turns out to be $1.022*10^8$ hours. Now we know that the cost inflated figure for the engineering manhour rate is 131.81 per hour.

So the cost of engineering in the production phase would be the product of the hours needed and the rate per hour. So putting in the numbers pause the video at this stage and calculate this number. The number turns out to be 13.47 into 10 power 9 or 13.47 billion dollars.

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The tooling costs in RDT and E phase can be determined by the expression in terms of the empty weight the maximum speed and the quantity produced. So again putting in the number for RDT and E phase there are only 6 aircraft produced the maximum speed and the aircraft empty weight is already known. And the factor 2 takes care of the material. So this number turns out to be $1.943*10^7$ hours.

The cost inflated manhour rate is as mentioned. So therefore the cost of tool will be the product of the hours required and the manhour rate. This is as shown in the screen. So at this place you should pause the video and do this calculation the number comes out to be $2.495*10^9$ or 2.495 billion US dollars.

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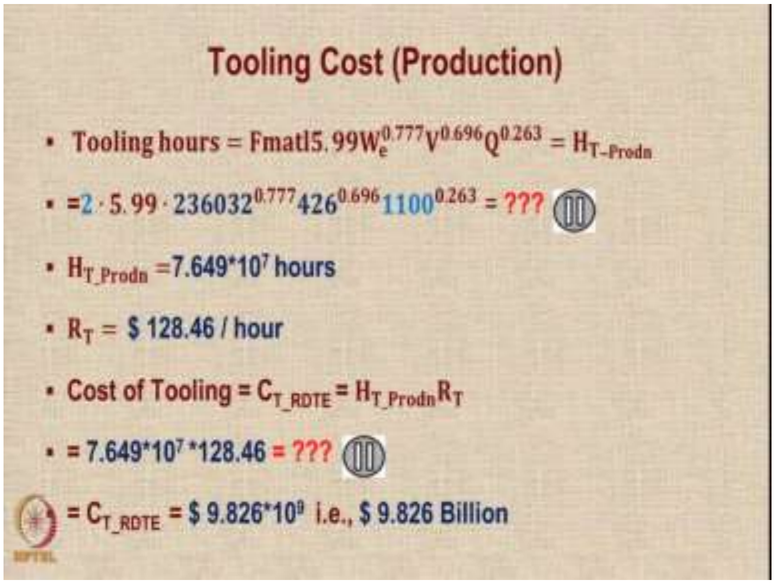

Look at the tooling cost in production phase the formula is the same. The only difference is that now instead of 6 we will use 1100 which is the quantity produced during production. So once again pause the video and do this calculation turns out to be $7.649*10^7$ hours the tooling manhour rate is as mentioned multiply by that rate to get the value of the cost of tooling. And that would be $7.649*10^7 *128.46$. Please pause the video and do this calculation now. The value comes out to be 9.826 billion.

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Manufacturing labor and quality control. Now what we have done here is that we have actually included a factor of 13.3% in terms of 1.133 for the quality control costs because what we have done is the manufacturing hours are going to be increased by 13.3% to take care of the quality control hours. And we also assume here we make a spot departure we assume here that the cost of the people or the manhour rate for the quality control is the same as that for manufacturing labor. This is because the in reality the costs are slightly higher.

However in the interest of ease of calculations we have just assumed this cost to be the same. So this number is likely to be slightly higher than the number is slightly lower. So the number of hours are going to be correct because the factor is included. However we multiply it by the manufacturing labour manhour rate. And we get the total cost of manufacturing as $2.514*10^7*109.47$.

So let us see what number is there please pause the video and do the calculation the number turns out to be 2.751 billion. In reality what you should do if possible is that calculate the hours by using the using only 0.133 here but when you multiply by the manhour rate for the quality control you can use a higher rate of around 120 odd dollars. So that way you will get slightly more cost for the quality control. But we have assumed that the two are same and made it a bit simple here.

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Similarly for the quality control and the labour cost during production the formula remains the same. The only difference is that you have to insert 1100 here instead of 6 which was there earlier. So please do this calculation by pausing the video and then you can compare your numbers with the value of 10 by us which is $7.097*10^8$ hours. In other words if we now assume the same man hour rate for manufacturing labour and QC which is simplification as I mentioned then you can get the value.

For total cost of manufacturing labor and quality control the production would be $7.097*10^8*109.47$ please pause the video here and do the calculations. The value comes out to be $7.7683*10^{10}$ or 77.683 billion very large amount of money is needed for manufacturing labor and quality controlling production.

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Let us look at the manufacturing material cost and we will look at both the RDT and E phase and the production phase together because it is just 1 equation the only difference being the number of aircraft produced. So the formula is the same for both only thing is that when you calculate the manufacturing material cost for the RDT and E phase you use 6 here and this factor takes care of the inflation from 2012 to 2020. So this number turns out to be $1.963*10^8$ okay.

And then it comes out to be 0.1963 billion. Similarly when you do this calculation again pause the video and do the calculations you put 1100 here is instead of 6 everything else remains the same do the calculations please the value is 12.626 billion.

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Development support and flight test costs are incurred only during the RDT and E any phase. So there is a formula available for the development support cost in which we have inserted a factor for inflation. So these 2 are the parameters which are already known and this is an assumed inflation factor please calculate the value it comes out to be 648.2 million or 0.6482 billion dollars.

Similarly the cost of flight test is available in terms of the empty weight maximum velocity and the number of flight test aircraft. So we assume here that all the 6 aircraft which are made during the RDT and E phase they all are used to undergo flight testing. So hence we have put the value 6 here. So please calculate this number turns out to be 197.2 million or 0.1972 billion dollar. Again these two costs are incurred only during the RDT and E phase.

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Let us look at the engine production cost. So the cost of the engine is available through a formula in terms of the maximum thrust maximum Mach number and the turbine inlet temperature and Ne is for a number of engines. Which we know is 2 so I would suggest that even though there is no pause button here and no question mark you should actually pause the video here do this calculation and determine the value of C_{EP}.

It turns out to be 25.25 million dollars in 1998. This formula was available for 1998. So if you use the inflation ratio from 1990 to 2020 as given in the same source then the factor is 1.573. So if you scale up the values you get 39.72 million. But remember as per Raymer suggestion turbofan engines have around 15 to 20% higher cost. So we have taken the higher value of these 20% higher cost. So the cost scales up to 47.661 million.

So since there are 6 aircraft each of them will cost 47.661 million. So because the number of engines is already included here so this is the total cost of the 2 engines which is scaled up to 2020 values. So we go for the calculation and we get the number as 0.286 billion for the RDT and E phase because just 6 of them have engines. But if you go to the production phase it is 52 billion dollars or more because there are 1100 aircraft to be produced.

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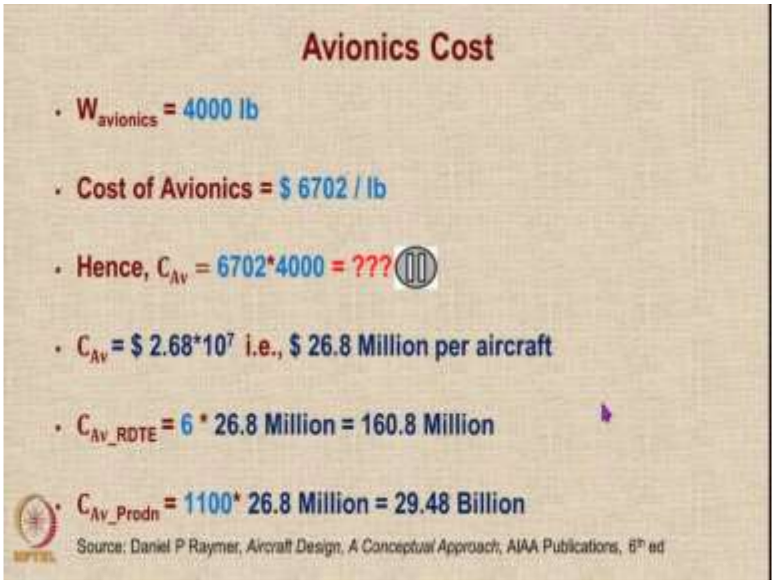

Quite a bit cost avionics cost as I mentioned we do not know the mass of avionics and we do not know what is the cost per mass per unit mass. So as per Raymer suggestions the avionics weight of a typical transport aircraft varies between you know 2000 to 6000 pounds so I have taken a value of 4000 pounds. So therefore the cost of avionics supposed to be 6702 into 4000 which turns out to be 26.8 million per aircraft. And therefore the total cost in the RDT and E phase would be 6*26.8 million because there are 6 of them produced it is 160.8 million and during the production that are 1100 aircraft the costs will be 29.48 billion.

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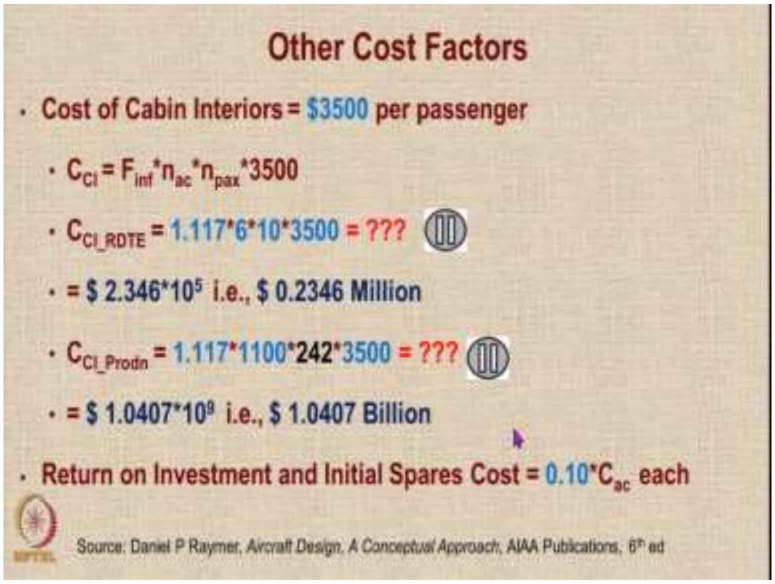

There are a couple of other cost factors we have to consider which may not be some of them may not be very very prominent. For example every aircraft has an interior cabin interior and that costs some money. So suggestion by Raymer is to assume 3500 dollar per passenger. And that too it is the number given in 2012. So the RDT and E phase interior they will be 6 aircraft. And we assume that there are 10 seats in every aircraft just an assumption because very few people go when you actually go for flight testing.

And this is a escalation cost escalation factor or the due to inflation. So calculate this number please. It is a relatively small amount of 0.2346 million dollars. And but in the production cost this is going to be much larger number because the multiplying factor is not 6 but 1100. And the number of seats is not 10 but 242 which is a maximum capacity of Boeing 787-8 as specified in the manual. So therefore this cost comes to around a billion dollars.

Now we also assume that the company that makes the aircraft which is Boeing would like to get some return on investment that we assumed to be 10%. And initial spares cost of the aircraft is also 10%. So we will scale up the cost by 20%. To take care of the fact that some initial spares have to be used. So let us look at now how all these costs are put together in a straight table. So here we see all the 9 sub components of the flyaway cost.

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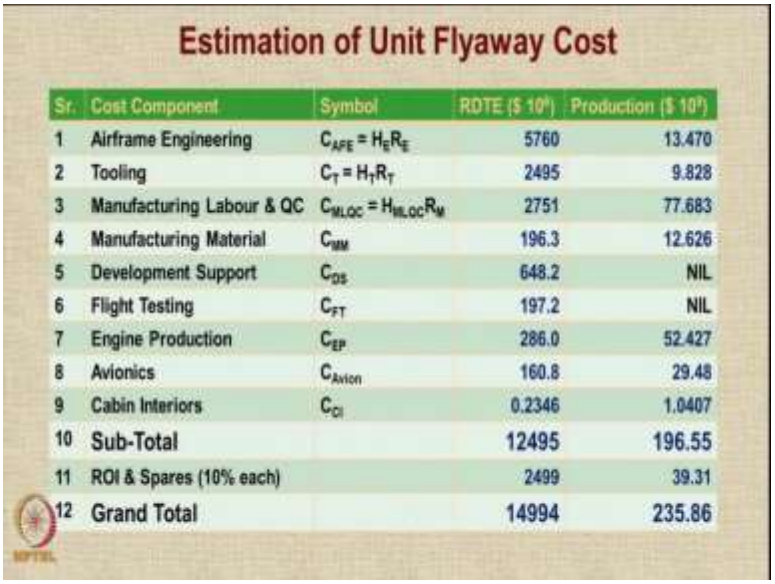

Estimation of Unit Flyaway Cost

Sr.	Cost Component	Symbol	RDTE ($ 10^6)	Production ($ 10^9)
1	Airframe Engineering	$C_{AFE} = H_E R_E$	5760	13.470
2	Tooling	$C_T = H_T R_T$	2495	9.828
3	Manufacturing Labour & QC	$C_{MLQC} = H_{MLQC} R_M$	2751	77.683
4	Manufacturing Material	C_{MM}	196.3	12.626
5	Development Support	C_{DS}	648.2	NIL
6	Flight Testing	C_{FT}	197.2	NIL
7	Engine Production	C_{EP}	286.0	52.427
8	Avionics	C_{Avion}	160.8	29.48
9	Cabin Interiors	C_{CI}	0.2346	1.0407
10	Sub-Total		12495	196.55
11	ROI & Spares (10% each)		2499	39.31
12	Grand Total		14994	235.86

And then there is a subtotal both for RDTE and production or that we add 10% each towards the return on investment that is a profit for the company. And spares initial spares that go with the aircraft to get the grand total we see that the RDTE cost is approximately 15 billion dollar. And the production cost is 235 billion dollars.

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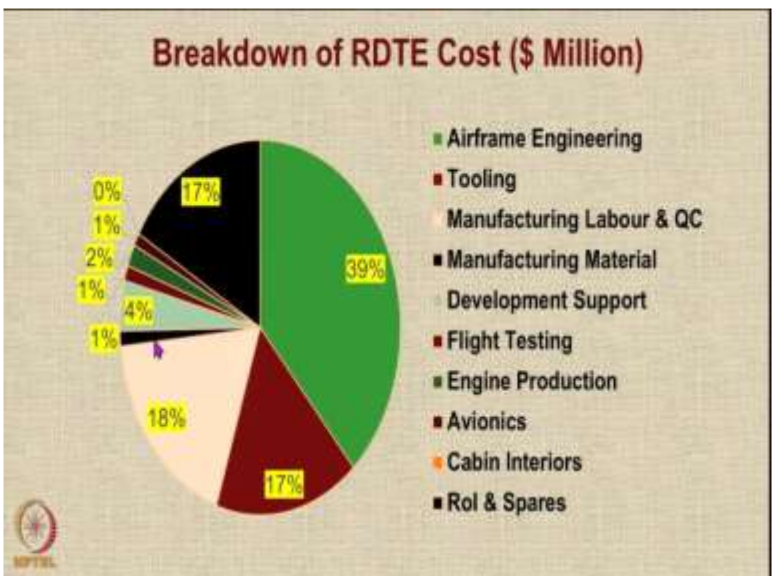

Let us look at the breakdown of the RDTE costs. So in the breakdown we observed that the largest component is of the airframe engineering cost followed by the cost for manufacturing labour and quality control and equal weightage for the manufacturing material and the cost of tooling. So these together correspond to approximately 70% or more in fact much more this is 25%. And you know so around 80% of the costs are because of this 80, 90%. And the remaining all costs come under these small pies.

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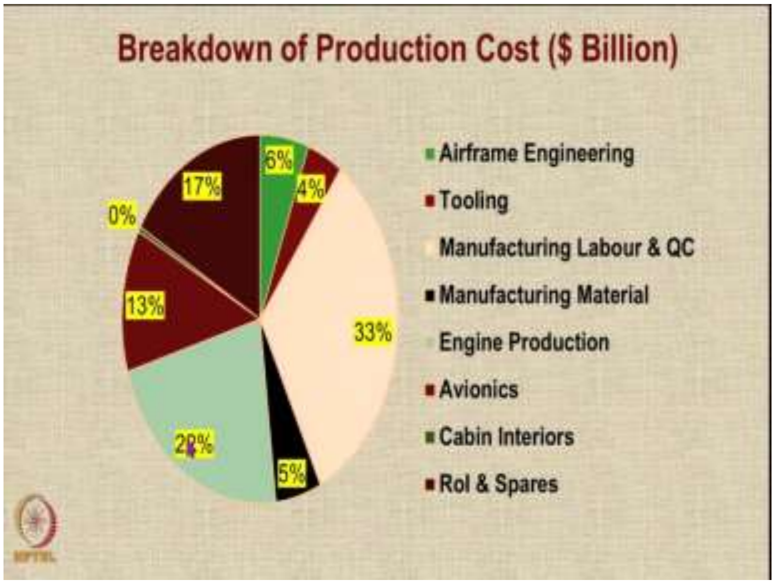

Here is a breakdown of production cost in billion dollars. So now in the production cost we notice that the largest component is the manufacturing labour and Quality Control Act respected followed by the airframe engineering and the tooling and avionics. These are the major components and everything else corresponds to the remaining.

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So let us now estimate the unit flyaway cost. So we have seen that the RDTE cost is approximately 15 billion dollar 14.99 to be precise the production cost was 235.86 billion. So together the total program cost turns out to be the addition of these 2 costs which is 250.857 billion dollars. Now the unit flyaway cost would be the cost of the total program divided by production run which means it will be 250.857 million divided by the number of aircraft sold which is 1100. So per aircraft it comes out to be 228 million dollar.

Whereas if we look at the list price of Boeing 787 dash 8 in one of the online sources we see that the quoted price or the list price is 224.5 million dollar. So the difference is only about 1.6%. So we have obtained just 1.6% higher cost the quoted price is 1.6% lower.

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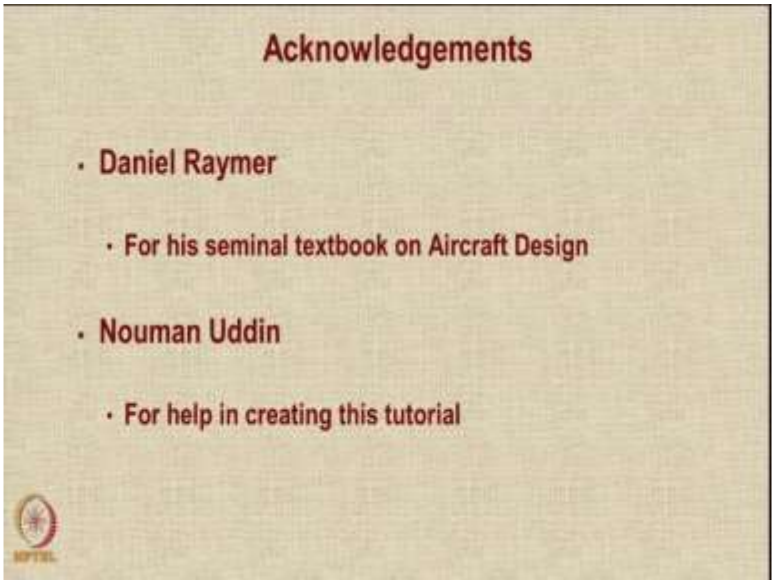

Before I close I would like to acknowledge Daniel Raymer for his seminal textbook on aircraft design which we have followed in this tutorial for all the formulae and the calculations and Nouman Uddin have been for help in creating this tutorial. Thank you for your attention.