Introduction to Aircraft Design
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Lecture - 72
Tutorial on DT and E Production Cost Estimation of HALE UAV

Let us have a look at how we estimate the design testing and evaluation or the DTE cost and production cost for a military aircraft.

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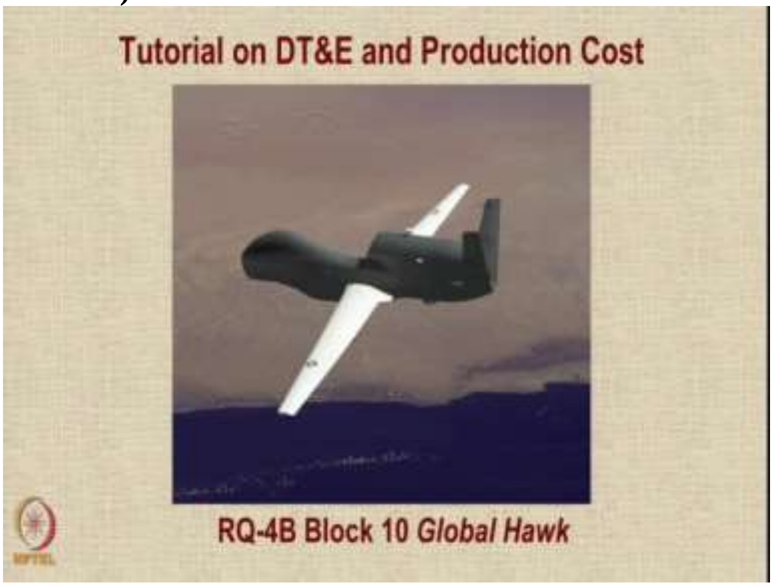

Another example, we have taken a RQ 4B block 10 Global Hawk aircraft. At this point, I did like you to ensure that you have watched the video clips of the lecture on estimation of acquisition cost of the aircraft because the example of Global Hawk was shown there and we are going to just take up the details of that particular calculation here.

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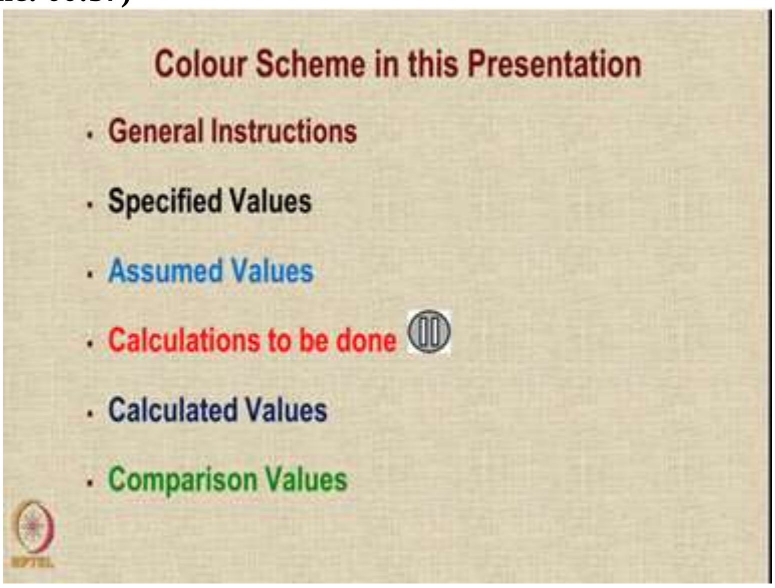

So, like every time we follow the same colour scheme in this presentation, the general instructions are going to be given in brown colour, the specified values will be in black colour, these are the specs of the aircraft available from some reliable source, there are some values which will be assumed, and those values will be shown throughout in this light blue colour.

Wherever there are some calculations to be done, we will have some question marks in red colour. And there will be this pause symbol. So, whenever you see this symbol, it is a good idea if you pause the video and do the calculations, because aircraft conceptual design is learned only by doing the calculations not by just watching a video and nodding your head you will have no feel for it unless you do the calculations yourself.

The calculated values will be shown in this dark blue colour. And towards the end if we do a comparison with any value or parameter published online or in sets in some resource, we are going to show those quoted values in green colour. So that we can compare with our calculations in blue colour.

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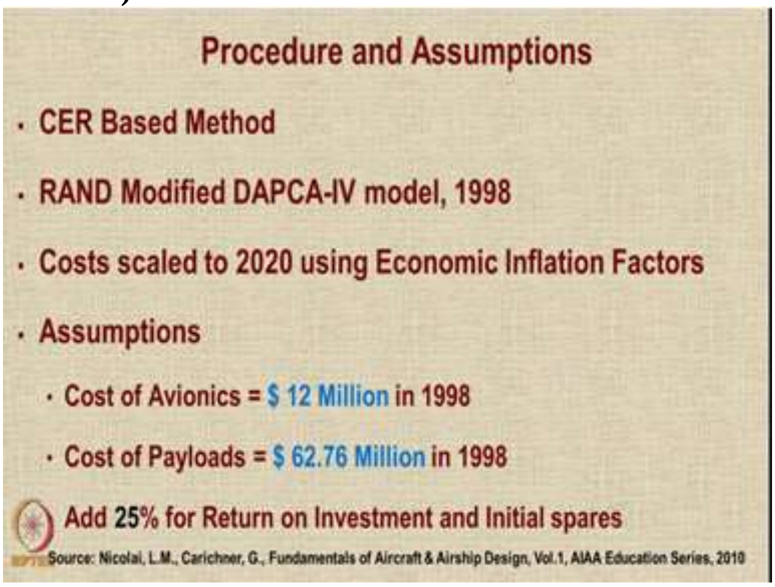

Let us first look at the procedure that we will follow for carrying out the estimation of DTE and production costs for Global Hawk and also some of the baseline assumptions that we will make. So, here also we used a CER based method where CER stands for cost estimating relationships. And in this particular exercise, we are using the same RAND modified DAPCA 4 model.

But the difference is that now we are going to use it for 1998 formulae given in the textbook by Nicolai and Carichner. So, let me clarify the other tutorial that talks about the estimation of R DTE cost and the production cost of Boeing 787 dash 8 in that the formulae are taken from the RAND modified DAPCA 4 model of 2012 as given in the textbook by Daniel Raymer.

But here we are going to look at the same model, but 1998 based formula given by Nicolai and Carichner and a costs that we obtain in 1998, either by calculation or by specifications, they will be scaled up to the current values of 2020 using economic inflation factors. So, we are going to make some assumptions of the cost parameters. For example, the cost of avionics is going to be assumed as 12 million dollars per aircraft in 1998. The cost of payloads would be 62.76 million in 1998. And as per the suggestion in the textbook by Nicolai and Carichner, we should add around 25% for return on investments and initial spares.

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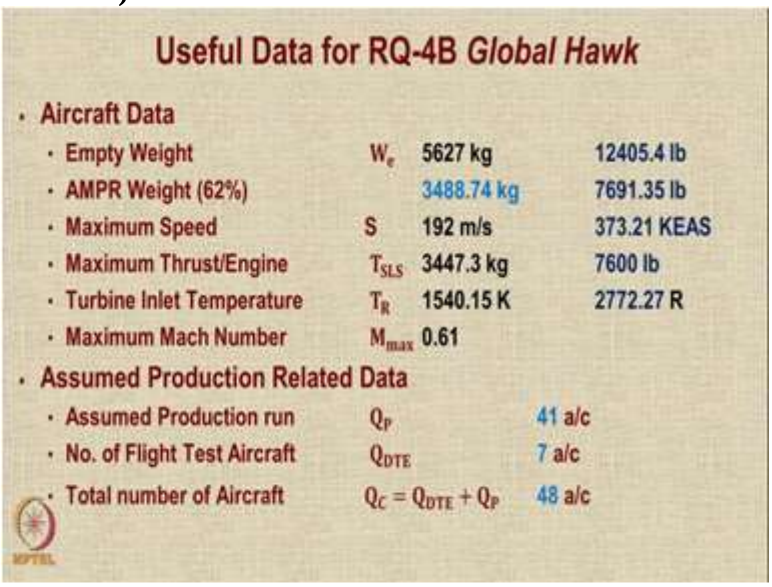

Let us look at some useful data for RQ 4B Global Hawk aircraft which we will need in our calculations. The aircraft data would be empty weight 5627 kilograms specified in the specifications converted into pounds. The AMPR weight is assumed to be 62% as per standard practice the maximum speed so the symbols are a different here. The maximum speed is shown by S here and it is specified to be 192 meters per second which converts to 373.21 knots.

The maximum thrust per engine is 3447.3 kg there is only one in and this becomes 7600 pounds. The turbine inlet temperature is 1540.15 degree Kelvin which becomes 2772.27 degrees Rankine the maximum Mach number for this aircraft is 0.61. The assumed data related to production is as follows we assume that 41 aircraft are produced in the production run 7 aircraft are produced in the RDTE any phase during flight testing and they are not sold eventually. And therefore, the total number of quantity produced is 48.

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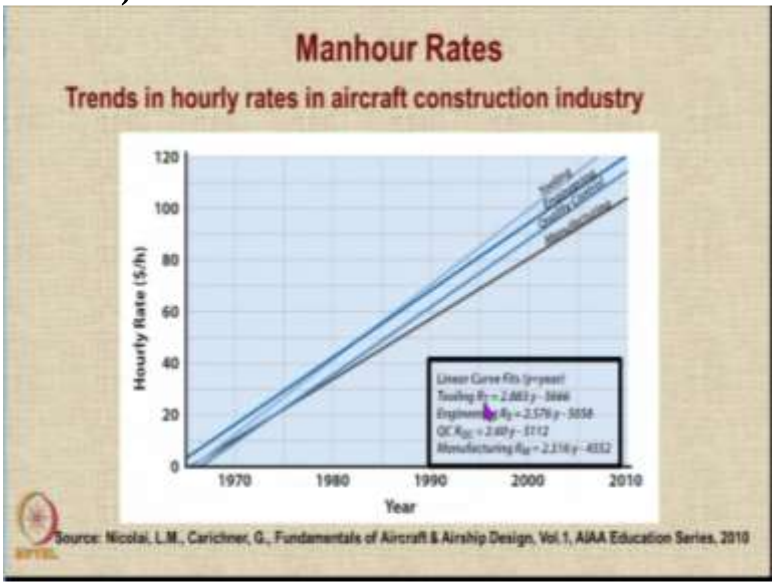

Let us look at the man hour rates applicable for this we look at the trends in the hourly rates in the aircraft construction industry as mentioned in the textbook by Nicolai and Carichner these follow a straight line and there are linear curve fits available for man hour rates versus the year and there are different equations for tooling engineering quality control and manufacturing costs.

We will use these corresponding equations into our calculations where the letter y stands for the year for example 2020 so, it will become 2.883 into 2020 minus 5666 that would give you the value of tooling applicable not only man hour applicable in 2020.

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Manhour Rates $/hour

Average hourly rate (US Dept of Labor)	Symbol	Linear curve fits (y = year)	$/hour (2020)
Tooling	R_T	$2.883y - 5666$	157.66
Engineering	R_E	$2.576y - 5058$	145.52
Quality Control	R_{QC}	$2.60y - 5112$	140.00
Manufacturing	R_M	$2.316y - 4552$	126.32

Let us look at the man hour rate. So, if we use the same equations as mentioned in the previous slide, then the costs that the man our rates which appear are as follows for tooling it is 157.66 dollars per hour for engineering it is 145.52 dollars per hour for quality control it is 140 for manufacturing it is 126.

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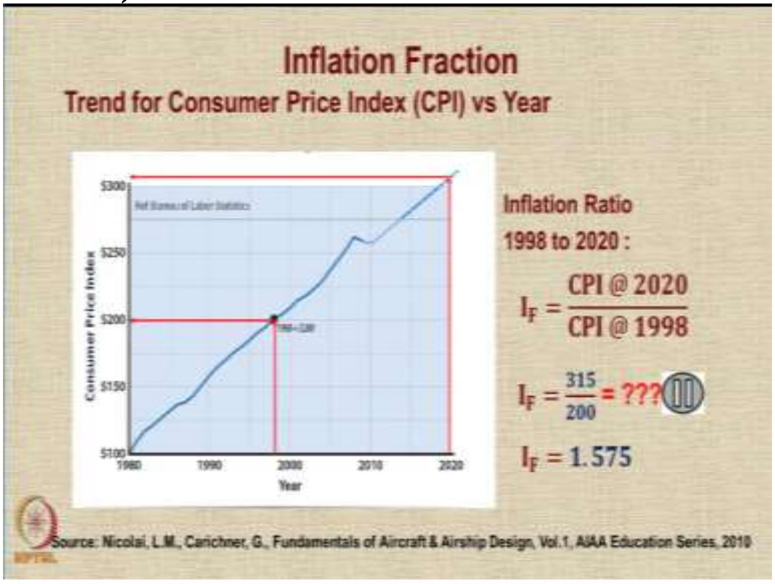

So, we noticed that the highest man hour rates are for the tooling because this is very specialized. And quality control is done by the engineers or the quality managers who are actually come who have to have a work been taken from the production side itself, so the costs are slightly lower then. We also need to know how to inflate the rates to take care of the consumer price index change per year.

So here is again a graph from the textbook by Nicolai and Carichner, where we have the base value for the consumer price index as 200 for the year 1998. So, if you want to calculate the values in 2020, then we need to just go along this line. So, for the base year, the number is 200, that is 89 so for the year 2020 the number reads from the graph as around 315. So therefore, the inflation ratio to scale up a cost from 1990 to 2020.

Would be CPI at 2020 upon CPI in 1998. So, at this stage, you should just calculate the value, so the value is going to be 1.575. Remember this number because this number will be used to scale up the costs from 1998 to 2020, in many places in our calculations that follow. So, the inflation fraction is 1.575.

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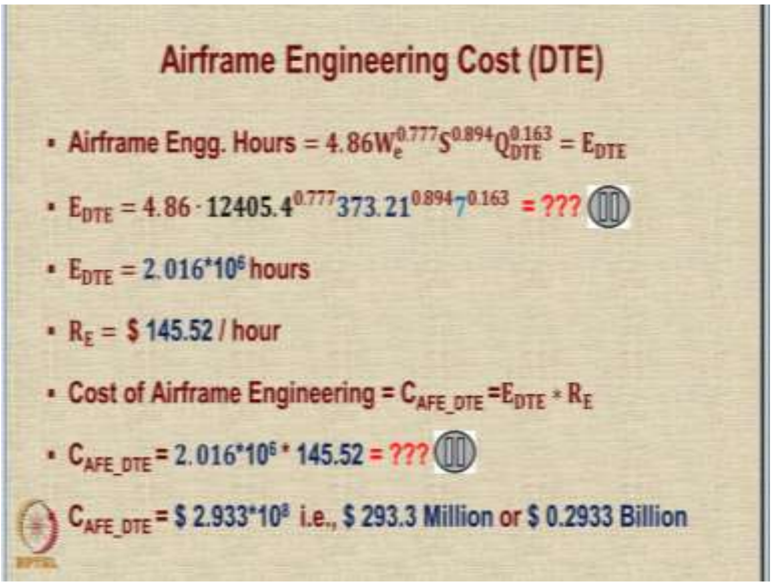

Let us look at first cost of airframe engineering in the DTE phase. The formula given in the book by Nicolai and Carichner relates the airframe engineering hours with the empty weight in pounds, the maximum speed of the aircraft and the number of aircraft produced or the quantity produced in the DTE phase. So, for our aircraft, we know that the empty weight is 12405.4 the maximum speed is 373.21 in knots and the quantity produced in RDTE phases 7.

So, at this point, you should pause the video and do this calculation to get the value of man hours. So, you just have to multiply these quantities which are shown on the screen the value comes out to be $2.016*10^6$ hours so many hours are needed in the airframe engineering. And we have just calculated in the previous slide the man hour rate for airframe engineering that is 145.52.

This rate is in 2020. And the hours are also there. So, if you multiply both of them you will get the cost of airframe engineering, which would be just the multiplication of E DTE and R E which means it will be $2.016*10^6$ multiplied by145.52. Please pause the video and calculate this number. You first calculate in million dollars and then you can convert it in billion dollars. So, it turns out to be $2.933*10^8$ or 293.3 million and that will become 0.2933 billion dollars. Approximately 0.3 billion dollar is being estimated as the cost of airframe engineering for the RDTE phase.

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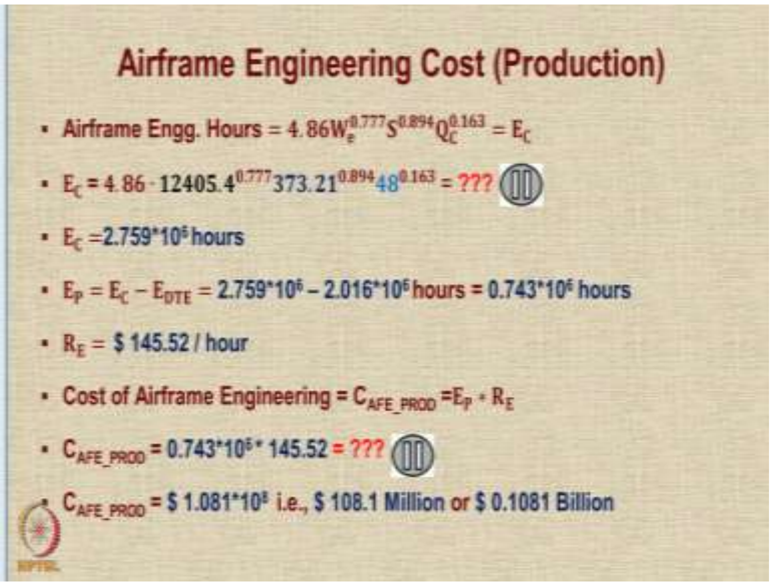

The same formula now applied to the production phase. You have to apply the same formula. The difference is that here we are going to use all the aircraft produced including the 7 aircraft produced in the previous phase in finding out the hours. This is because when you produce 7 aircraft and then after that you start producing the 8 aircraft to the 41 more aircraft, the knowledge and experience gained in the first 7 aircraft stays with you.

So, therefore, the hours that you need is can be obtained by getting the cumulative hours. So, the cumulative hours are going to be $2.759*10^6$. From this, we should subtract the hours which were consumed in the first 7 aircraft to be produced which were $2.016*10^6$. So, the difference is only $0.743*10^6$ hours. So, you notice that for producing 7 aircraft, you need $2*10^6$ and to produce 48 unit only 2.759.

So, the difference is not, you know something like 7 times the difference is only very small number. This is because of the learning curve. Now, the man hour rate is known to us as 145.52 per hour. So, therefore, to get the cost of airframe engineering, we just have to multiply these 2 numbers 145.52 with $0.743*10^6$, please do this calculation. And you will get the answer as $1.081*10^8$, which is 108.1 million, or 0.1081 billion.

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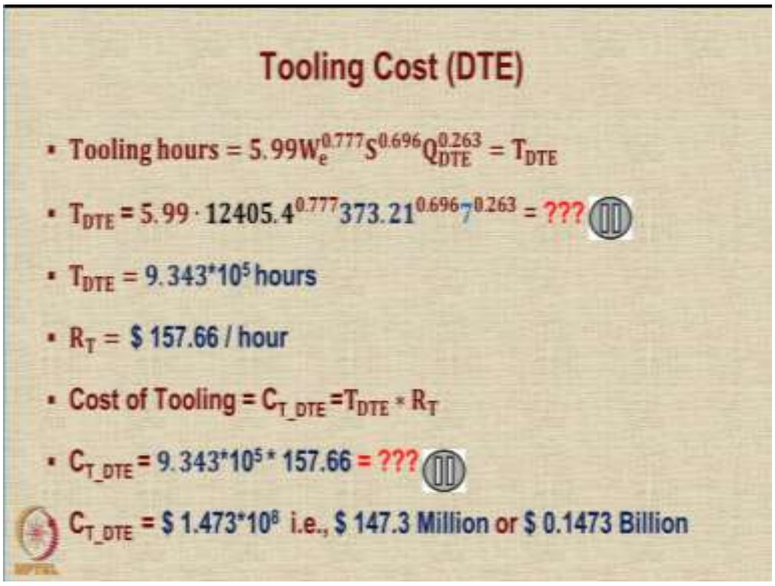

Let us look at the tooling cost in the DTE phase. The tooling hours again are obtained as a function of the empty weight in pounds maximum speed in knots, and the quantity produced during the DTE phase. In our case, the empty weight is 12405.4 pounds, the maximum speed is 373.21 knots and the quantity produced in the DTE phase only 7. So please pause the video and calculate this number.

It comes out to be $9.343*10^5$ hours. So, this you have to multiply now with the man hour rate of 157.66 per hour. And if you do that, then you get this expression $9.343*10^5$ into 157.66 please pause the video and do this calculation and get the value. The C_T in DTE phase is $1.47*10^8$ or 147.3 million or 0.147.3 billion. So much money is needed in the tooling for only 7 aircraft.

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Now let us see what happens in the production phase. In the production phase again, the formula remains the same. But once again, just like in the previous case, we use 48 as the quantity we get the cumulative tooling hours, and then we subtract the hours required for the RDE phase. So that the number of hours come as $1.55*10^{6}$ for the total phase or the cumulative phase.

From there, you subtract the values that you got in the previous slide of 9.343. So, the answer is $6.157*10^{6}$ that is the only additional number of hours needed. So, notice, to produce 7 aircraft we need $9.343*10^{5}$ to produce 41 aircraft after producing 7 aircraft the additional hours are only $6.157*10^{5}$ and the man hour rate is 157.66 per hour. For therefore, cost of tooling would be a multiplication of these 2 quantities.

And that would be $157.66*\ 6.157*10^{5}$, this number turns out to be $9.707*10^{7}$ or 97.07 million or 0.09707 billion dollars.

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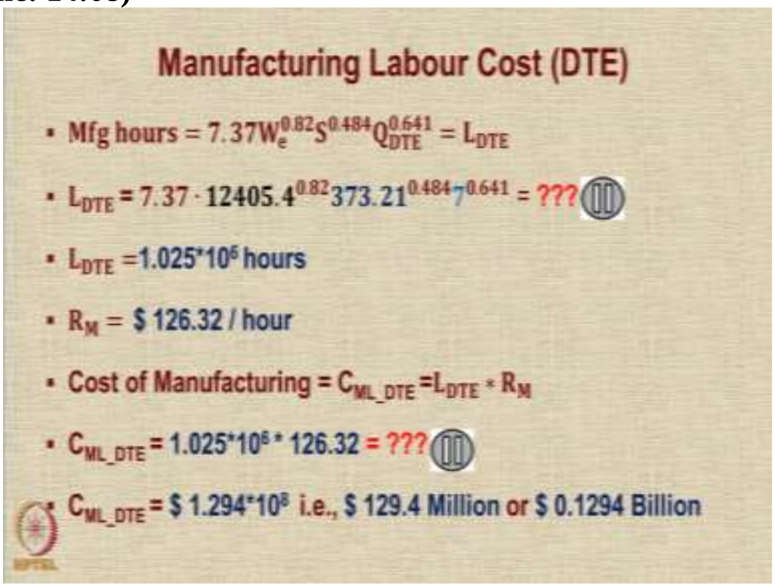

Moving ahead, let us look at the manufacturing labour cost for the DTE phase. Here also the formula relates the 3 parameters as before we insert the values of those parameters in the formula and please pause the video and do this calculation get the value of L DTE it is $1.025*10^{6}$ hours. Now the manufacturing rate is 126.32 dollars per hour as seen earlier. So therefore the cost of manufacturing will be a product of these 2 quantities L DTE and R M which will be $1.025*10^{6}*126.32$ pause the video and do this calculation, please this number comes out to be 129.4 million or 0.1294 billion dollars.

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We repeat the same calculation for the production but for that we first get the cumulative hours. So, in that the formula remains the same as the last one, but the number of aircraft becomes 48 from 7 because the total phase consists of 41 + 7=48. So, you calculate the total hours needed $3.522*10^6$ from here, we will subtract the hours needed earlier for 7 aircraft and the balance only is needed in the production phase which is $2.497*10^6$.

And the value of the maintenance man hour rate is the same as obtained earlier. So, when you want to obtain the cost of manufacturing, you have to multiply these 2 quantities. That is $2.947*10^6*126.32$ per hour, please pause the video here, do this calculation and try to match with our value of 315.4 million or 0.3154 billion.

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Moving at to quality control cost in the DTE phase, it is given in the textbook by Carichner and Nicolai that the quality control hours are just 0.133 times that of the hours required for the manufacturing phase. The only difference being that if there is a cargo aircraft, this ratio is a little bit smaller. But ours is not at your cargo aircraft. So, we simply multiply the hours that we had required for the aircraft production in the DTE phase, multiply those hours, that is $1.025*10^6*0.133$ to get the new hours.

And these hours are then multiplied by the man hour rate. If you multiply, you will get $1.363*10^5*140$ pause the video here, do the calculation the value is $1.908*10^7$ or 19.08 million, or 0.019 billion dollars.

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Let us look at the quality control costs in the production phase. Again, the formula is same, the hours needed are only 13.3% of the hours spent in production, which were $2.497*10^6$ as in the couple of slides behind. So, we just multiply by 0.133 to get the number of hours, those number comes out to be $3.32*10^5$, now, the rate is 140 per hour. So, you just have to multiply these 2 quantities to get the total cost.

That cost is going to be $3.321*10^5*140$. So, what is the answer, $4649*10^7$ or 46.49 million or 0.04649 billion.

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Let us look at the manufacturing material cost in DTE and production. Here we will do both together because this cost is they are not done no there are no hours to be calculated this is just a cost in terms of the number of aircraft. So, to manufacture 7 aircraft, you just put 7 and the other parameters are already known to you get the value. So, when you multiply all these numbers $16.39*12405.4^{0.921}*373.21^{0.621}*7^{0.799}$ you will get the value as 18.08 million or 0.0180 billion dollars.

Similarly, for the manufacturing phase, the formula remains the same. The difference only is instead of 7 aircraft which were manufactured in that phase the in this phase we will make 41 aircraft. So, it will be as shown on the screen in 1998 then year dollars, but these number has to be multiplied by the inflation fraction to bring it current to 2020. And hence you ultimately get the value as 0.11691 billion dollars.

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Development support and flight testing costs we are assuming they occur only in the case of the aircraft DTE phase. So, therefore, it will only have formulae related to empty weight of the aircraft and the area. This is a theoretical calculation. So, but with that in mind, they have obtained the value of C minimum should be point you know you need a very high Cost in this case.

And the value of the value of the cost comes out to be $5.521*10^7$ or 55.21 million dollars in 1989. So, then this cost has to be escalated by 1.575 and brought to the current levels. Which is 850 is 86.95 million dollars or 0.0806 billion dollars. The next calculation from the flight test cost this also is a fixed number, remember that these coefficients change from the formula given in remember to the formula given here only because the formula in Raymer's book are for 2011.

So, this number will be appropriately maybe higher and in our case here the costs are given in 1989 terms. So, these values tend to be lower again we plug in the value of W_e S and Q for the flight test, there are only 7 aircraft the initial prototype, so, the cost comes out to be $5.429*10^7$ or 54.29 million, but this cost has to be scaled up to the year 2020 by multiplying by a scale coefficient 1.575. So, if you apply this, this coefficient to multiply you will get the value is 0.0855 million dollars or 85.5 million dollars.

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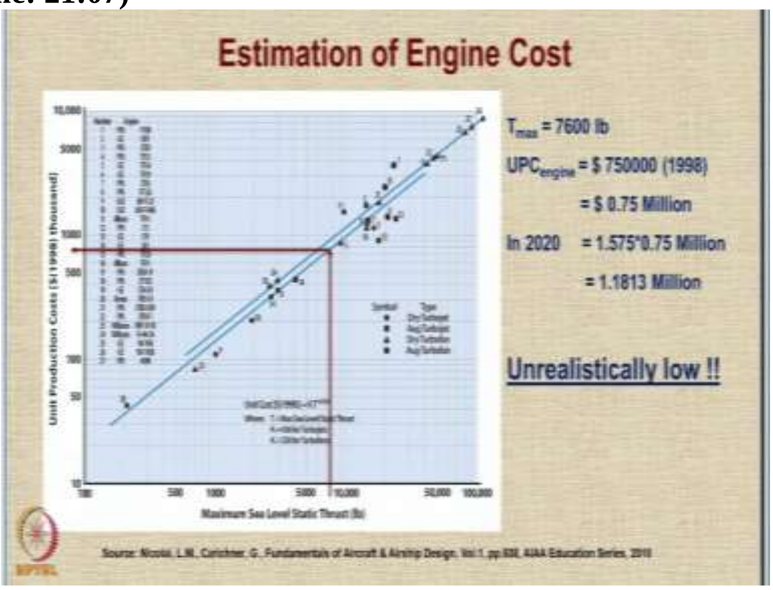

Now, we go to the engine cost. So, there is a graph in the textbook by Nicolai and Carichner which talks about the cost the unit production cost of various types of power plants as a function of the maximum sea level static thrust. And there are 2 lines here, the 1 on the top is basically for aircraft after burners, and the one on the bottom most of the aircraft are like our aircraft B9 aircraft going at Mach number 0.61 maximum.

But it should be able to provide some connectivity. So, we know that the thrust max of this engine is 7600 pounds. So, going on the screen, this gives you an indication this gives you a global average. So, the global average says that the engine costs should be somewhere between 7 and a half to a billion dollars. So, we have taken the minimum value cut by this line. And the unit production cost per engine comes out to is 0.75 million dollars in 1998. And turns out to be 0.75 that is actually a very low value so even if you scale it up to 2020, it is only 1.18 million dollars. It is actually a unrealistically low value for the cost of an engine.

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So therefore, we do not use this graph we use the formula given by Nicolai and Carichner. Now, this is the formula which has been given in the book applicable for transport aircraft. So, we use this formula. And so there was a requirement to know a few things, we will see how it goes ahead. Now, in this expression, the term 7600 stands for the maximum thrust in pounds at sea level 0.61 transfer the maximum Mach number, and 2772.27 stands for the value of thrust required.

So therefore, if you plug in these values, you get the value as $2.152*10^6$ or 2.151 millions. That seems reasonable in 1998, around 2 million dollars, instead of 1.75 million dollars. And then when you scale it up from 1998 to 2020, the fly factor you know is 1.575. So therefore, the cost in 2020 would be into 1.575 or 3.3894 million dollars. Now, there are 7 engines needed for 7 aircraft because our single engine aircraft, so in the DTE phase, it will cost us 7 times this number 3.3894 per million per year. So, we will get 23 million dollars to be spent every year in making this fleet run.

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Now, only 2 costs are remaining the cost of avionics and the cost of payloads. As far as avionics cost is concerned, we have assumed the cost to be 12 million dollars per aircraft in 1998. So, in 1998, the value will come out to be 7 into 12. Please calculate the number I know it is 84 million dollars. And then we have to multiply by the factor to upscale that cost to 1998 to 2020. So, you multiply by 1.575 to get 132.5 million dollar.

This is the money that we will be spending the RDTE face on the engine cost. And then the next thing would be what would be the cost of the payloads which will go on the aircraft so each of them carries 41.8 each of them is going to in there will be a cost of 41 into 12 that is for 492 million dollars because there are 41 aircraft which are going to carry the avionics and this number turns out to be 774.9 million dollars..

For the production aircraft we have 1100 aircraft, for those where we have 7 aircraft it can go to much smaller only 492 million, but here also there is a question how do you get such a large amount of money 492000 is not a small amount to save or to obtain.

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Let us also look at the payload cost we have assumed that the payload cost is $62.76*10^6$ dollars per aircraft. And therefore, for 7 aircraft, we are going to get 7 into 62.76 million, which is 439.32 million, same way, you can get the cost in escalated fashion for 2020 691.9 million dollars. Now, if you want to calculate the cost of payload for the production aircraft, we are using the full production quantity.

Here we are assuming that these 7 kits which are there in the aircraft, they actually have to be kept as a standby. So, we have to do a fresh and many changes would be made for we may have to go a fresh in the calculation. So, we assume that a small sub program is launched to get the things going, and that will cost us by inflation, it will cost us this number as shown on the screen.

The escalation factor into the year into the divided by year into the cost per day. So, the payload cost comes out to be 48 into 62.76 billion dollars, but this number is in 1998 3 billion dollars. So, you have to multiply by 1.525 and get 4.749 billion dollars. So, a large amount of money is required by the payload.

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Summary of all cost terms

Sr.	Cost Component	Symbol	DTE ($ 10^6)	Production ($ 10^6)
1	Airframe Engineering	C_{AFE}	293.3	108.1
2	Tooling	C_T	147.3	97.07
3	Manufacturing Labour	C_{ML}	129.4	315.4
4	Quality Control	C_{QC}	19.1	46.49
5	Manufacturing Material	C_{MM}	28.5	116.9
6	Development Support	C_{DS}	87.0	NIL
7	Flight Testing	C_{FT}	85.5	NIL
8	Engine Production	C_{EP}	23.7	139.0
9	Avionics	C_{Avion}	132.3	774.9
10	Payloads	C_{PAY}	692.0	4744.9
11	Sub-Total		1638.2	6342.9
12	ROI & Spares (25%)		409.6	1585.7
13	Grand Total		2047.8	7982.6

So, let us look at the summary of all the items in one shot. The first one was airframe engineering where the costs were 293.3 and 108.1 respectively. Similarly, tooling similarly manufacturing, similarly quality control, manufacturing, material development support, flight testing, engine production, and avionics, these are the costs will be incurred on the military aircraft.

And all these have cost some money. So, we have to recover this money from the sale of the remaining aircraft. And payloads are very expensive, the largest component of the cost, as you can see is the payload 692 million dollar in this entire landscape. And 47449 million dollars is in this particular scheme. So, a lot of work is going on all over the world in reducing the cost of the avionics so that these numbers add up like this.

But we have no information on anything about now working right now. So, we go for ROI of 25% we assume that the person who does the coating will only take maybe around 10 to 12%. And the remaining will be available as the additional cost of some of the sub system that you may have to buy. So, the grand total comes out to be approximately 2 billion dollars for the DTE phase and approximately 7.9 or 8 billion dollars for the production phase. Together, it comes to around issues as these numbers come to nearly 1 million, I do not mind my spread sheet can justify the using 1 million because I have not done any rounding of errors.

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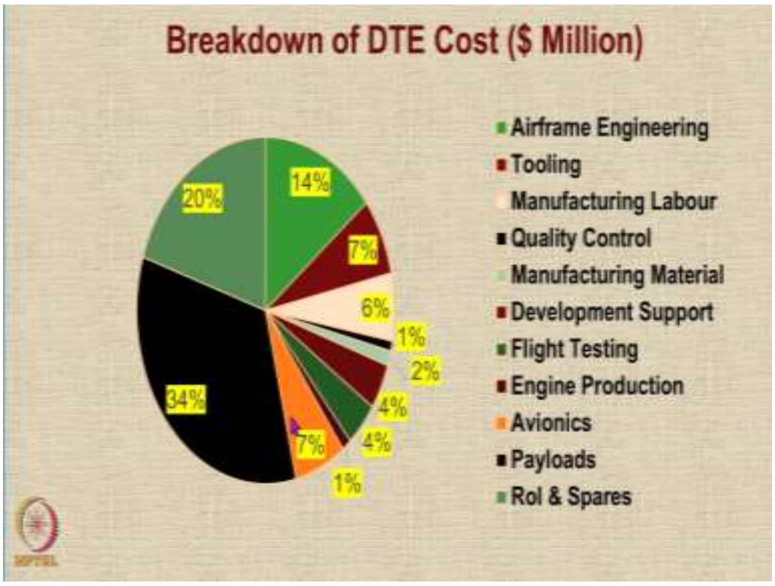

So here is a breakdown of the DTE cost, we can see that the largest component 34% or nearly 1 3rd happens to be the cost of payloads. The remaining major components are 20% and 14% for airframe engineering and ROI and spares ROI and the spares is also a large value. And everything else comes in this small portion of the pie chart.

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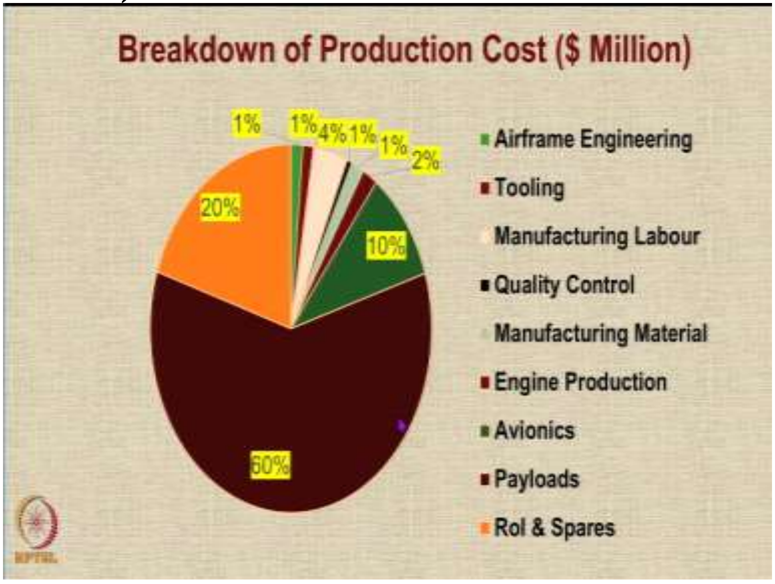

When we move to the production cost again we know now that the largest component would be the cost of the payload because this aircraft is nothing but a carrier for a payload. So, payload is very, very expensive and that is the main thing. Notice, the other 2 major costs are the ROI and spares here the ROI is basically driving this number high and the cost of avionics remaining everything engineering tooling etc., it becomes a very small component of the total cost.

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So now we want to estimate the cost of flyaway. So, we have just now seen that the RDT and E cost or the DTE cost is 2.048 billion. These costs have to be recovered from the 41 aircraft which are sold and to produce the aircraft we need to spend around 8 billion dollars 7.983 to be precise, so the total cost is around 10.031 billion dollars. And if you want to calculate the flyaway cost you just divide this number converting it into millions divided by 41. Because only 41 aircraft are sold. Get this value please this value is 244.67 million dollars or your answer will be actually 0.24467.

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Cost Item	Quoted (2012)	Scaled (2020)	Estimated (2020)
RDT&E	3971.8	4635	2047.8
Production	5914.2	6901	7982.6
Total Program	10021	11536	10031
Quantity Procured	----	45	41
Flyaway Cost	----	256.36	244.67
% Difference	----	------	- 4.56

Finally, let us compare our calculations with the quoted price in some source in literature, the cost of the development testing and engineering RDT and E the quoted value into 3971.8, but the scale value is 4635, but the value that we estimate is much lower is 2047.8, because we have been little liberal in assuming that the material that are also conventional and the aircraft also conventional actually their aircraft is highly unconventional.

Therefore, there will be larger cost in RDT and E phase, but we have no way of estimating it. Secondly, the production cost, you can notice that the quoted value is around 5914 including inflation and here the scale value is 6901. So, there is also there is a difference around 10 lakhs, that is because of the years differences in the years also the total program cost is 10021 million dollars.

Which is spent on market set of 41 aircraft. So, if all of them are sold. Now, when you look at the data from the GA office, which is given in the bottom of the screen, the quantity produced is 45. But actually we have seen that the quantity produced is 41 plus 7 as per our assumption. So, we get a flyaway cost using that so what we do is 10031 divided by 41 is 244.67 and 11536 divided by 28 or whatever is the time 28 is when he is going to go back that the number of difference comes out to be very less in fact the percentage differences only around 5% we are under predicting by around 5%.

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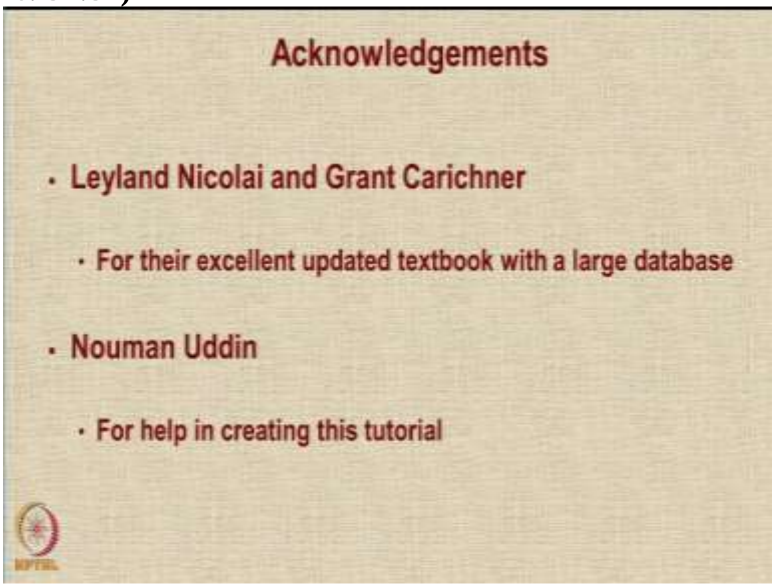

Thank you very much before I close I need to thank Leyland Nicolai and Grant Carichner for their excellent upgraded textbook with large database and Nouman Uddin for help in creating this tutorial.