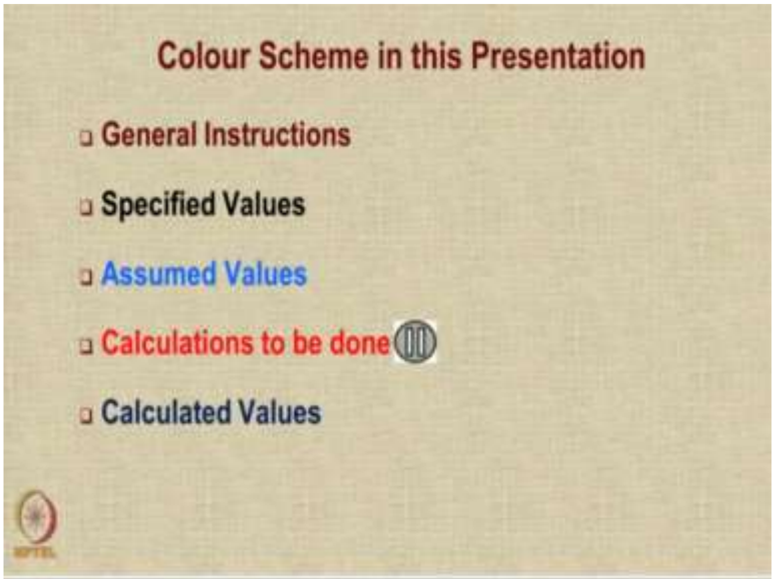
Introduction to Aircraft Design
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology – Bombay

Lecture – 68
Tutorial on Refined Sizing of Jet Fighter Aircraft

Hello let us have a look at how we carry out refined sizing of a military aircraft. And as an example, we have taken our F16-C which you may recall is a theoretical aircraft loosely modeled around F16-C.

(Refer Slide Time: 00:29)

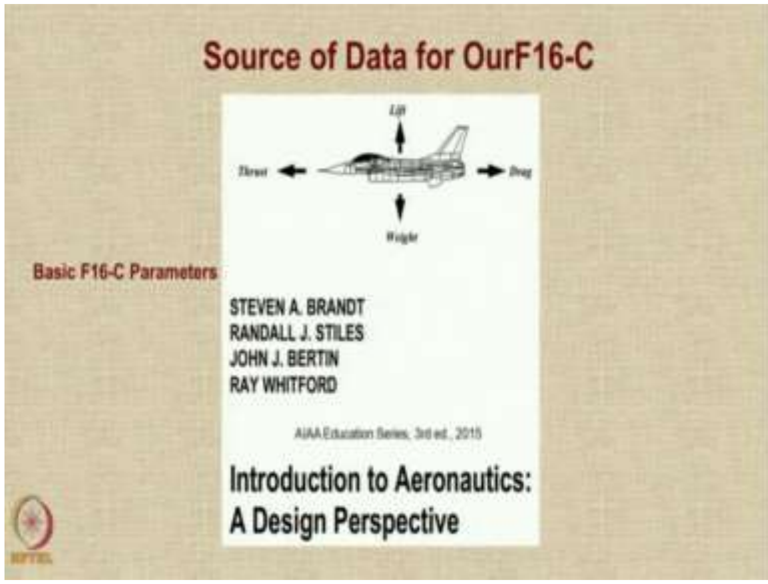
(Refer Slide Time: 00:39)



So, we will follow a color scheme in this presentation instructions for you which are general in nature will be shown in this brown color, the values of certain parameters regarding our F16 which have been taken from a standard source or the so called specified values from the mission profile will be shown in the black color, there are a few values which we have assumed those will be shown in the blue color.

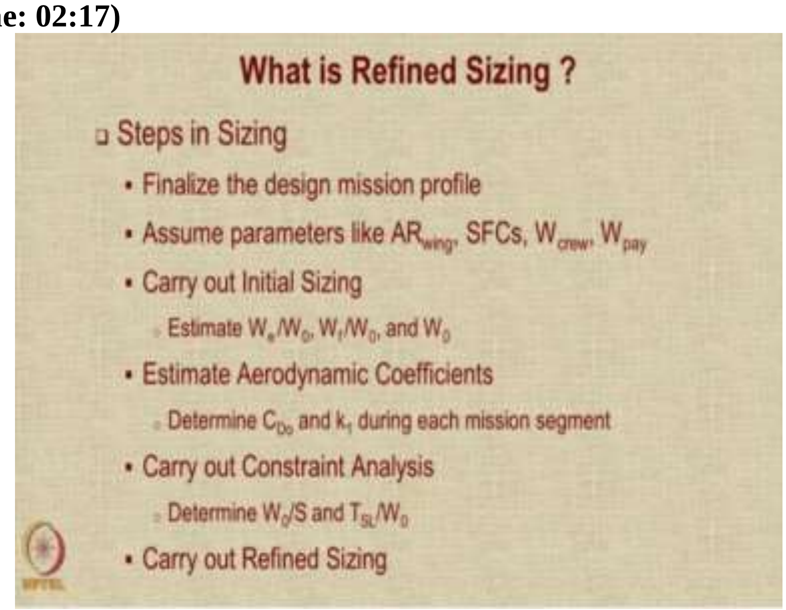
The calculations that you have to do will be shown or pointed out in the red color with question marks. And there will be this pause symbol next to it. So, wherever you see this pause symbol, it is expected that you will pause the video and do those calculations. Once again, I would like to reiterate that aircraft design is done and learned only by doing calculations. Just by nodding your head or going through the video you will not learn it unless you actually do the calculation. So please pause the video do the calculations and then you can check the values with our values. And the value that we obtain after calculating will be shown in this dark blue color.

(Refer Slide Time: 01:50)



So the basic source of data for our F16 aircraft is this textbook by Brandt, Stiles, Bertin and Whitford. In this textbook, there is a section that talks about the aerodynamic analysis, constraint analysis of F16-C. So we have taken our basic parameters from there. And also we have assumed a mission profile.

(Refer Slide Time: 02:17)



Let us do a quick recap on what is meant by refined sizing. At this state, I would like you to go and watch the video about the methodology of refined sizing if you have not done so, because this is just a tutorial and it assumes that you already know the procedure. Here we are only going to apply the procedure to sample problems. So, if you have not watched the videos regarding refined sizing, this is a good place to stop and to go back, locate and watch those video clips about refined sizing how it is done, what is the procedure and then come back here.

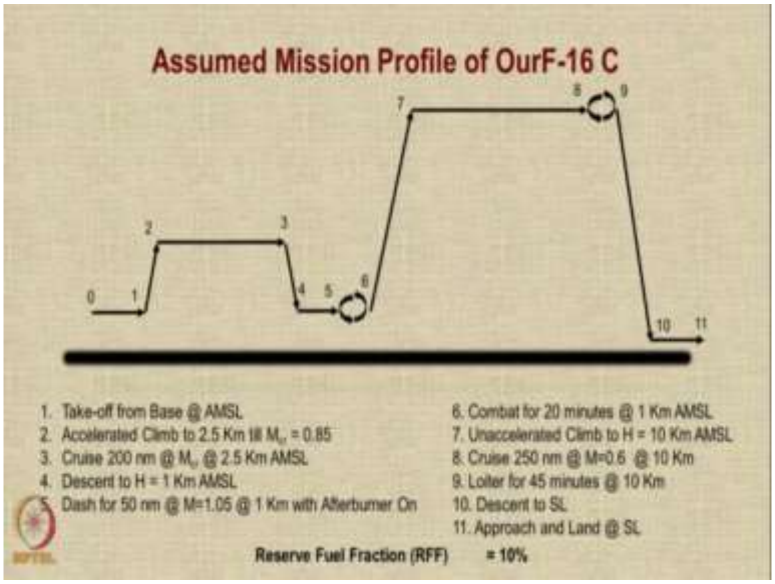
So here after we assume that you know the refined sizing procedure, so here is a quick recap, there are some steps to be followed in the sizing. First, we finalize the design mission profile, and then we assume some parameters like the wing aspect ratio, the specific fuel consumptions or SFCs in the various mission legs, the crew weight and the payload weight. Then we carry out initial sizing using these parameters and using the mission profile.

You may recall that in initial sizing, we estimate Empty weight fraction W_e/W_0, fuel weight fraction W_f/W_0. And finally after an iterative procedure, we estimate the design gross weight W_0. Then, we can do the estimation of aerodynamic characteristics, especially the zero lift drag coefficient C_{D_0} and K_1 during each vision segment. For refined sizing, we will only need the value of C_{D_0} during the various mission segments.

Once we have been able to do the dynamic analysis and initial sizing, we can then look at the methodology for a constraint analysis through which we determine the values of the design wing loading W_0/S, and the thrust to weight ratio under sea level static condition. This also has been taught and an example has been already demonstrated. So once we have the values of W_0/S, T_{SL}/W_0 etcetera. Then we can carry out the refined sizing which will be demonstrated now in the next few slides.

Remember one thing that the value of W_0 obtained in the initial sizing is just the initial estimate. At that point of time, we did not have much data about the aircraft. So we had to use a lot of formulae and procedures from the historical data. Even now, we will use a few of them. But, the number that you get there would be only the first estimate, you could use that as a starting point in this analysis, if you wish.

(Refer Slide Time: 05:16)



Let us have a look at the assumed mission profile of our F16-C aircraft. So, that is the ground the aircraft is expected to take off from a base which is located at mean sea level, it is then undergoes an accelerated climb to a height of 2.5 kilometers. The End Mach number of the accelerate climb is 0.85, so, from approximately 0.2 Mach number when it is at the end of the climb or at point number 1, it accelerates to Mach number 0.85 in an accelerated climb.

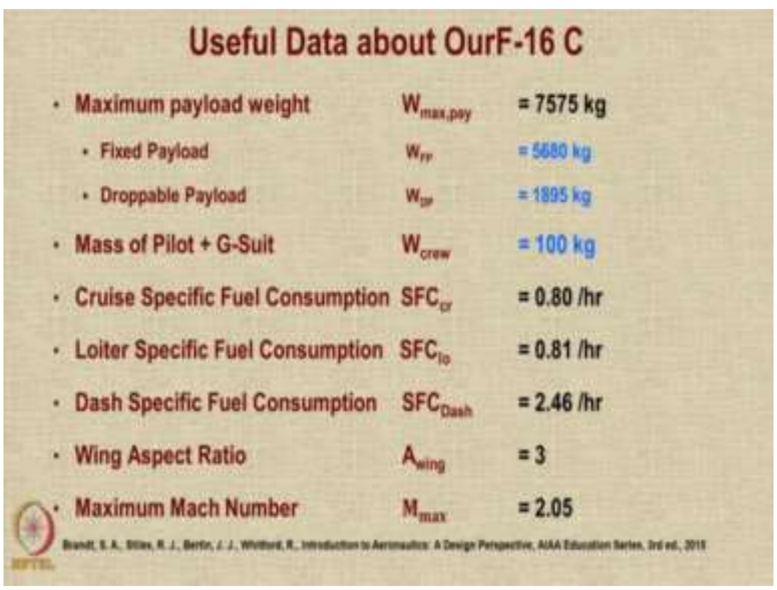
Then there is a cruise of 200 nautical miles at the same cruise Mach number M_{CR} a 0.85 at the same altitude then you come down to the combat zone. So you descend to a height of 1 kilometer, then you dash for about 50 nautical miles at Mach number 1.05, this is the fastest you fly in this mission with afterburner ON. So, a large amount of fuel will be consumed because you are flying for quite some time at a Mach number of 1.05 with afterburner ON.

So please notice and remember in the mission segment 4 to 5 although distance is very small, because the afterburner there will be huge fuel consumption then you spend about 20 minutes loitering at the territory where you are supposed to go and do your payload drop. So, about 1 kilometer, our mean sea level you are loitering there for 20 minutes. So, during this time, the aircraft is going to look around for the targets and then it is going to drop the droppable payload after that it will do an unaccelerated climb to a height of 10 kilometers.

So, this is a very slow and very relaxed climb. Then when you go to a very high altitude you are now reasonably away from danger, you can comfortably cruise back that 200 plus 50 nautical miles back to the home base. So, you fly at a comfortable Mach number of 0.6 at 10 kilometer altitude. So, the consumption of fuel will be very less even though the range is 250 nautical miles you will notice that the fuel consumption in this cruise will not be very high.

Then for about 45 minutes you are loitering at a comfortable altitude of 10 kilometers at a most optimal speed for loiter. This is so that you are ready for any other requirement if there, be if not, you come back descent and then land. So this is the assumed mission profile of our F16-C for which we will do the refined sizing. Earlier, we have already completed a tutorial for the initial sizing of this particular mission. And from there we got an estimate of the initial gross weight of the aircraft. Also remember that the reserve fuel fraction is 10% which has to be so the fuel consumed in the mission, you have to multiply by 1.1 to get the total fuel to be carried.

(Refer Slide Time: 08:46)

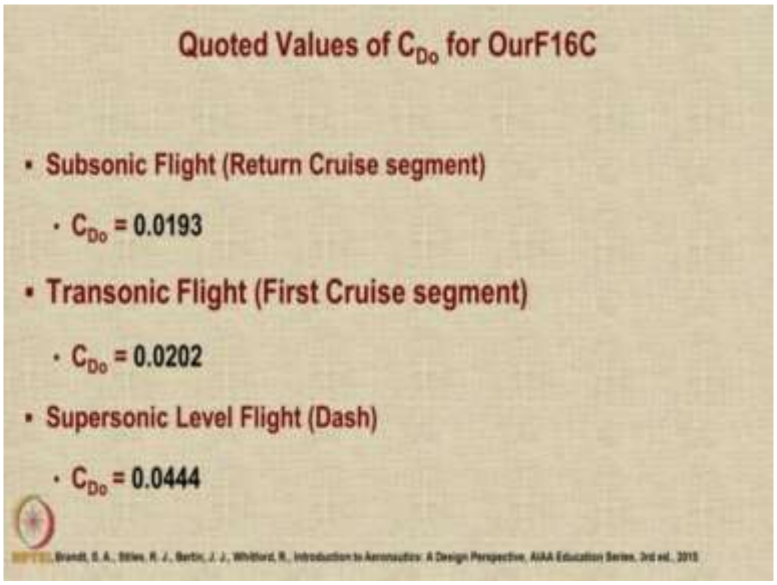


Let us look at some useful data about our F16-C aircraft. It may be a good idea for you to note down this data in a notebook because you might need it in the calculations ahead. The maximum payload weight of this aircraft is specified as 7575 kg. And here we make an assumption that around 25% of that would be the droppable payload 1895 kg which corresponds to 4 bombs of 1000 pounds each and little bit for the bullets that are carried.

So we assume that some of the bullets are gone and 4 bombs have gone remaining payload remains with the aircraft. We also assume that the mass of the pilot and the G-suit would be total about 100 kilograms. This is also an approximation. The specific fuel consumption during Cruise is already given as 0.8 per hour; during loiter as 0.81 per hour. And during dash because of the afterburner, it is almost 3 times more 2.46 per hour. And the wing aspect ratio is known to be 3 and so is the tail aspect ratio.

So this information is used to calculate the numbers and the maximum Mach number of the aircraft is given us 2.05, this number will be used only while estimating the Empty weight fraction. So may be a good idea to note down these values or remember them.

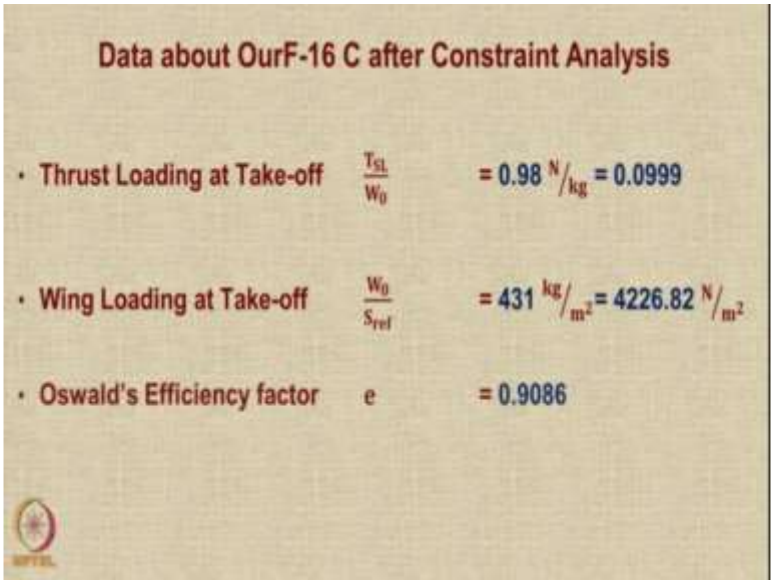
(Refer Slide Time: 10:15)



Then there are some quoted values of C_{D_0} for our F16 aircraft in the textbook by Brandt, Stiles, Bertin and Whitford for the subsonic flight that is Mach number 0.6 in the return cruise segment, C_{D_0} is given as 0.0193 for the transonic flight Mach number 0.85 which is in the first cruise segment, we are given C_{D_0} value as 0.0202. And for the supersonic level flight dash at Mach number 1.05.

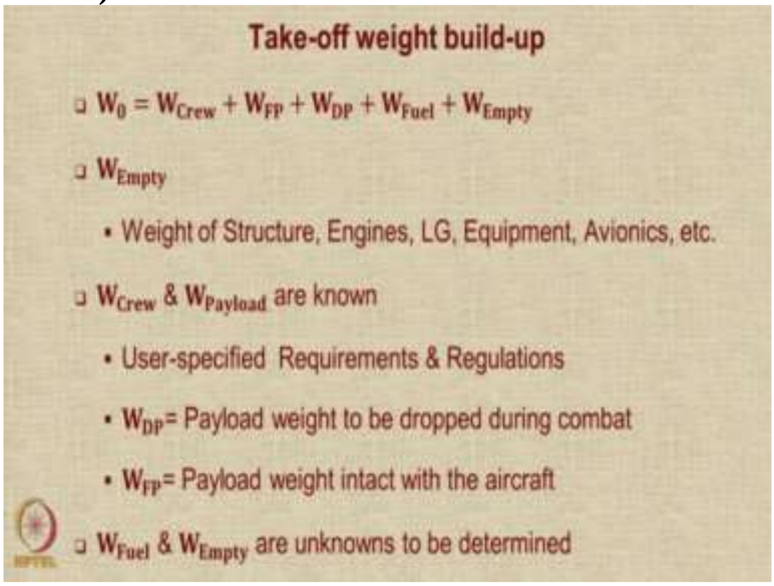
Which happens as shown in the segment from 4 to 5, 50 nautical miles at Mach number 1.05 is afterburner working, the consumption of fuel is very large, it is 0.0444. So, roughly it is and the value of C_{D_0} is also almost double of the transonic value. So, once again these 3 numbers may be noted down, because we will require these values when we calculate the fuel consumed in each of these missions.

(Refer Slide Time: 11:19)



We also look at some data about our F16-C which we obtained earlier in the constraints analysis. So, we have obtained the thrust loading to be 0.98, and wing loading to be 431 kg per meter square we are converting them into dimensionless units and written in my meter square here for our calculations, Oswalds efficiency factor was determined using the aspect ratio and the Mach number as 0.9086. So, we keep it like this.

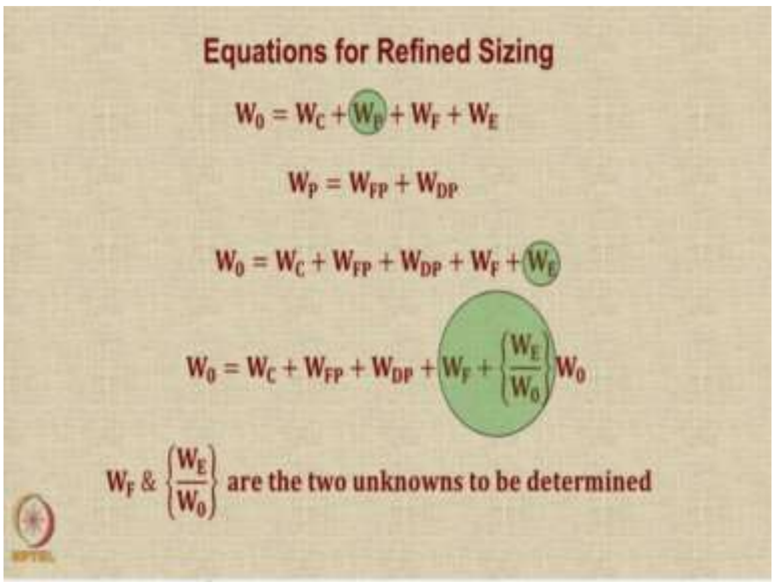
(Refer Slide Time: 11:53)



Let us look at the first step in refined sizing which is the takeoff weight built up. So, as per refined sizing procedure the aircraft weight is considered to be consisting of these elements, there is a crew weight, there is a fixed payload, and the droppable payload, there is a fuel weight and the empty weight. The empty weight consists essentially of the weight of the structure the engines the landing gear equipment, avionics etcetera.

All that comes under empty weight, W_{crew} and $W_{payload}$ are known, they are known either from the user specified requirements or from regulations. So, this means that W_{DP} which is the droppable payload and W_{FP} which is the fixed payload are the 2 things which are available from the specifications. So, W_{crew} is known, W_{FP} is known W_{DP} is known, the only 2 unknowns are W_{Fuel} and W_{Empty} these are the ones which have to be determined in the refined sizing procedure.

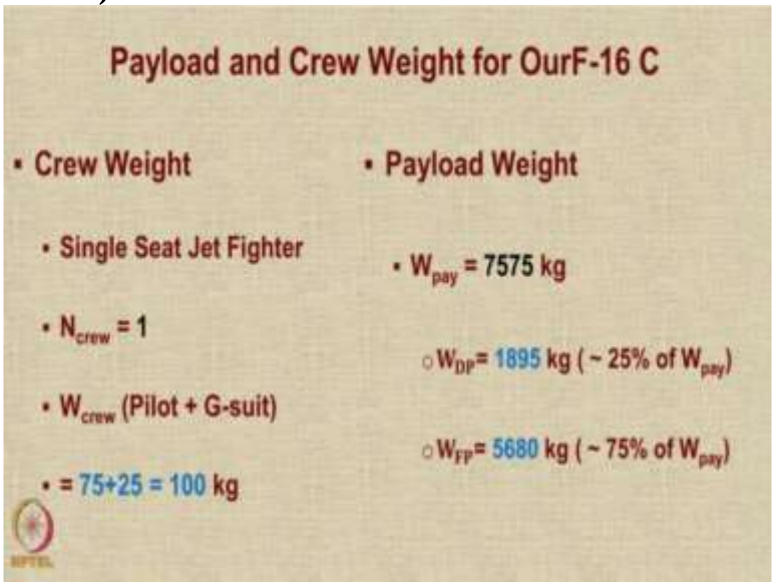
(Refer Slide Time: 12:50)



Let us look at the equations for refined sizing. So, once again W_0 as a summation of these 4 components Crew, Payload, Fuel and Empty. For payload we have seen there are 2 terms of fixed payload and droppable payload. So, for empty weight we have empty weight fraction into W_0. So, it becomes an equation of iterative of nature because on the LHS we have W_0, on the RHS also we have W_0 and this ratio is to be determined.

So, now, the 2 unknowns remaining only are W_F and W_E/W_0, they are the only 2 unknowns remaining. If you recall in the initial sizing, the 2 unknowns were the fuel weight ratio and the empty weight ratio, but in refined sizing, since the method is able to handle payload drops or sudden reduction in the aircraft weight except other than the fuel consumption, we directly calculate W_F not the ratio, but directly the empty weight still we go by the ratio.

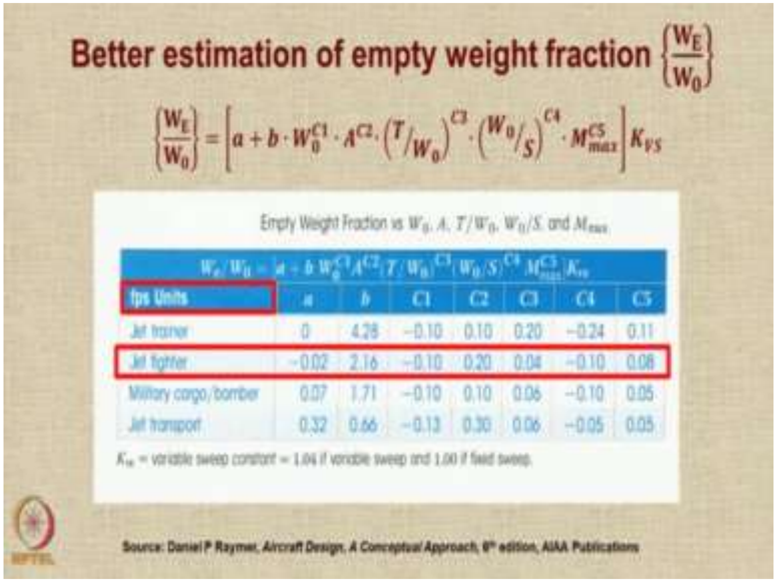
(Refer Slide Time: 13:53)



So, look at the payload and crew weight of F16 or F16-C for crew weight very simple, we have a single seat jet fighter. So, therefore, the number of crew members is one and we also assumed that the pilot and the G-suit together will weigh approximately 100 kg This also includes anything else that the pilot takes with him or her for example, the helmet etcetera. All of that comes under 100 kgs. As far as the payload weight is concerned, it is given in the specifications that the maximum payload is 7575 kg.

So, we assume that 25% of that is droppable and the remaining 75% of that is fixed. Let us start with the estimation of the empty weight fraction for this we will use the assumed or obtained values of parameters.

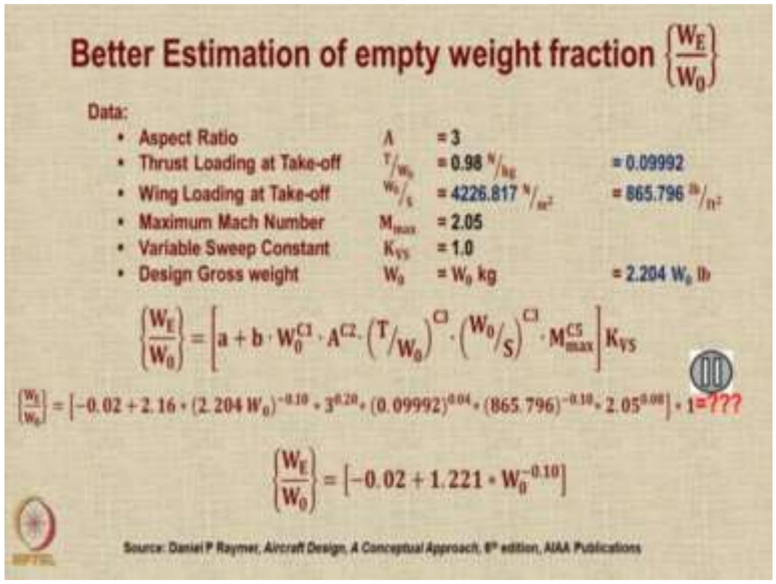
(Refer Slide Time: 14:43)



So, first let us see how we can get a slightly better estimate of empty weight fraction compared to the earlier one. In the initial sizing the value was $A * W_0^c$ where A and C were constants on the basis of aircraft type. But now, since we have more idea about the aircraft, we know for example, W_0 estimate, we know the maximum Mach number, we know the wing loading, we know the thrust loading.

So, therefore, there is a slightly more accurate estimate which it which is in terms of the 5 constants C_1 to C_5, which are inserted as powers to the variables W_0 aspect ratio of the wing A, T/W_0, W_0/S and M_{max}. So, in the textbook by remember sixth edition, we have this table that gives you the formula for empty weight fraction versus these 5 parameters. And for various military aircraft types, you know you have for example, we are looking at a jet fighter. So, the coefficients of all these parameters are given, but it may be noted that this formula works in fps system. So, therefore, the value of you know W_E/W_0 is going to be in pounds.

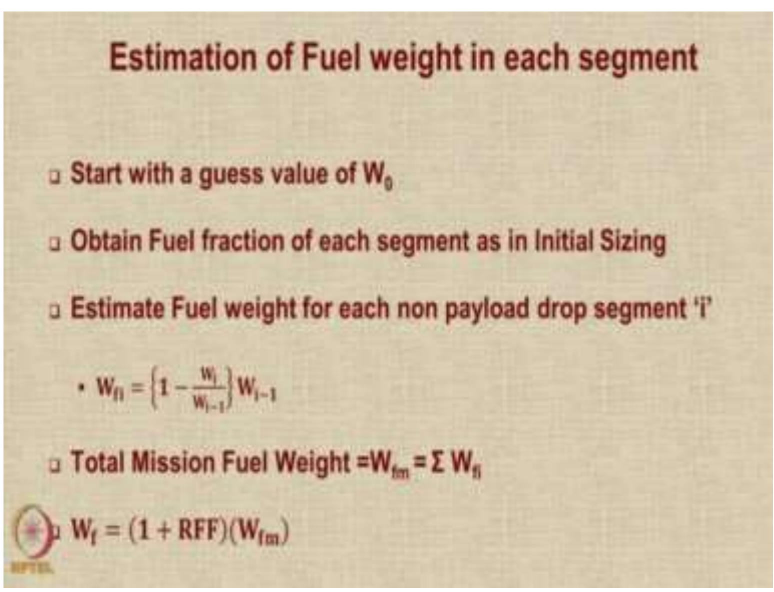
(Refer Slide Time: 16:11)



So, here is the formula. So, based on this formula and assuming that the aspect ratio is 3, the thrust loading is 0.98, the wing loading is 4226.817, Mach number as 2.05 and variable sweep constant is 1.0. You can estimate the Empty weight fraction value. Now, the design gross weight is not known, so it remains as it is so. So what we get is finally an expression. So, I think we need to calculate this expression. So, this is a place where you should pause the video and calculate these numbers.

Let us look at the estimation of the mission fuel weight; we use the approach of refined sizing in this particular case.

(Refer Slide Time: 17:11)

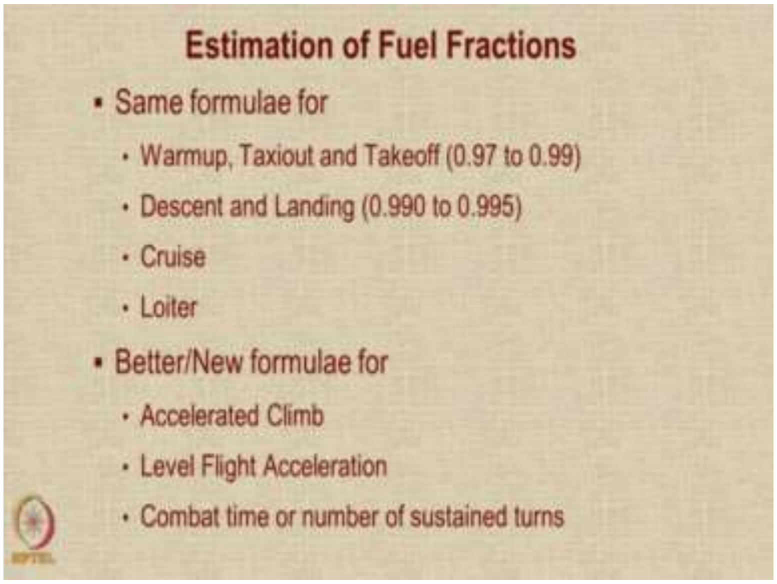


So, we will go segment by segment and we will start with a guess value of W_0; this whole process will be started by a guess value of W_0. We will then obtain the fuel fraction of each segment as an initial sizing. But we do not remain to the fuel fraction; we then calculate the fuel consumed by using this formula where W_{fi} is the fuel consumed in the ith segment. Which would be $\left\{1-\frac{w_i}{w_{i-1}}\right\}w_{i-1}$. So, the total emission fuel weight is going to be the summation of all these fuels. And then you have to just put 1+RFF to get the total fuel to be carried with the reserve factor included.

(Refer Slide Time: 18:00)

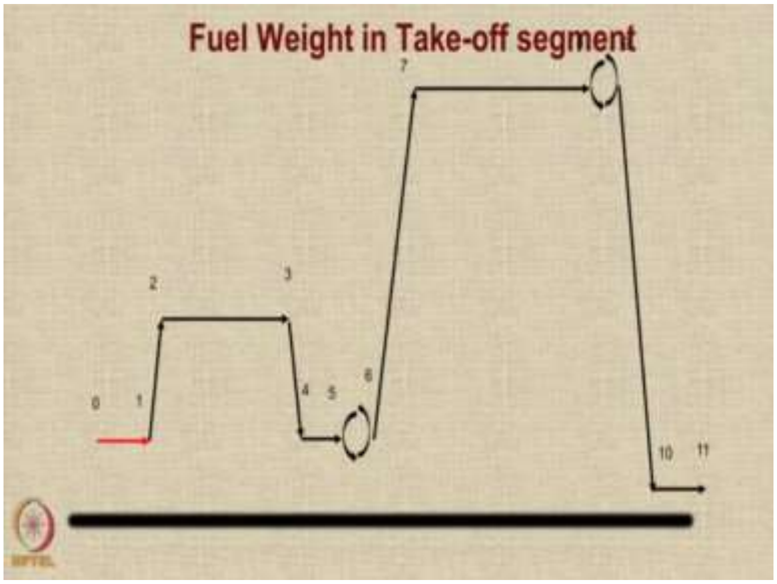
Let us estimate now the mission segment weight fractions. So, for the warm up, takeoff and landing weights fractions, we use historical trends like before. For the descent segments, there are 2 descent segments here, we assume that the fuel consumed and the distance traveled is ignored or it is considered to be 0. And therefore, these are the 4 standard values that we will be using in our calculations as specified by Raymer.

(Refer Slide Time: 18:36)



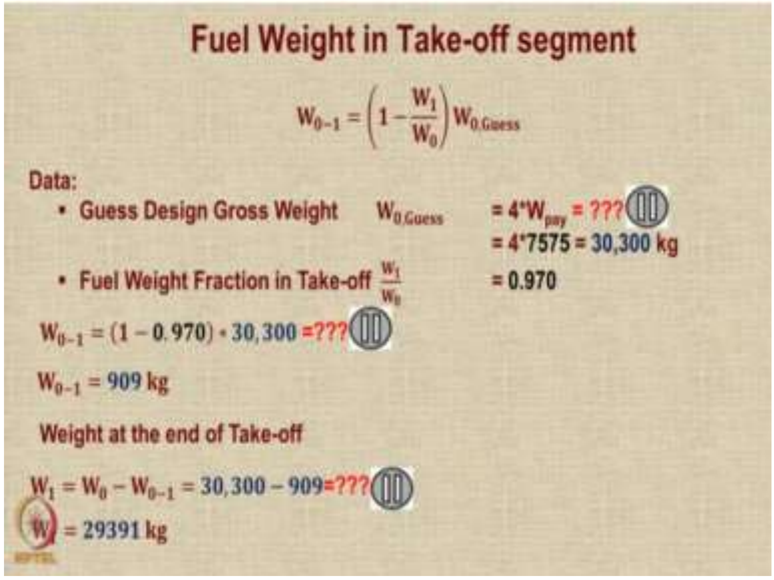
So, the formulae are the same for warm up taxi out and take off. The ratio also is similar the descent and landing crews and loiter the same formula, the difference is that there will be a much better formula for accelerated climb, level flight acceleration. And for the combat using the combat time or the number of sustained turns, we are going to get a formula to directly estimate the value of fuel.

(Refer Slide Time: 19:08)



So we are now looking at the first segments shown in the red color, which is the takeoff segment.

(Refer Slide Time: 19:16)



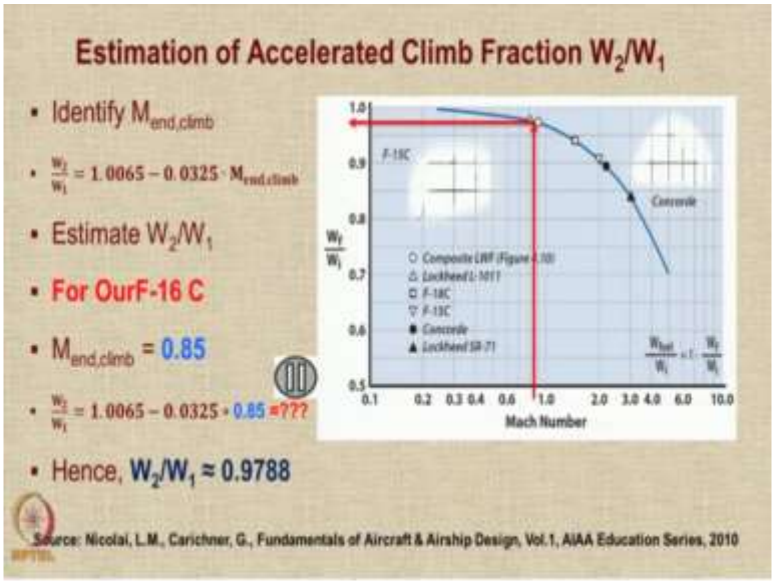
So

$$W_{0-1} = \left(1 - \frac{W_1}{W_0}\right) W_{0,Guess}$$

This is a basic formula. The data is you have to guess the design gross weight as a starting point. You could use the value calculated by you in the initial sizing or you could take it approximately 4 times the payload. So what would be the value just multiply 4 with the maximum payload of 7575 and you will get 30300 so this will be a good guess for the starting value.

The fuel weight fraction in the takeoff is assumed to be 0.970 this is this is for warm up taxi out and takeoff. So, therefore, the weight of the fuel consumed in this segment will be W_{0-1} and that would be 909 kilograms. So, therefore, the weight at the end of the segment would be 30300 – 909, please calculate the value. So, from 30 tonnes the aircraft weight becomes around 29 tonnes 391 kgs when it comes to the beginning of the accelerated climb.

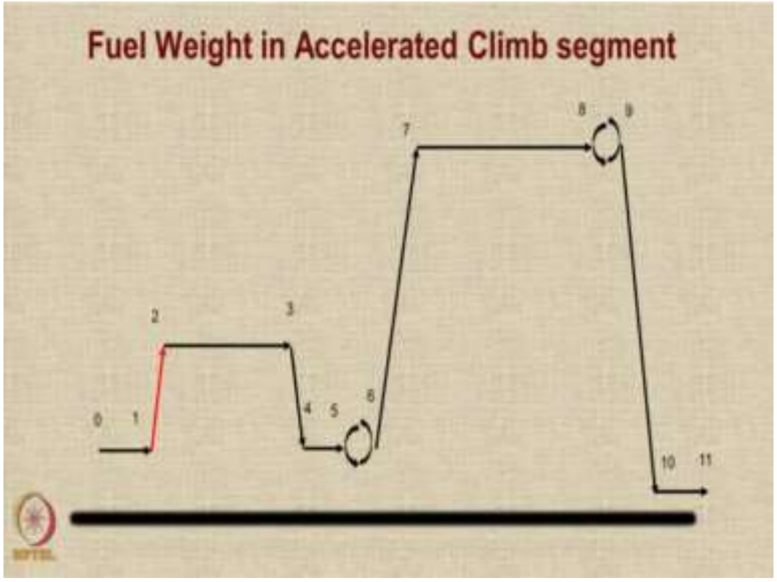
(Refer Slide Time: 20:36)



So, to calculate the fuel fraction in the accelerated climb, we first identify what is a Mach number at the end of the climb, then we use this equation to get the value if the climb is supersonic and if there is subsonic there is another formula available with that you estimate $\frac{W_2}{W_1}$. For our F16-C aircraft, the Mach number at the end of climb is 0.85 which is the cruise Mach number.

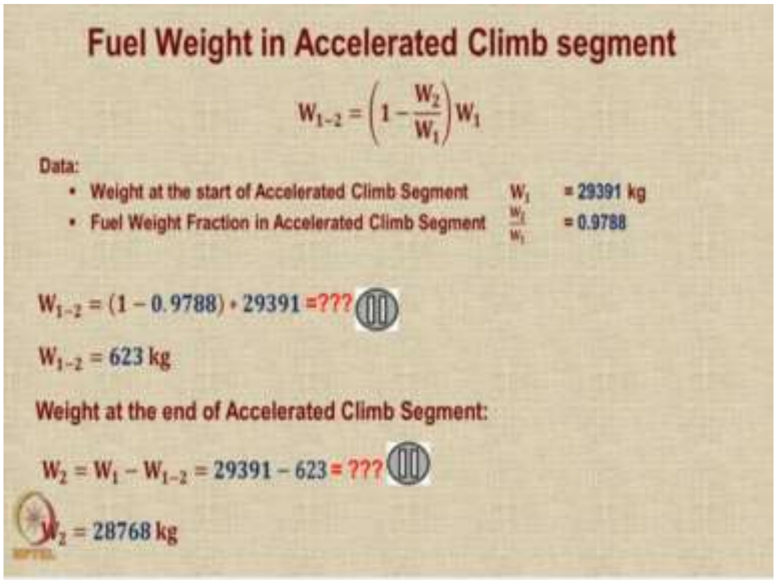
So, therefore, in the graph which has been given by Nicolai and Carichner in their textbook, you start the value of 0.85 on the x axis go to the line and you can read out the value of $\frac{W_f}{W_i}$ or you could actually use this formula and calculate this value the number comes out to be 0.9788 I hope you have paused the video and you had calculated this number.

(Refer Slide Time: 21:45)



Moving on to the accelerated climb segment, which is segment from 1 to 2 shown in the red color.

(Refer Slide Time: 21:54)

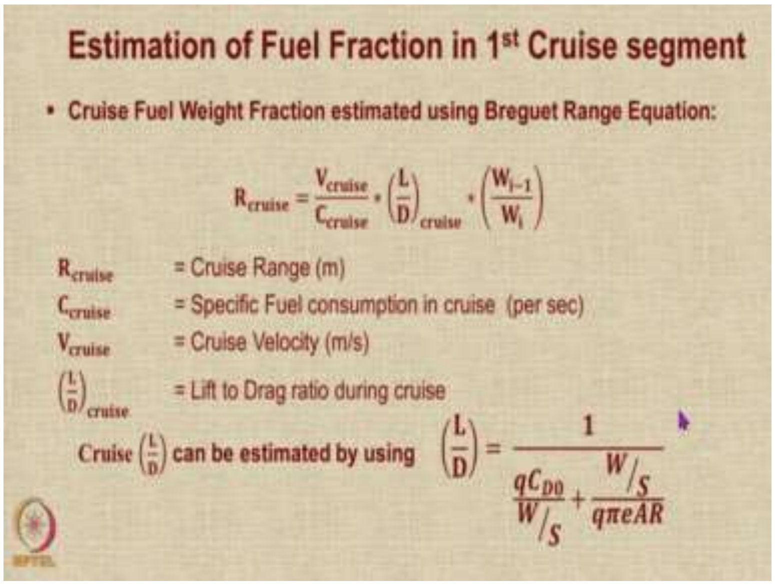


So, this is a standard formula for every segment, fuel consumed in a segment will be equal to 1 minus weight ratio at the beginning on another segment into the wait at the beginning of the segment. So, we know that for this aircraft, the weight at the start of the accelerated climb is what we got earlier as a weight at takeoff minus the fuel consumed during takeoff and warmer and we also know the value of fuel weight fraction. We have just seen it in the chart or done the calculation.

So, therefore, the fuel consumed during this segment will be 1- 0. 9788 into 29391, please calculate the value, the value is 623 kilograms. So, at the end of the segment the weight will be 29391 –

623. It will be this value which is the beginning minus the value which is available at the end of the segment. So, the difference of these 2 is going to give you the fuel weight at the end of this segment and that value is 28768 kilograms. So we have gone from approximation here we are not looking at any values beyond decimal point, we are looking only at whole number values. So we are rounding up the numbers of to the 0th decimal place.

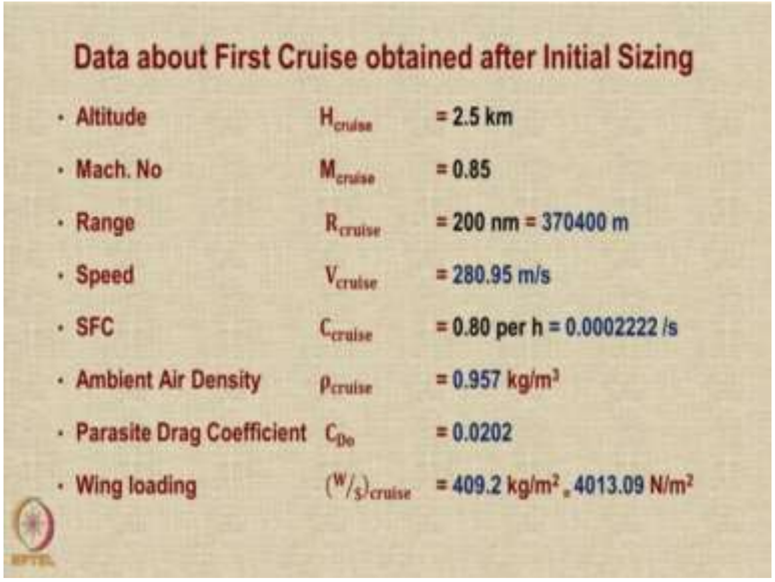
(Refer Slide Time: 23:28)



Now we come to the first of the slightly complicated segments. It is actually a simple cruise segment, but the methodology for estimating the fuel fraction is a little bit complex. So, for the cruise fuel weight fraction, we again take recourse to the Breguet range equation which has V_{cruise}, C_{cruise}, L/D cruise and the weight ratios in the calculation. So, here R_{cruise} the cruise range in meters, C_{cruise} the SFC during a particular phase during takeoff, during landing, during climb and the cruise velocity also has to be calculated.

So, the first 3 R_{cruise}, C_{cruise}, V_{cruise}, they will come from the mission profile, but the last one has to be estimated, earlier we took the L/D as equal to the 0.866 times L/D max. I think because it is a jet engine aircraft in a cruise, but now what we do is since we know the value of C_{D_0}, W/S and e and AR and hence we also know value of q.

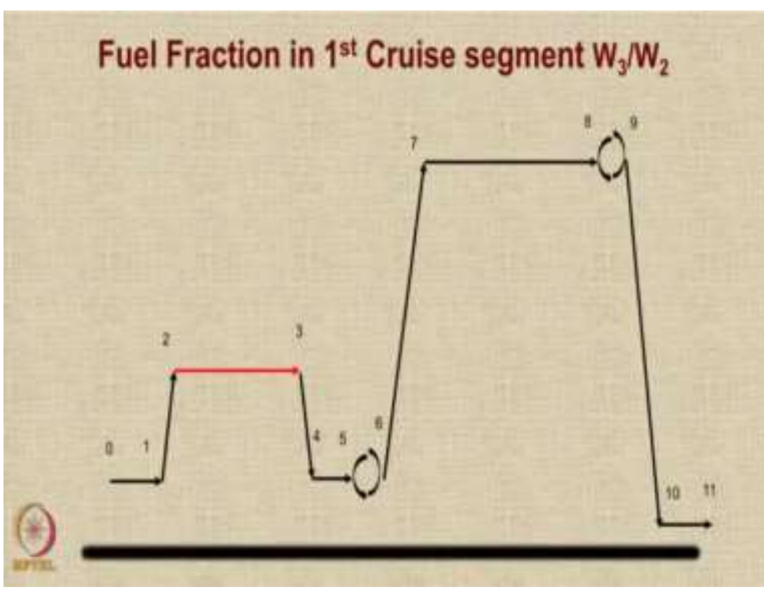
(Refer Slide Time: 25:04)



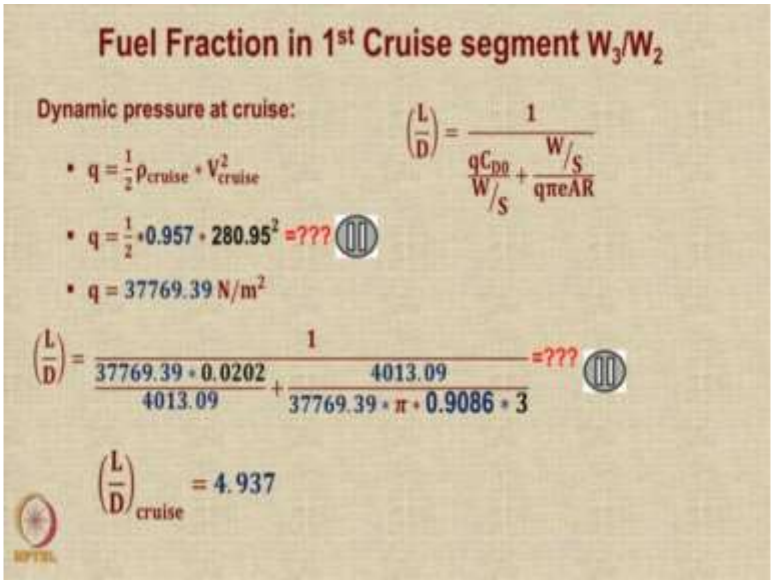
So, we need some data regarding the first 2 segments, the first cruise takes place at a height of 2.5 kilometers, the Mach number is 0.85, the range traveled is 200 nautical miles which is 370400 meters. The speed because of the Mach number of whatever specified value of Mach number is there at that Mach numbers around 0.6 I think you will get some speed, and then you have the SFC at that particular speed which is already specified as 0.80 per hour.

You know a density of air 2.5 kilometers from the tables and the parasite drag coefficient is 0.0202 because the aircraft is going to be flying in the transonic region and the wing loading can be calculated from the constraint diagram for that particular point.

(Refer Slide Time: 25:54)

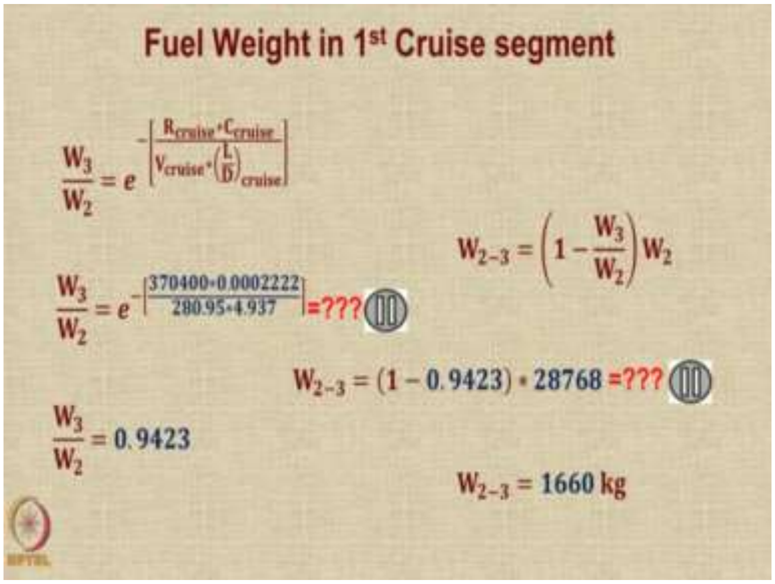


(Refer Slide Time: 25:59)



So, keeping all this in mind, you can calculate the fuel fraction in the first cruise. So, q is $\frac{1}{2}\rho V^2$, ρ is 0.957 at 2.5 kilometers and V is 280.95 at a given Mach number, so, q is 37769 per square meter again the same formula so, insert the values of q C_{D_0} W/S, W/S and also the value of q and e AR. So, plugging in these values and calculating the numerical value we get, L/D is only 4.937.Previously, this number was very high, because we assumed that the aircraft will fly at the optimum condition, but now we are flying the aircraft at a given condition. So, therefore, the L/D Max is much lower than that.

(Refer Slide Time: 27:07)

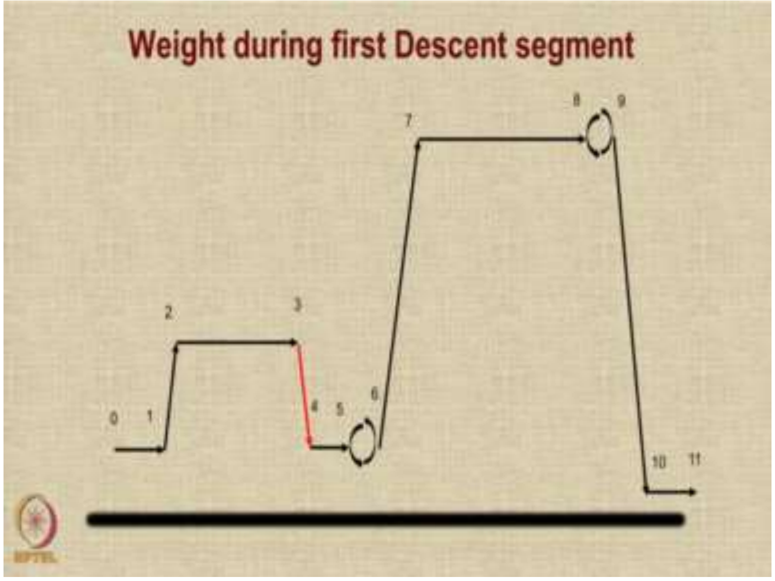


Fuel in the first cruise segment. So, once the ratio is known by inverting both sides, you can get

$$\frac{W_3}{W_2} = e^{-\frac{R_{cruise} * c_{cruise}}{V_{cruise} * \frac{L}{D}_{cruise}}}$$

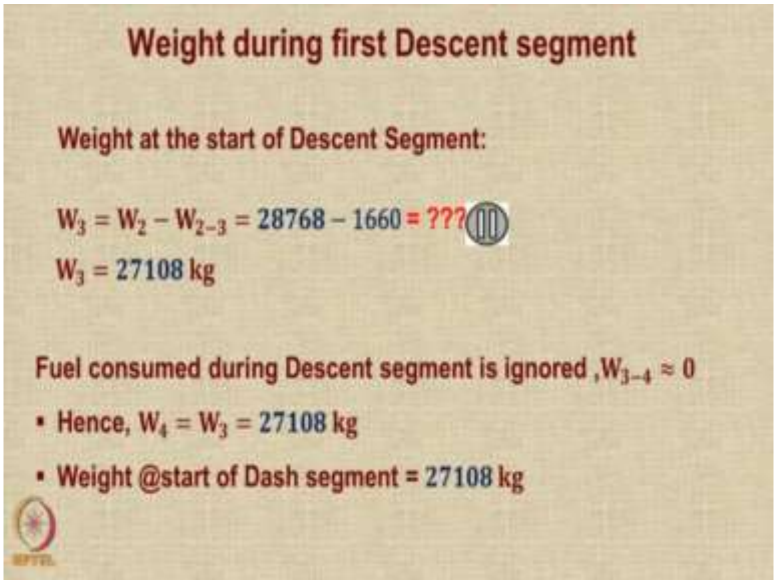
just put in the values of the various parameters that you have already calculated and we get $\frac{W_3}{W_2}$ as 0.9423. Now, we want to actually weigh the fuel weight. So, with that, you can get the estimation of weight in the cruise segment and that weight is 1660 kg.

(Refer Slide Time: 28:27)



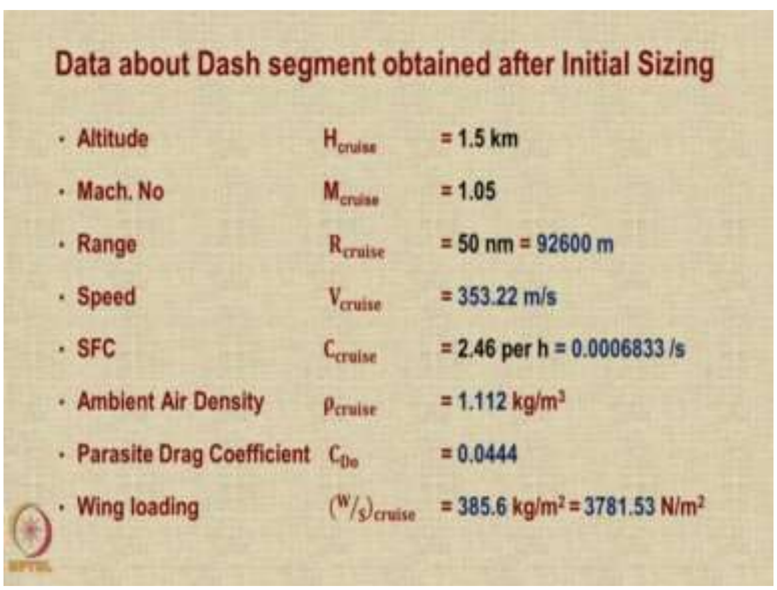
Now, Let us look at the descent segments. Remember that in descent segments, we have ignored the distance travel and the fuel consumed.

(Refer Slide Time: 28:33)



So, weight at the start of that descent segment is the weight at the end of the previous segment which is 28768 - 1660 kg, which we know is 27108 kg. Now, from this you subtract whatever is consumed during the descent. So, in the descent, we can assume that certain components of the system like the sensors etcetera are working. So, therefore, W_4 is equal to W_3 is equal to 27108 kg because there is no reserve needed for any mission specific information. So, the weight at the beginning of the next segment also will be the same as way to the beginning of the previous segment 27108 kg.

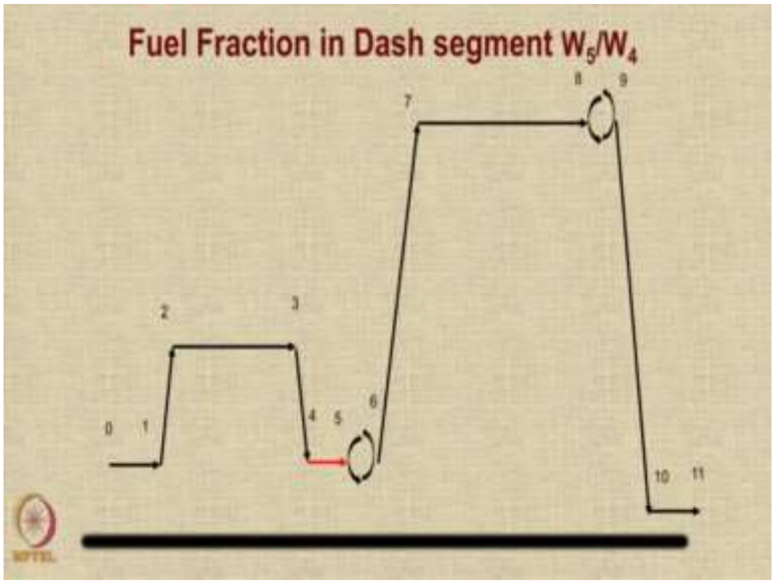
(Refer Slide Time: 29:21)



Now dash occurs at 1.5 kilometers. The Mach number during the dash is given as 1.05; the range is 50 nautical miles. The speed is 353.22 because you are flying at supersonic Mach numbers. The

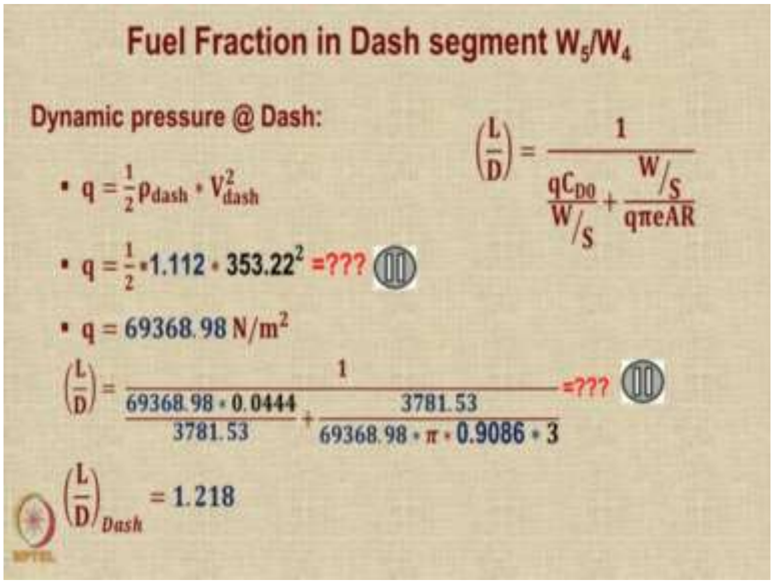
SFC is 2.46 per hour, which is very high. It is more than 2 times that of these 2 aircraft during peacetime. The density of air at 1.5 kilometer also plays a role. And of course there is a parasite drag coefficient which is twice the normal value and the wing loading is cruise given as 385.6 from the initial sizing.

(Refer Slide Time: 30:04)



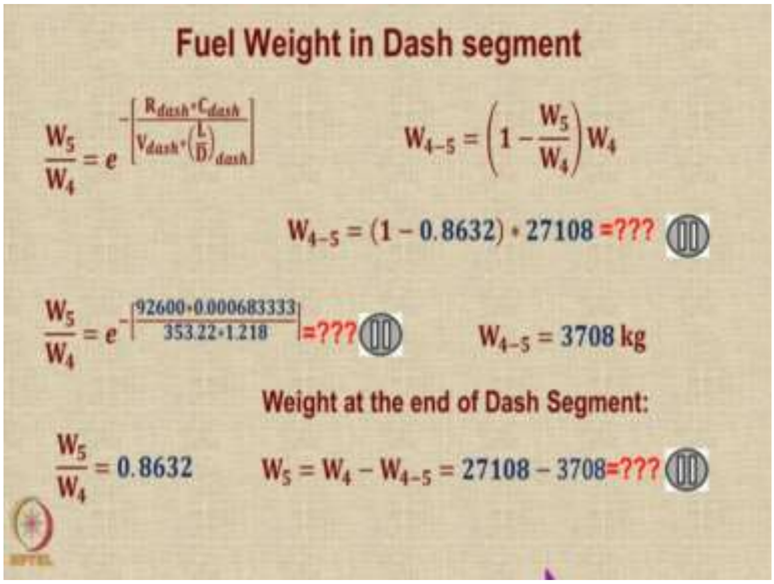
So, after completing the initial sizing and the constrained analysis, we can now calculate fuel fraction in the dash segment, which is a low altitude accelerated flight.

(Refer Slide Time: 30:25)



So, the value of q is available by multiplying by density and the velocity that is 69368 Newton per meter square and then you can estimate the L/D using this formula. So, putting in the numbers, so, the L/D in this condition is very poor, it is only 1.2. Whereas, L/D can be as high as 20 during an optimized cruise and we also got it around 12. But here it is 10 times less it is just 1.218. So, remember in the fuel fraction, because of very low L/D will come in the denominator here, there is going to be a large value of the you know, fraction in the dash.

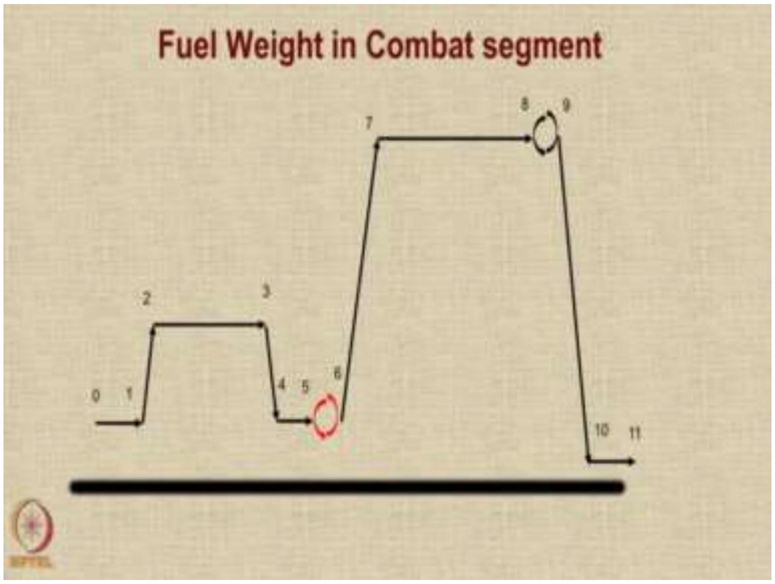
(Refer Slide Time: 31:21)



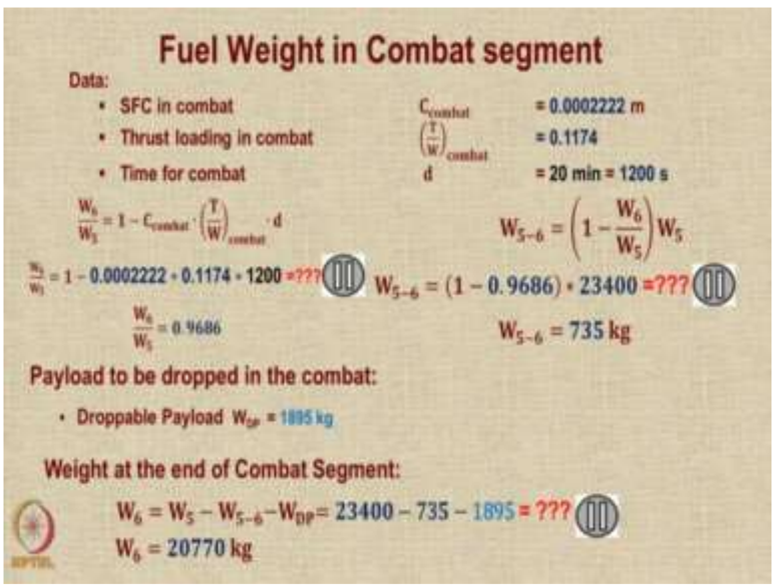
Let us look at the fuel weight. So, the formula is known this already we have calculated 0.8632 is the weight fraction. So, 23% of the aircraft is gone in just one mission which is the dash mission. So, the weight of the aircraft at the end of the program would be what we are spending is a actually this ratio. This is what is the actual price of the purchase of the frame. So, however, we took the challenge to calculate what is W_4/W_5 and we find that the value of that gives you convergence is 5.05.

So, Let us look at the weight at the end of the dash segment that would be the weight of the beginning of that segment minus 370. So, notice the fuel consumed in dash is very high is 3.7 tons in a 15 nautical mile dash. So 27108 - 3708, 23400 kg is now the weight of the aircraft at the end of the dash segment.

(Refer Slide Time: 32:33)



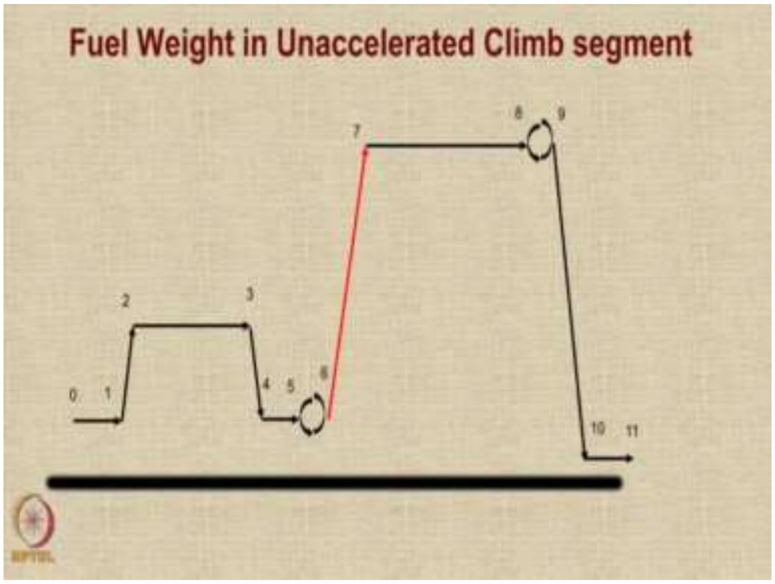
(Refer Slide Time: 32:39)



After that, we do a combat for 20 minutes. So, it is given that the SFC is 80 per hour or 0.0002222, thrust loading in combat is known from the previous initial sizing calculations, the time for combat is specified as 20 minutes or 1200 seconds. So, the weight fraction in the combat would be 1 minus SFC of the combat into T/W of combat into d. So, it turns out to be 0.9686. So, for the combat segment, once again the weight would be just 1 minus the ratio into the old weight.

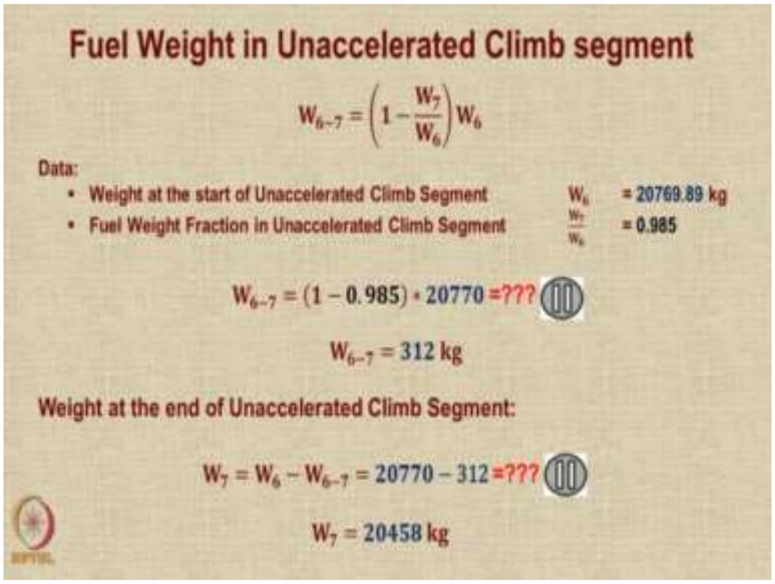
the weight at the beginning of the segment that is 735 kg. So, you can see in combat we have spent additional 735 kg now the payload to be dropped in the combat was assumed to be 25% only that is 1895 kg. So that can be released now. So, the weight at the end of segment will be that that value minus 1895 kgs. So it will be substantially lighter now. That means it will come to 20770 kg.

(Refer Slide Time: 33:58)



Now we go to the peaceful and relaxed unaccelerated climb to add to the height of 10 kilometers, the end Mach number is 0.6.

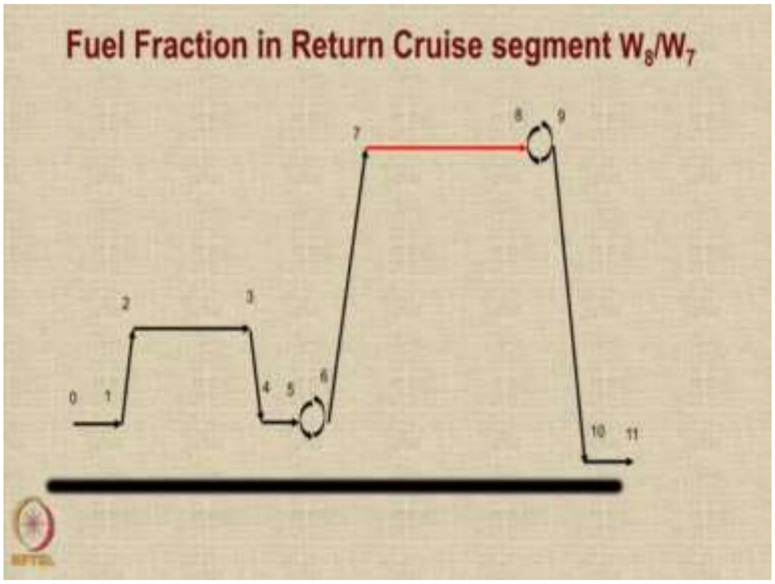
(Refer Slide Time: 34:09)



So once again the formula remains the same. But the data would be as follows the weight at the start of the climb is 20769.8 or 20770 actually, the fuel weight fraction in an accelerated climb is given as 0.985. So therefore, you can just put 0.985 in this expression and W_6 in this expression and you will get the W 6 to 7 that is a fuel consumed. How much is it? Can you please calculate 1- 0.985 whole brackets into 20770 it is just 312 kgs.

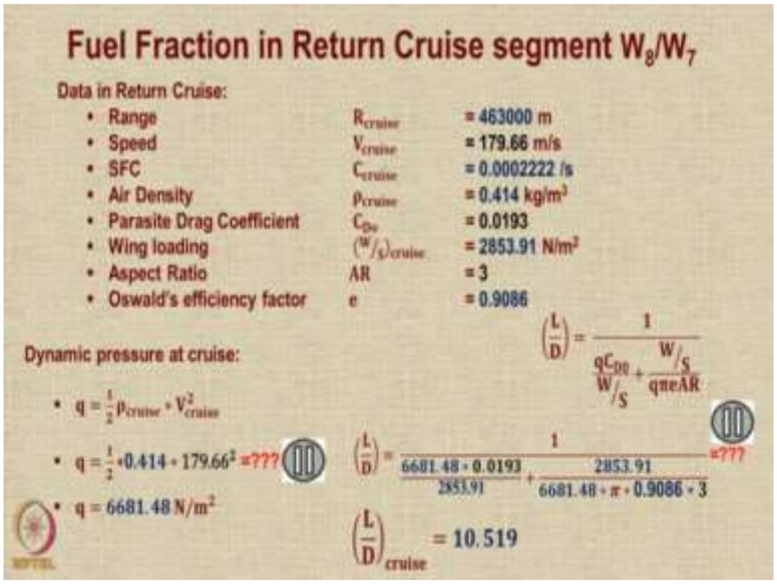
So the fuel spent in loitering for 20 minutes to 312 kg weight of the aircraft at the end of the unaccelerated climb is as follows. First thing is you should know the self-weight. So, it will be 20770 - 312 that means, you have to keep it to cater for this weight in case it is required for us to relocate to Mumbai. So, Let us look at the fuel weight the fuel weight is very simple 20770 was the weight at the beginning of the climb at the end of the previous phase and the value now is 312 kg has been estimated as the fuel consumed during the unaccelerated climb. So, therefore, the difference is going to be the simple weight addition during the segment.

(Refer Slide Time: 35:45)



We look at the return cruise now, which is happening at a comfortable Mach number of 0.6 at a height of 10 kilometers.

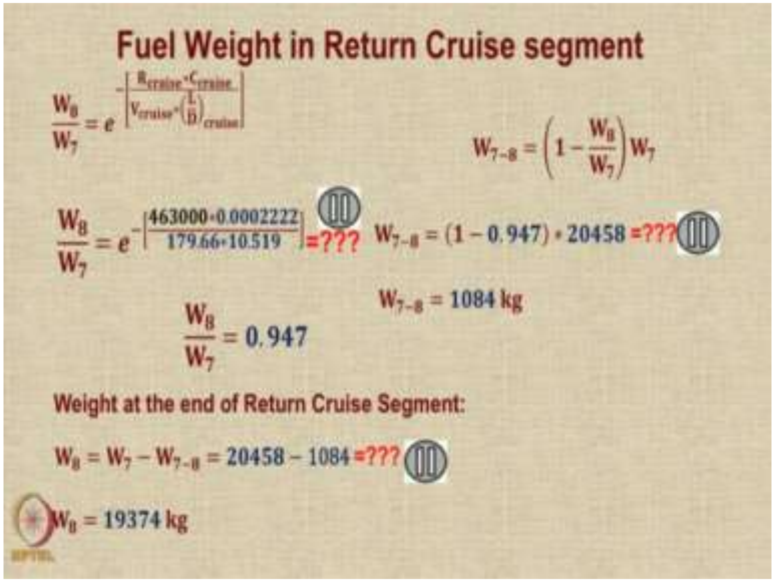
(Refer Slide Time: 35:53)



So, the range is 463000 meters that is 250 nautical miles, the speed is 179.66 that is from Mach number 0.6, the SFC is given as SFC cruise as 0.0002222 per second, the density of air at the altitude of 1.5 kilometer I assume would be 0.414 kg per meter cube the parasite drag efficient is 0.0193 because you are at a very benign low speed flight, and the wing loading as determined by the initial sizing for this segment is given.

So, therefore, dynamic pressure turned out to be 6681 Newtons per meter square, same formula applies here also. And putting in the numerical values, I would like you to note down these values, pause the video and check whether your number matches roughly with my number. You can do this in MATLAB or any other software also. The L/D value we get is 10.519 for the return cruise segment.

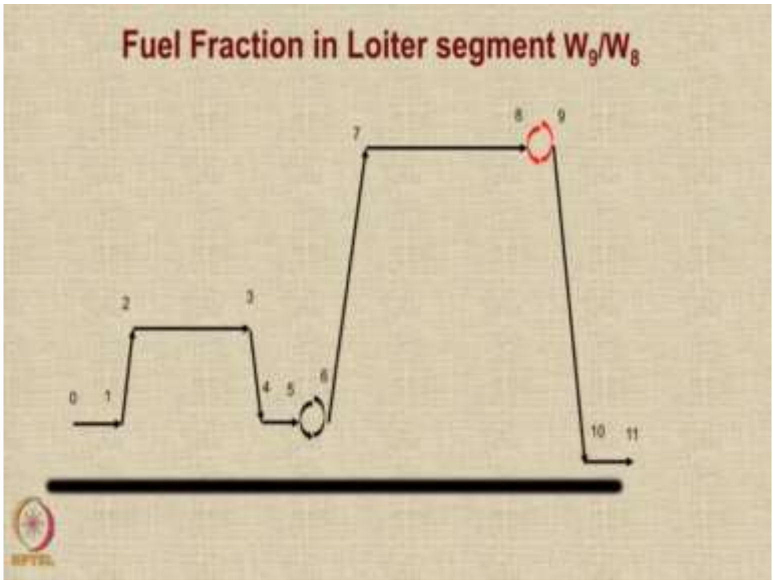
(Refer Slide Time: 37:16)



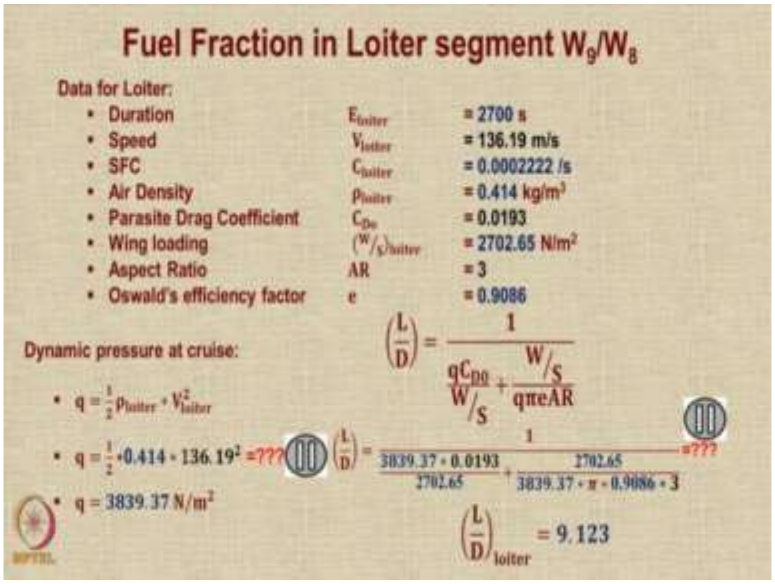
And the value of the empty weight fraction is obtained by the endurance equation in which W_8/W_7 is 0.947. So, putting in the values in the formula, you can get the weight fraction as 0.947. And then the same formula applies even here. So, this is the weight fraction in this segment, and this is the weight at the beginning of this segment do calculate the value of W_7 to W_8 it is 1084 kgs.

So, in the return cruise segment although we have traveled more distance, the total fuel consumed is less than that one third than that are consumed in dash, because dash is a very time very fuel guzzling kind of mission afterburner is on and you are there for 20 minutes. So, W_8 would be 20458 – 1084, because at the end of cruise, there is this nasty divergence segment for which we are going to do the calculations separately. So, what is the value of W 8 here 19374 kg.

(Refer Slide Time: 38:26)



(Refer Slide Time: 38:29)

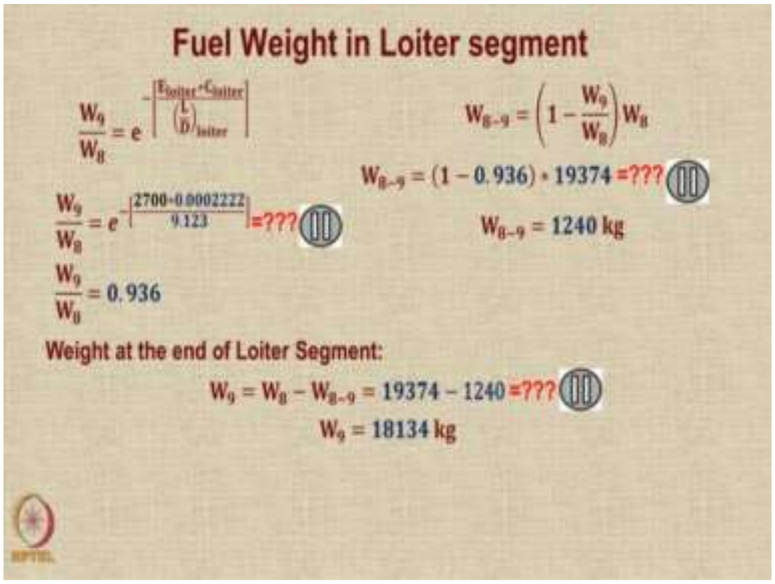


Finally, we come to the loiter segment at the end of the flight. So, for that we have been told that the loiter is happening for 45 minutes at the speed that we choose to be the optimum speed for the SFC would be 0.0002222 per second, density at 10 kilometer is 0.414, parasite drag efficient is 0.0193, Oswalds efficient factor is 2702.65 And finally, efficiency factor e is also needed in the calculation it is 0.9086.

So, with this you can calculate dynamic pressure at the cruise, what is the value of this expression please calculate, the value is 3839.37. Remember this number will be in Newton per meter square, then when we put density in kg per meter cube and velocity meter per second, we do not get dimensionless value, you get meter cube per second something like that very awkward units.

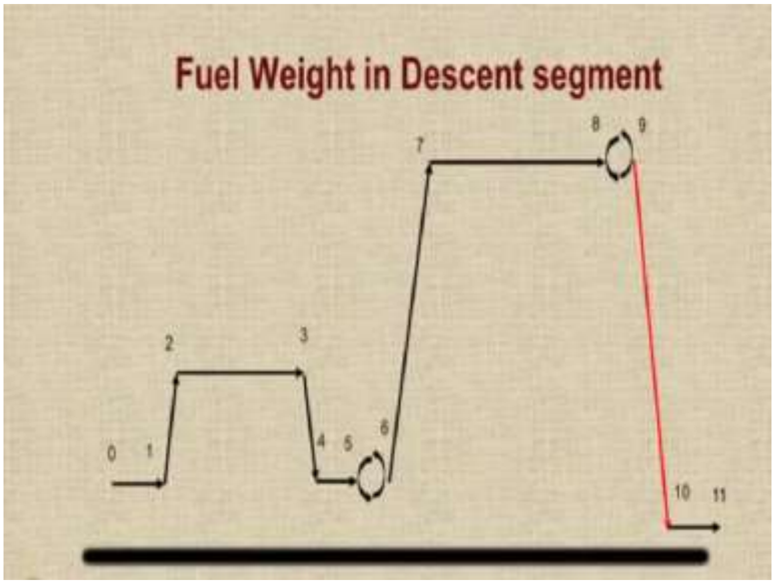
So, therefore, we need to be careful, we have to use if you use kilograms and kg per meter cube, then you get units in terms of actually no units are needed then, but that is the value. So, L/D the same formula the expression is similar only the numerical values have changed slightly so, please do calculate this number L/D loiter is 9.123.

(Refer Slide Time: 40:17)



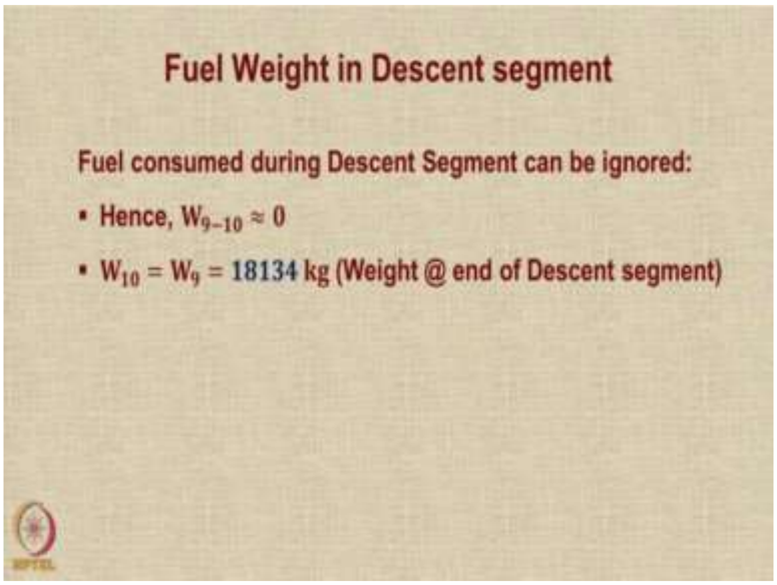
Now, Let us go to the loiter segment again we use the Bregeut range equation W_9/W_8, this is the equation for the weight remaining W 8 to 9 this segment, we are having a vacancy in weight. So, the value of the fuel consumed is 1240 kg, 20 minute loiter and a 10 kilometer altitude. So, the weight at the end would be 19374, which is the beginning of the loiter minus 1240, it is 18134.

(Refer Slide Time: 41:00)



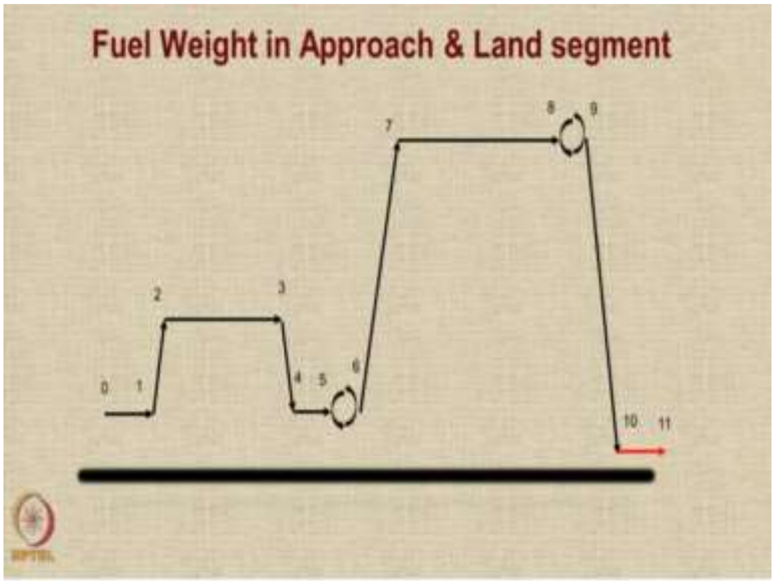
The next segment is the descent segment and recall that in descent segment we are ignoring the fuel consumed from the distance traveled.

(Refer Slide Time: 41:07)

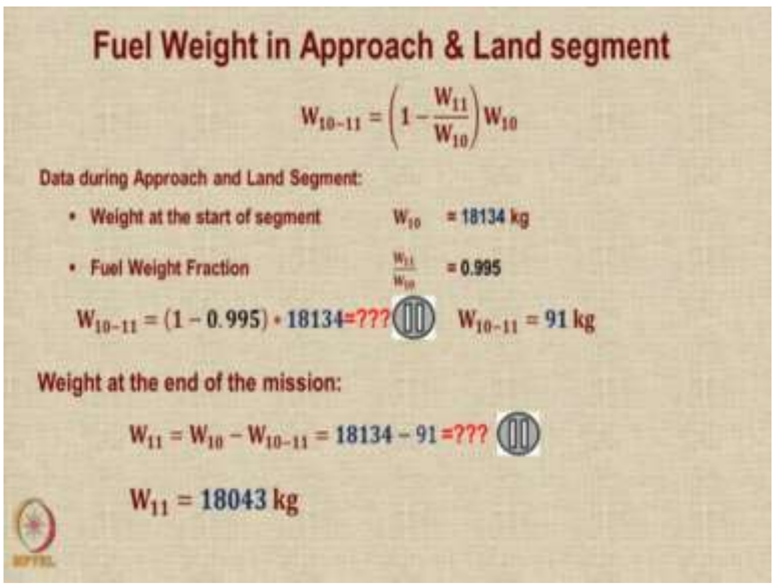


So, they are the same and also we assume that the aircraft comes back intact without dropping the payload also. So, you can get the value of W_{10}.

(Refer Slide Time: 41:22)



(Refer Slide Time: 41:27)



Finally, we come to the approach and landing segment. Which is again a standard from historical data; the formula remains the same these are the 2 parameters which are known to us a priori. One is that the weight at the start of the segment it has to be 18134. And also we know that the weight ratio in the approach and landing segment is assumed to be 0.995. So, just multiply 1 – 0.995 into 18134 you will get the answer. So weight at the end of the mission will be equal to the weight at the beginning of this particular segment minus the fuel consumed this segment is 91 kgs. So, the answer is 18043 kg.

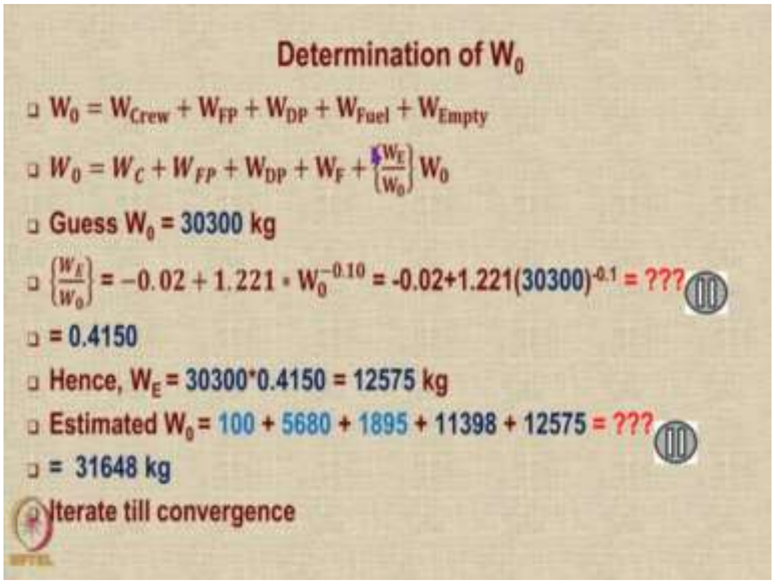
(Refer Slide Time: 42:06)

Let us see how we calculate the fuel weight in all mission segments. So, for that we just sum up the sum of the fuel consumed in each segment. So, W_{FM} would be just the addition of all the weights in each segment right from 0-1 to 10-11. And these numbers are written here for your convenience to this number corresponds to 909, this corresponds to this. So, notice that the onboard cruise segment has more fuel consumption than the return cruise segment.

Mainly because the aircraft is lighter much lighter, it has knocked off 3708 pounds of cargo. The least segment the least fuel is consumed in the approach and landing segment, we neglect the fuel consumption in the both the descent segments and this is the big daddy 3708 the fuel consumed in the dash, so fuel consumed in loiter and fuel consumed in return cruise are quite low. But the main consumption of fuel is happens in the dash segment.

So if you add up these numbers, I think you should do it yourself by pausing, the video the total fuel comes out to be 10362 kg on this we have to slap an additional 10% because of the reserve fuel. So therefore the total fuel will become 1+RFF times this value which will be how much, please calculate this value turns out to be 11398 kgs.

(Refer Slide Time: 43:46)



So now once we know now the fuel weight for an assumed value of W_0. Let us see how we find the W_0 in their refined sizing. So once again, the formula contains crew, drop fixed payload, droppable payload, fuel and empty. Empty is replaced by ratio W_E/W_0. Now, the guess weight is 30300 kg. So, W_E/W_0 can be calculated how much is this, please calculate this number is 0.415.

So, therefore, the empty weight will be 0.415 times 30300 that is 12575 kg, and the value of estimated W assumed W_0 as 30300 and we got all these values we got empty weight fraction also and then we put it back here. So, crew is 100, fixed payload is 5680, droppable is 1895, fuel as estimated now is 113898, and empty is 12575. Now, if you add this number, you will see that it is become more than the LHS it will become 31648 kg which is more than the left hand side. So, therefore, we need to iterate we will take probably this value as the initial value, do the whole process again. So, we keep on iterating till we receive achieve convergence.

(Refer Slide Time: 43:46)

Comparison of Fuel Weights

Fuel Weights	Symbol	Refined Sizing	Initial Sizing	% Diff.
Take-off	W_{0-1}	982	1091	10
Accelerated Climb	W_{1-2}	673	776	13
1st Cruise	W_{2-3}	1791	1035	-73
1st Descent	W_{3-4}	0	0	0
Dash	W_{4-5}	4005	609	-558
Combat	W_{5-6}	792	778	-2
Unaccelerated Climb	W_{6-7}	339	481	30
2nd Cruise	W_{7-8}	1180	1798	34
Loiter	W_{8-9}	1342	1561	14
2nd Descent	W_{9-10}	0	0	0
Approach & Land	W_{10-11}	99	141	30
Mission Fuel Weight	W_{FM}	10530	8270	-27
Reserve Fuel Fraction	RFF=10%	1053	827	-27
Total Fuel Weight	W_f	11582	9097	-27

So, this is the answer finally, this is what you get. So, these are the symbols various segments in refined sizing we got these numbers and these are the numbers which we got earlier in the initial sizing you can go back and check there. So, we noticed that there is a huge difference between the fuel consumed in refined sizing, versus the fuel consumed in initial sizing. So, the difference is very large it is around 600% by 50% in the case of dash segment and larger than that, so, the net you have 27% additional fuel compared to initial sizing.

(Refer Slide Time: 46:04)

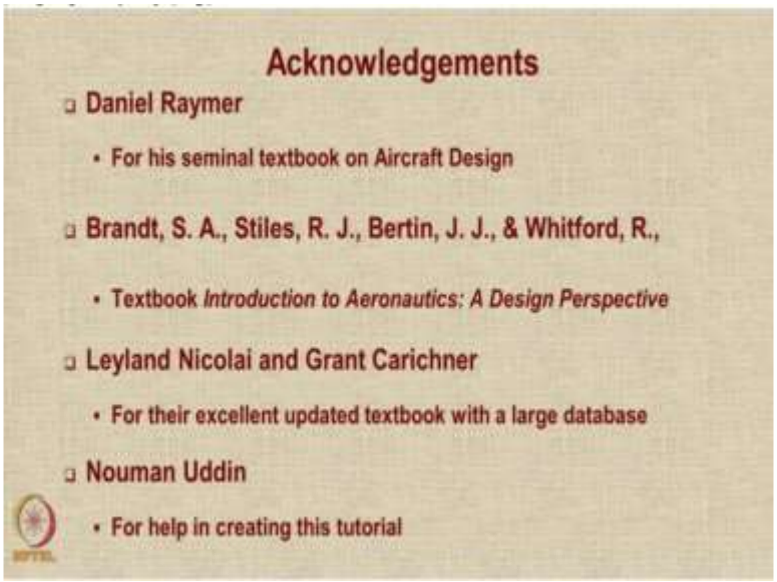
Aircraft Weight Breakdown Comparison

Parameter	Symbol	Refined Sizing	Initial Sizing	% Diff.
Empty Weight Fraction	W_E/W_0	0.41175	0.53875	-24
Fuel Weight Fraction	W_F/W_0	0.35380	0.25018	41
Empty Weight	W_E	13480	19591	-31
Fuel Weight	W_F	11582	9098	27
Design Gross Weight	W_0	32737	36364	-10

And this is the weight breakdown. So, we will look at Empty weight fraction, fuel weight fraction Empty weight, fuel weight and design gross weight. These numbers you get in refined sizing.

These numbers we got in initial sizing. You will notice that the values are away by about 24%, 41%, 31% percent etcetera. But the design gross weight you get is roughly around just 10% away.

(Refer Slide Time: 46:34)



Before I close, I like to acknowledge Daniel Raymer for his seminal textbook in aircraft design. Brandt, Stiles, Bertin Whitford for their textbook, which has become the baseline for us to use for getting the data of our F16-C. Nicolai and Carichner have given graphs for estimation of the fuel in the unaccelerated climb and also have very good updates about the aircraft and Nouman Uddin the teaching assistant for helping creating this tutorial.

Thanks for your attention. And I hope that the numbers obtained by you have also matched with our numbers. If there is a discrepancy, please bring it to our notice and we will take care. Thank you.