Aircraft Design
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Lecture - 05
Mission Requirements

Good morning. In the last lecture we are talking about how to get an idea of the weight of the airplane you are going to design. Typically, if we start thinking in terms of let us say passenger aircraft, and we decide maybe 100 passengers 200 passengers, we have an idea what sort of a range I want, what sort of a speed I want. If you have got few parameters as customers requirement, then todays scenario we immediately see the database. We try to select a baseline aircraft whose performance parameters are almost like whatever you are looking for.

Generally, what happens? For any new design you try to add some new aspects, to that new design, but overall requirements based on mission requirements you will find some aircraft already in is existing, which is closer to what requirement. We have because lots of designs are available lots of airplanes are available they are flying. There is no point in reinventing will as we understand for aircraft if I talk about material there is so much development in material. And that impacts the strength to weight ratio there are sensors there is huge development in sensors. So, you will find over a period of time dynamically there is a change. In the overall configuration of an airplane we say this is material property we say which is sensor capability.

So, since all these data are available which are result of lot of work done by generation after generation, it is always wise to look for a baseline airplane to get enough idea what will be the weight. Just to give an example, if we are planning for a 4 seater or a 5 seater low speed airplane, which is like a business propeller driven airplane, then immediately we think of maybe Cessna 2 0 6 piper Saratoga all this class you get an idea the weight will be around 1500 to 1600 kgs right. If we are talking about bigger aircraft, you have to see whether it is close to 83193 20 or Boeing immediately you have got the weight and basic parameters available right.

So, the whole point what we are contesting is, once we have got a machine requirement you can always find out some baseline airplane. And in baseline airplane one of the primary parameter which you look for is what is the weight of that airplane.

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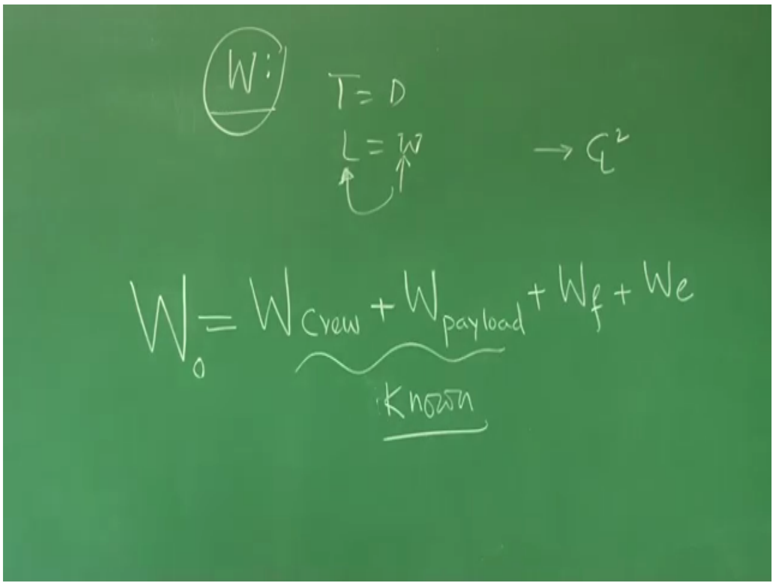

And why weight is important, we know when I say weight then I know trust equal to drag lift equal to weight after all from ground to air I am flying. So, there is a requirement of lift. And lift will lift requirement will be more as the weight increases. So, weight decides what sort of lift, I need to generate a lift means, it is function of density of the air the speed the wing area. So, all these things get connected to weight right. Similarly, if we see drag. Drag has component with C L square right.

So, in in a very simplistic term the lift is more drag also will have it is more contribution and since weight increment results is more lift. So, I can always assume that will also make ourselves to look for more trust or more power to work on the drag or drag related power. So, finally, if you find weight gets linked to everything, which is ideally true also without going into all these equation after all I am going to able to lift something. So, more weight means more lift more effort right.

So, that is where weight is extremely important, and we will be now asking ourselves how do I get initial estimate of the weight. Knowing very well through a baseline approach if I select a baseline aircraft I have rough idea about the weight class, I am talking about what is the method routinely we follow to get an hang of what is the weight we are looking for. And when I talk about the weight, is weight is what I am talking about weight is takeoff weight that the gross weight, what it is composed of it will have weight crew member, weight payload, then weight fuel and weight empty.

So, this has been broken up very smartly into these 4 categories. What is the first one the crew member, crew member weight we always will know (Refer Time: 06:32) it is a human weight. And there are a vision standards and they have to follow that that when you design an aircraft of particular type you have to take weight of the human being to be 75 kg or 100 kg depending upon the regulations. Then payload also we know because whether the passenger whether the cargo we know a priori if it a 200 seater. So, I know average weight of one person I will add those I know how much baggage will allowed them to carry.

So, this W crew and W payload they are in our hand, we know a priori right known let us say. So, life is not that difficult.

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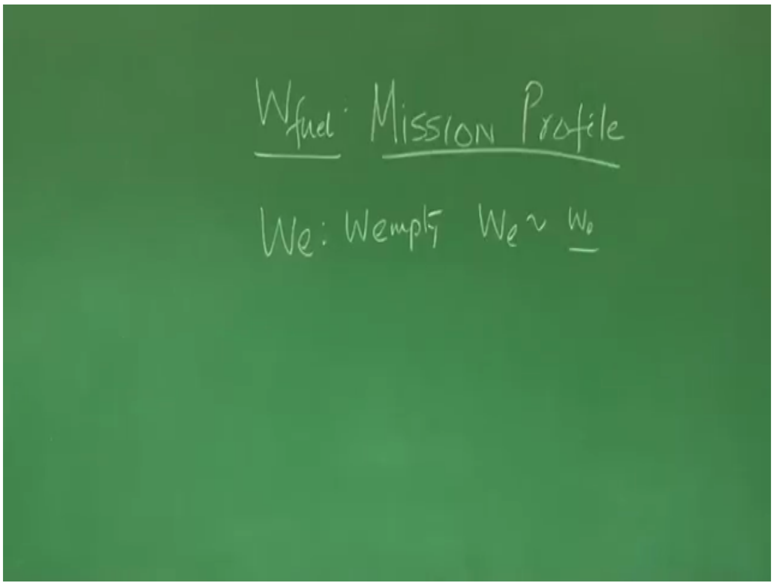

Now, come back here the third one the fuel weight, how much fuel I should carry, how much fuel is required, who will decide that. Natural position ground how far you want to go, at what speed you want to go, how much time you want to loiter. All these thing will decide how much fuel is required. Because for every operation fuel will be consumed during taxing acceleration takeoff climb cruise, loiters landing sometimes combat, all these things are necessitated by power delivered by the engine and which is at the cost of fuel being burnt.

So, if I want to have an idea about fuel I need to know what is the mission profile, this is extremely important. It is as simple as this if you are driving a car, and if from Kanpur if you want to go to Delhi, how much fuel you should carry in your fuel tank who decides that first thing, I need to know what is the distance from Kanpur to Delhi the road distance and what is the fuel consumption rate of the car. Also you know that we need to also know how is the road condition. Why that is important because we know that there is a particular speed at which fuel consumption is minimum.

And the question comes whether I will be able to drive my car meeting those requirements are not because road condition traffic conditions may not be what I am thinking to have an optimal speed. So, all these things will be considered, then you say I if have 30 liters forty liters 50 liters. And if it is not sufficient how do you plan you plan for a refueling you plan that after this many distance, nearest fuel pump or petrol pump I will fill my car. These all mission similarly for a aircraft also we have to have some mission profile what this airplane is going to do. And that will primarily decide weight of fuel, but it is just not mission profile, you understand the mission profile you have to visualize through the weight of the airplane. Because we have seen as weight increases drag increases, power increases and though naturally your fuel requirement will also increase.

So, there will be if a separate approach for estimating W fuel and this one W e which is W empty that has been also added separately. For simple reason that W empty means it is more driven by your structural design, what material you have use, what sort of stress relieving structure you have, and those will those things will decide what is the empty weight. Again you will find this empty weight will also be somehow I can link to W naught may be linearly proportional based on the statistical data. These are all initial statistical data driven inferences, which will be used to get the first parameter for a conceptual design.

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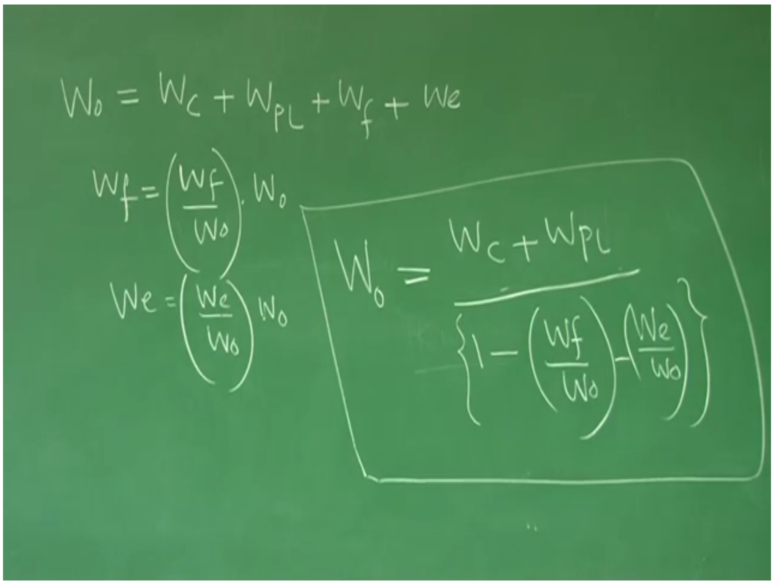

Now, I come back here again. So, I write W naught equal to W crew, plus W payload, plus W fuel, plus W empty. And this I can write W f with assumption that I will be working more with the fraction of gross weight, and W e also I will model at W e by W naught into W naught. Please understand this approach. Here we are trying to find out how much percentage of the gross weight is the fuel weight, how much percent gross weight is the empty weight. And then I multiply by W naught to get fuel consumption weight. This is purely based on the statistical data. That makes life simpler if I substitute this here then I can write, you can do yourself W naught equal to W crew then W payload by 1 minus, W f by W naught minus W e by W naught. Keep this back of your mind will see how to use this.

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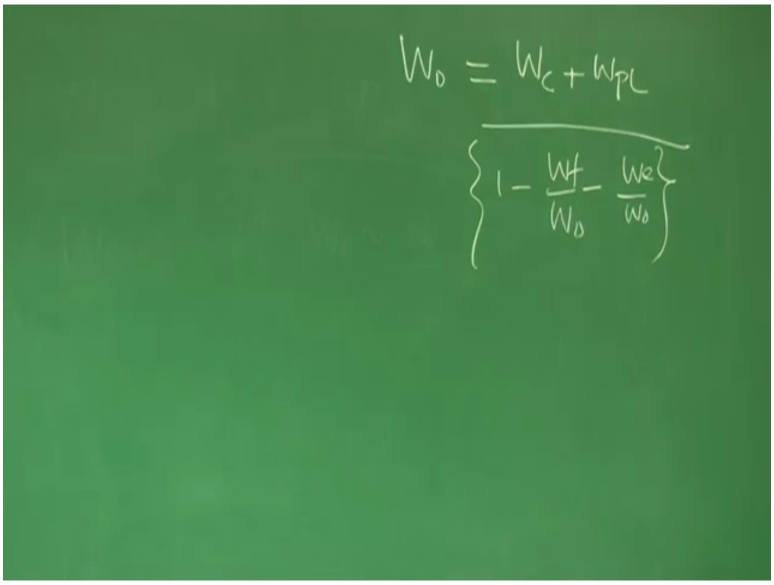

So, let me write this expression here, because you will be using this W naught equal to W crew plus W payload divided by 1 minus W f by W naught minus W e by W naught.

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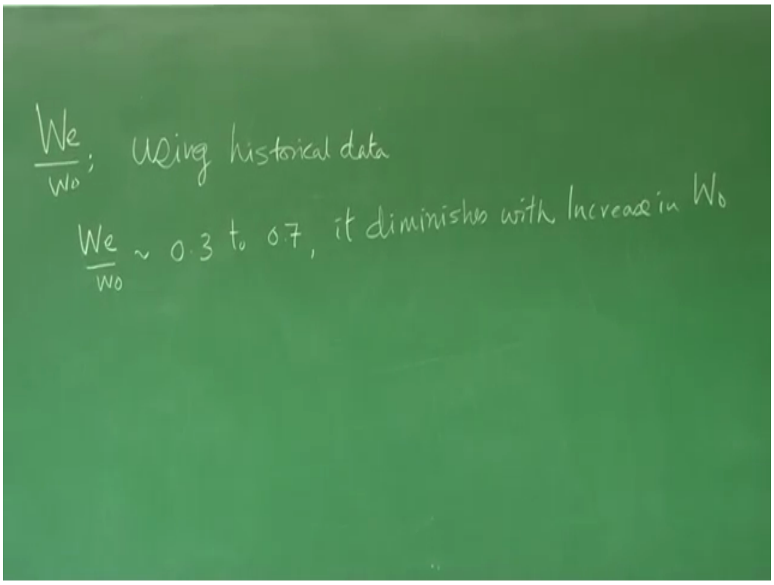

We will first discuss about W e by W naught. That is empty weight fraction and these are estimated using I told you using historical data. Please understand all this efforts are to get the initial numbers for the design to start the design conceptual design.

Generally, you find from historical data, this W e by W naught vary from 0.3 to 0.7. And another important observation is that it diminishes with increase in W naught what is W naught. So, for I am taking, W naught, is the gross weight everything included right.

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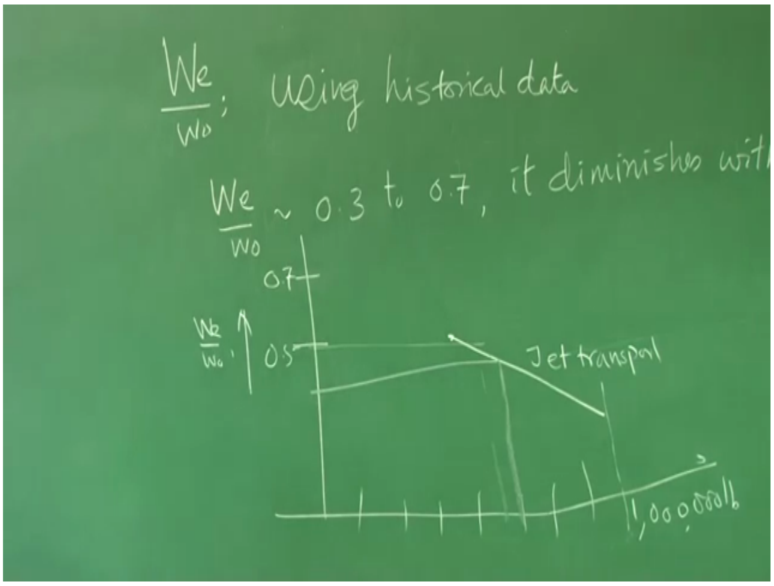

Just to give an example historical data representations, typically if I take this is 0.7 summer, it is 0.5, and I am just trying to give a qualitative representation of a jet transport jet transport, and here this will be around should have. So, if you are designing a jet transport airplane then depending upon what weight class you want to design you can get roughly what is W e by W naught this is.

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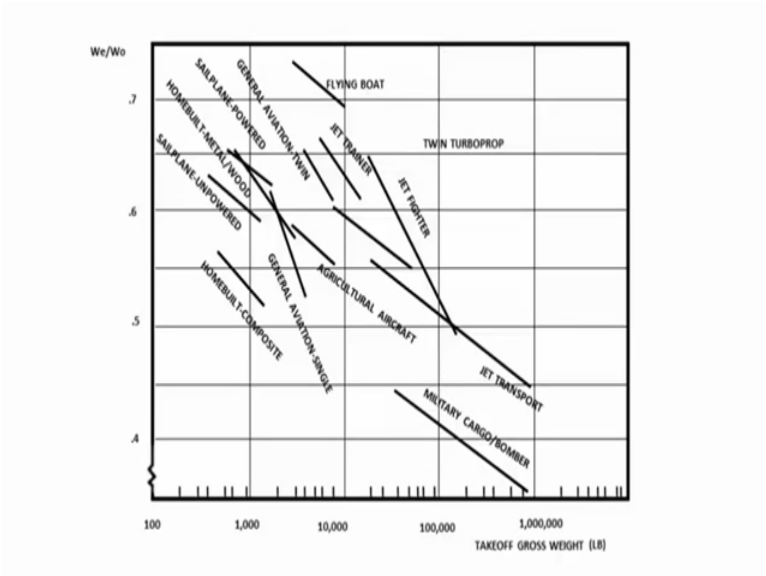

This we can focus on figure the empty weight fraction trends. You could see that for sailplane powered for thousand pound this W e by W naught is around 0.65. Again if you go further you find for a jet trainer for a 10 thousand pound for a jet trainer, it is around 0.65 to 0.62. Focus on military cargo bomber weighing around one lakh pounds, the W e by W naught can vary between 0.45 to 0.1. So, this figure empty weight fraction trend which is based on historical data is a guideline for it.

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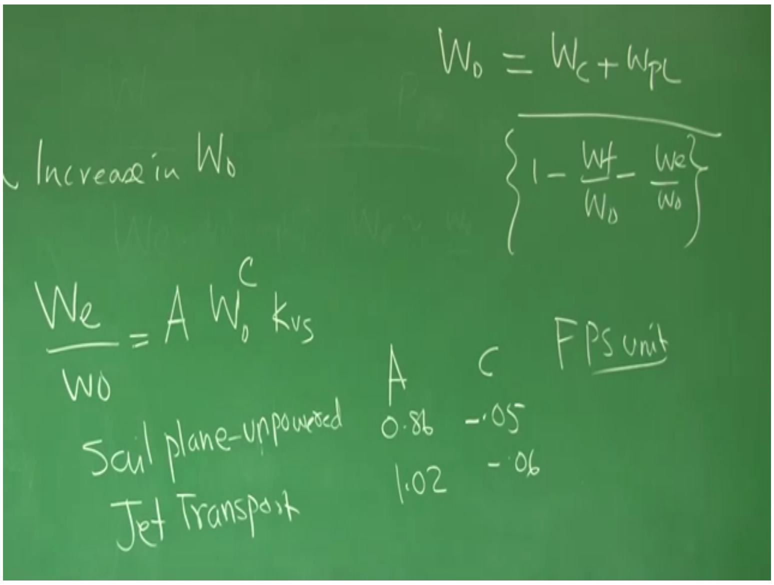

Based on whatever figures we have seen the author has done a good work in giving us a correlation where, it will been a into W naught C in to Kvs. Where you could easily see W naught is the gross weight and C at a are constants they vary for different type of configurations. For example, for a sailplane, for a sailplane unpowered a value is 0.86 and C is minus 0.05 and for a jet transport a is 1.02 and this minus 0.06.

What is interesting to note here that the C is negative, that is exactly I was telling as W naught increases W e by W naught decreases. That we should be very clear given it was shown here as well, but you can use this correlation, but only my request is use fps unit, fps unit to all this calibration chart which I am using from book aircraft design by raymer, all the details I will be giving you they are available with me in fps unit.

So, I strongly advise you will use fps unit unless otherwise I give you those collaborations or those correlations in MKS. The new book of raymer, does give equivalent MKS constants, but I will be it using fps unit is right. You can refer this empty weight fraction versus W naught, and you could see that for sailplane unpowered value of a is 0.86 C is minus 0.05, for a gel aviation single engine it is 2.362, the value of a and minus 0.18 is value of C for the jet trainer it is 1.59 and minus 0.10. Like this this values have been generated using the historical data using the figure which I was shown earlier right and that is the huge work.

Just to repeat these correlation this empirical relation is derived using all though historical data. And it for a designer it is very handy you can even write your own code, using a lookup table and get these numbers easily, but it is designer you must understand that W e by W naught if it is between 0.3 to 0.4 around this. That is a good one first with class of around one lakh pound or less than that. Then what is Kvs, this Kvs factor you see because there is a change in the material from metal to composites.

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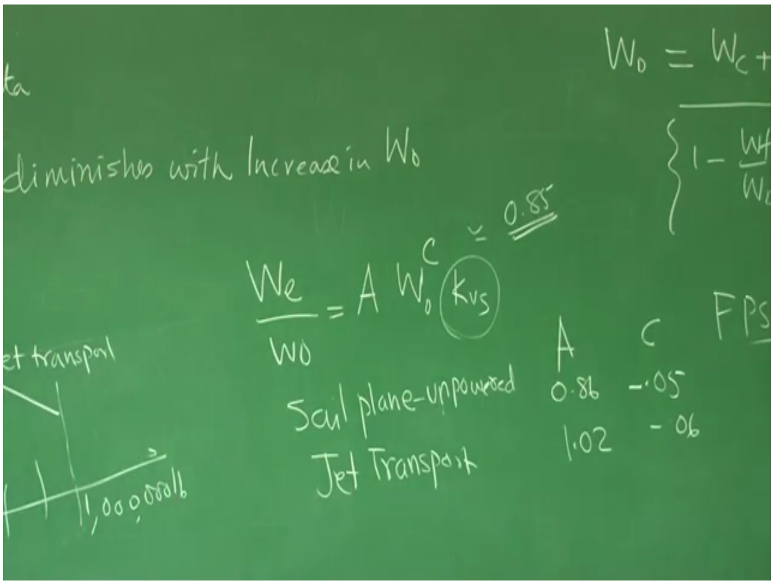

And then there has to be some reduction in the weight and this value would be somewhere around 0.85 that is 15 percent reduction I generally take 10 percent reduction at the initial stage, or sometime I may take it as one because I do not know any initially how many components I will be making using composites.

So, do not give too much advantage on that to have an initial design we take around one right. And as you grow you will develop feel and then you can play around with that. So, once W e by W naught is over our next attempt is W f by W naught that is the fuel fraction.

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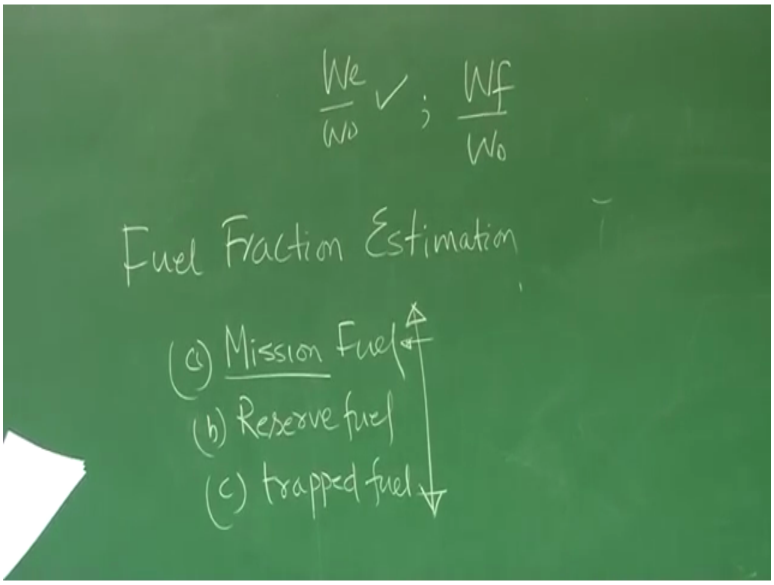

Now if I write fuel fraction, estimation, I need to be clear about number one, mission fuel I need to be clear about reserve fuel, and also third one trapped fuel. It is very clear when I talk about mission fuel, the fuel required to complete the whole mission from takeoff to landing back right.

What is use of fuel? That when you are going for a mission you need to give something reserved because of so many emergencies contingencies. So, you can think like this I should have 30 minutes extra fuel or I should plan reserve fuel based on the nearest airport where I can be diverted based on the contingencies. So that sort of planning you have to do. And the trapped fuel is some fuel which you cannot take it out from the fuel tank. So, all this 3 you have to scatter for. Because when you are flying a machine, please remember safety is the at most criteria. You should not start because of fuel and made the ultimate conclusion.

So, we have to be careful about this things and no a priori. We will be focusing more on machine fuel how to systematically calculate that. That is a fuel and trapped fuel they get to come back by experience what sort of planning you have got it may be around 6 to 7 percent depending upon the situation. Those also we will highlight, but more importantly now we will talk about a mission fuel. Then what is the mission if you are talking about mission fuel what is the mission.

For example, I give you an example if I am going from Kanpur to Delhi, how much fuel I should carry I should know from what which point to which point I am going. And what I am doing in between right what should have speed I will be flying. How many times I will switch off the car and start. All these issues will come right and how is the road conditions. So, mission fuel when I am trying to look for I need to know.

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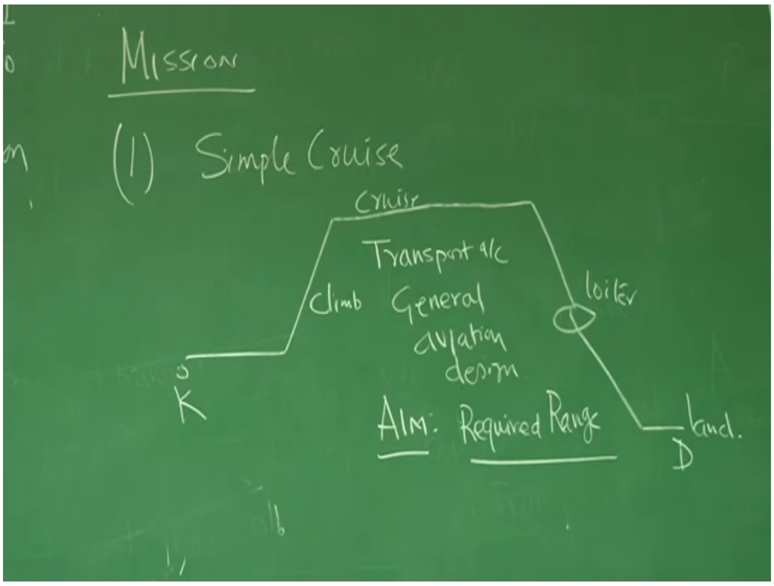

What are the possible missions, and I will now talk that is generic mission one, what I will be talking about a simple cruise? What is that now you start from here climb cruise do a loiter and land this climb, cruise loiter, and with land. That is, I am going from here let us say from Kanpur I am gaining a height around 8 kilo meters cruising and then I come near the Delhi airport, loiter get there air traffic lens and land.

So, from one point to another point I am going, but please understand if I am designing a military aircraft the situation may not be always this, because I take off from here beat the job and I come back to the base this is one possibility. There are other possibilities I do the mission then go to another base. So, the mission profile will change, even if it is a simple cruise right. It is like for transport aircraft, general aviation, design. What is the main aim for such aircraft is basically required range, that is a fore most strain, at what speed etcetera will follow, but main aim is have to move from one point to another point no other primary issues right?

So, these are covered under the mission was simple cruise mission. Like our elevation Cessna Saratoga this belong to this we take off from here go to (Refer Time: 26:14) and land right.

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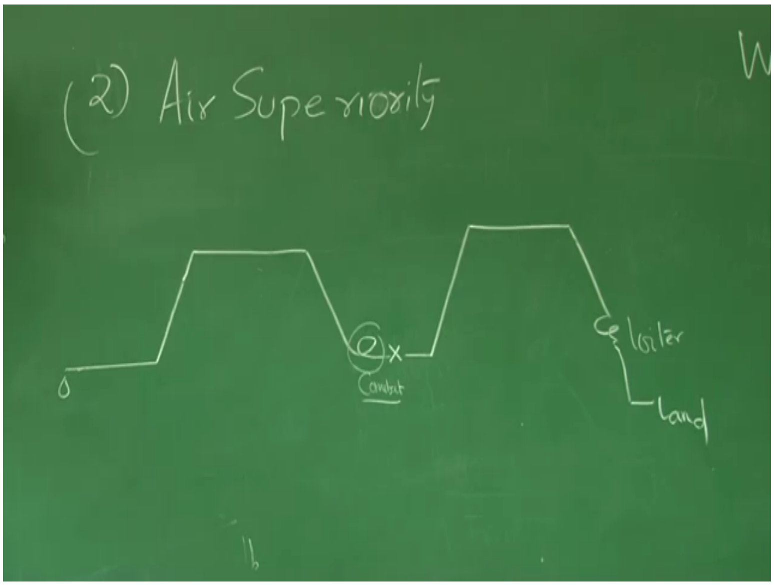

The mission 2 that could be here I am now going towards air superiority right. Now you can see that from Sybil we are not talking about little military. And such mission requirements demand the airplane takes off climb to altitude cruise, turns back do a combat drop bomb, weapon anything goes up loiter and land. Do you see this mission here? It takes off from here, goes to your cruise altitude dives, right, with our cruise and then do some another combat, drop repent whatever it is and again goes altitude goes and loiter and land.

Please understand assume that the aircraft is having a jet engine right. So, jet engine efficiency will depend upon the altitudes flying, the speed the temperature right. Now for a military air type aircraft you do not have option. If you want to do a low altitude combat or some undigit combat you have to be there, that did not be here right type of condition for the fuel efficiency. So, fourth assumption will change here some weapon drop will be there or when you do a combat a lot of high acceleration may happen. So, fuel consumption here will be all together different. So, it is in this area may not be a very highly fuel efficient domain. So, fuel consumption will be more, then you have to crew out and then loiter and land right.

So, that way when I will do calculate the fuel fraction W f by W naught, I need to know what are the mission requirement what the operation is they are do right. Here it is not that fuel efficient operation correct sometime after charger may be used extra fuel may pumped in. So, I need to know all these things, before I know how much fuel is required. So, I need to calculate W f by W naught taking this sort of a mission, if I am planning for it air superiority aircraft which is different from simple cruise type aircraft.

The third category, before I come to third category for air superiority mission we have one is cruise out these are the primary manual work cruise out.

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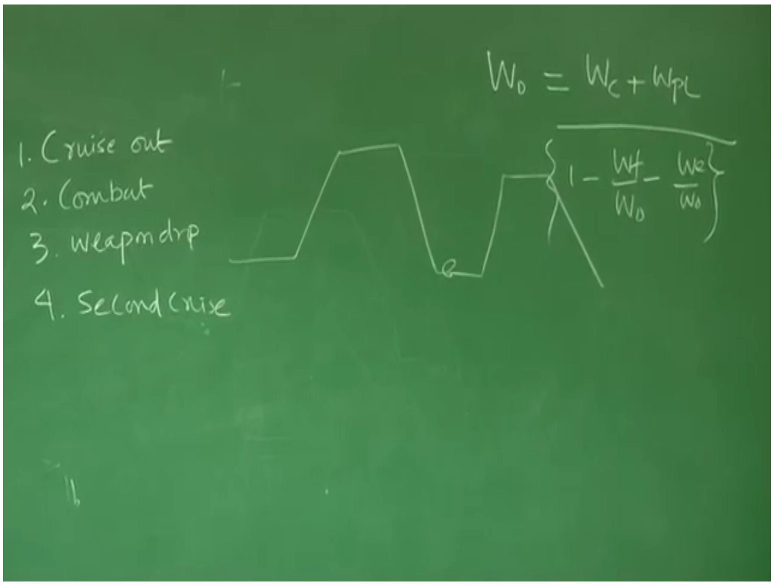

One second is combat which we have seen third word is weapon drop and fourth second cruise, because the aircraft must return to the base, that is when I am going like this this this this I do something here, load and I need to come back to the base. It is not for landing at different other bases where far we have taken off to come back there. So, whatever rage you have gone if you want to estimate how much fuel is required from a point a to point b whatever range you have covered you have ensure that you have to come back same another distance, almost same distance. Maybe flat conditions are different because while return you are not doing combat right.

So, we some time what do you do whatever cruise distance is there we duplicate, that to ensure that this part is used to compute the fuel assumption for return flight, if a air superiority, then we have this is another important I am giving military example, but please understand, we do not advocate who are right, but same time we should be enough prepared if somebody is below our belt we should be able to retaliate correct, but all these lectures are primarily for to be understanding what a technologies involved where the method involved, we do not forget most of the civilian things which we were using they are actually product of military technologies, here because then military technology the quality assurance is pretty high, and at an adverse condition to design things.

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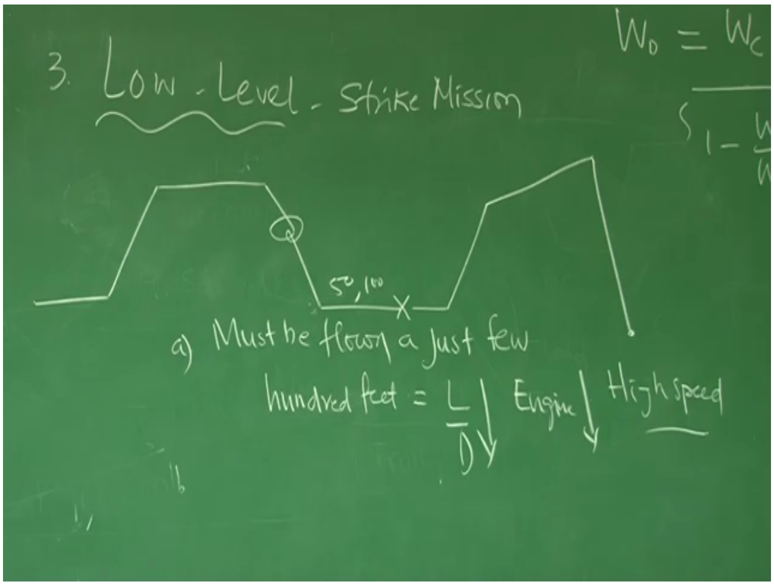

So, third one I will talk about is low level strike mission. The low level strike the word which is being traced is low level, but it was the word radar signature you want to be very clear see what you want to see. So, you have to flag every low altitude, the moment you want to flag low altitude you if that may not be at all aerodynamically very efficient, profile these low level means 50 feet, 100 feet, let us 100 feet under 50 feet, 200 feet we are talking about those distances right. We got is this strike mission you see a strike and come back right, but same time avoid capture by radar.

So, what are the criteria there it is let me draw the first profile, it is again almost similar the look loiter then come to 50 or 100, do whatever you want to do those. And here the condition is a must be flown at just few 100s feet of the ground this is to improve survivability that is avoid radar, and also it helps in locating the target. What is the problem is L by d goes down, engine efficiency goes down, I say high speed flight? You can imagine at low altitude (Refer Time: 33:30) high speed. So, how much fuel will be consumed L by d is low, engine is performance is low you want high speed.

Many times it happens the amount of fuel which will consume here that may be almost equal to the amount of fuel is consumed here. So, such mission profile when you are calculate fuel fraction you have to give a dew weight age here your most of the fuel will be consumed here right. And the last one which we will be talking about is strategic bombing.

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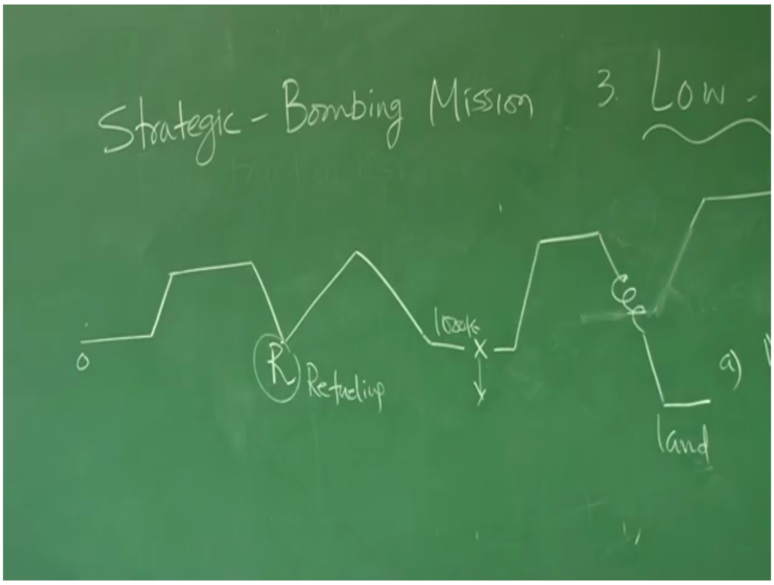

I wanted to omit this, because I did not like the word bombing, but then you should know it the deal, it is it has a new technology. So, very important you should notice. So, what is this again, same start from air cruise to altitude not very high altitude, come down and this r means refueling right.

So, get aircraft refuel here we have another aircraft again, you cruise out then come back to around thousand feet maybe, and then do whatever drop operations. Again you cruise now we land at some other base, not you are coming back to the original base right, to go from Delhi are landed somewhere in Ahmedabad or somewhere else. It is not you are coming back to the base right. This is important please understand many times in operation what happens you are carrying atom bomb, from the base you have taken off, but for some reason it could not release the bomb.

So, it is not advisable that that airplane lands back to the same base, because if there is accident it may create a problem. So, there are many such thing happens whether it is this type or not. So, even if it is supposed to come back to the base depending upon situation it may be advisable that you land somewhere else right, but for a strategy bombing mission this is very the important part is that refueling, so that you can have an extended range. So, you can understand refueling I am doing; that means, I am going for a longer mission. So, there is no point in coming back and land back here, better I land back nearest to that which is not the criteria other low level strike mission basically coming back to the base right.

So, you can very well understand and if you want to really calculate the fuel consumption for this, and if you follow simple cruise method you will not get because there are a huge thing are happening. So, all these things need to be known before we try to follow the methods which are listed. What we will do we will take simple example of a cruise mission, and a loiter mission. If you know cruise or loiter for that signal that concept you apply everywhere here. Basically it has 2 primary operation one is cruise, one is loiter. And there will be something for acceleration phase dye phase which will be added, but primarily crews and loiter that is why primarily range and endurance.

Once you have identified mission requirements, to ensure that whether we can use these mission requirement to calculate fuel fraction, what we will do our approach will be very simple we will take a example and we will actually find out fuel fraction and empty weight fraction for a given mission requirement. And that will be a simple cruises mission requirement. So, it will be like we will be actually computing W e by W naught and W f by W naught by for before that we will postulate what is the mission requirement for the airplane, we are going to design and that is also a solved example from this book. So, that you can refer that book and learn more beyond this lecture that will be my next part of my lecture tomorrow.

Thank you very much.