Introduction to Aircraft Design
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Lecture - 42
Estimation of Mission Segment Weights

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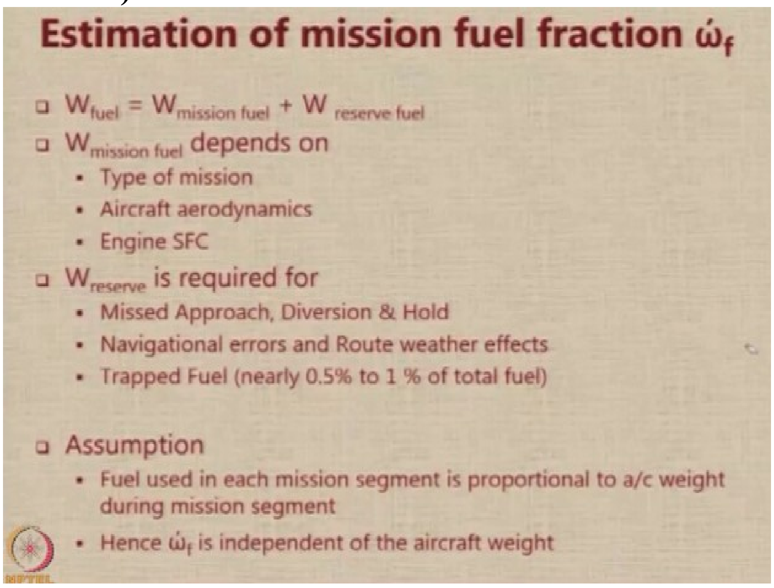

Let us have a look at how we estimate the mission fuel weight fraction $\acute{w}_f$. Just as a recap, we started with the defining the gross weight of the aircraft into 4 components, the payload weight, the crew weight, the empty weight and the fuel weight, we then converted them into fractions. And we saw that empty weight can be obtained by or empty weight fraction can be obtained using historical data.

Now, we look at how to get the mission fuel fraction. The fuel that you see in an aircraft or the fuel that an aircraft carries consists of 2 independent components. One is called as the mission fuel, which is the fuel that is planned to be used in the design mission and the other is the reserve fuel which is kept as reserved specified by the regulatory agencies. The mission fuel depends on the type of mission that you are performing the aerodynamics of the aircraft and what kind of engine performance you have.

Reserve fuel is fuel which is kept as reserve you require it for missed approach, diversion and hold you require it for navigational errors or any weather related route changes which can happen also, there is some amount of fuel which is trapped in the pipelines and in the system. And although it is there, it cannot be used because we need to have a continuity of fuel when we feed the engine roughly half to 1% of the total fuel is actually blocked in the pipelines and we call it as trapped fuel.

Now, we have to make an assumption here, when we want to estimate the mission fuel fraction and this is a very, very strong assumption. The assumption here is that the loss of weight of the aircraft as it carries out its mission is only because of the continuous fuel consumption and there is no sudden payload drop or there is no sudden change in the weight of the aircraft because of dropping of a payload or any other reason.

This assumption is valid for most transport aircraft, because we do not throw off passengers as we go nor do we lose the weight of the aircraft along the flight for any other reason. But in military aircraft, there are some situations for example, when you have an aircraft which goes on a combat mission and let us say drops bombs or even an aircraft that can have a drop tank and it drops it after the fuel is consumed.

Plus there could be a situation like an air to air refueling in which you acquire additional fuel while you are flying these kinds of missions in which we have a sudden addition or deletion of mass because of reasons like these, you may not be able to estimate their gross weight using this procedure for them there is a procedure that Reamer has suggested in his textbook, which can be taken up and we will discuss that later on when we go for the refined sizing.

So, we assume that the fuel used in each mission segment is proportional to the aircraft weight during that mission segment, because it is slowly being consumed. And hence $\acute{w}_f$ is becomes independent of the aircraft weight it only depends.

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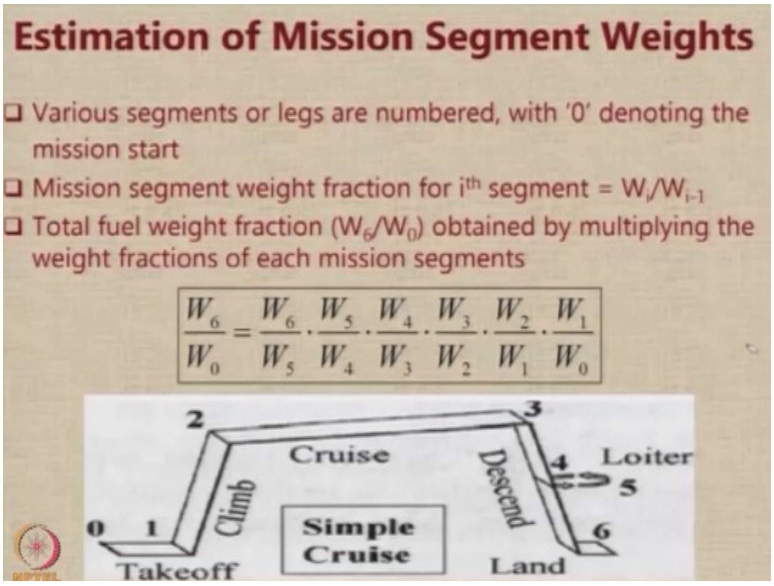

So what we do is we number the segments of the mission and we denote a number like 0 at the mission start and then we just number all the segments and for any i^{th} segment of the mission, the mission segment weight fraction will be the weight at the end of the segment upon the weight at the beginning of the segment. So, what we can do is for example, this is a simple cruise profile. So we have 0 to 1 takeoff, 1 to 2 cruise, etc, etc.

So there are totally 6 so what you can do is that total fuel weight fraction will be $\frac{W_6}{W_0}$ that means weight at the end of the mission divided by weight at the beginning of the mission and you can obtain this by a multiplication since we are not losing the weight of the aircraft due to any reason other than consumption of fuel, you can come up with this particular equation where the mission segment fuel of each segment can be multiplied and with that you can get the total fuel weight fraction $\frac{W_6}{W_0}$

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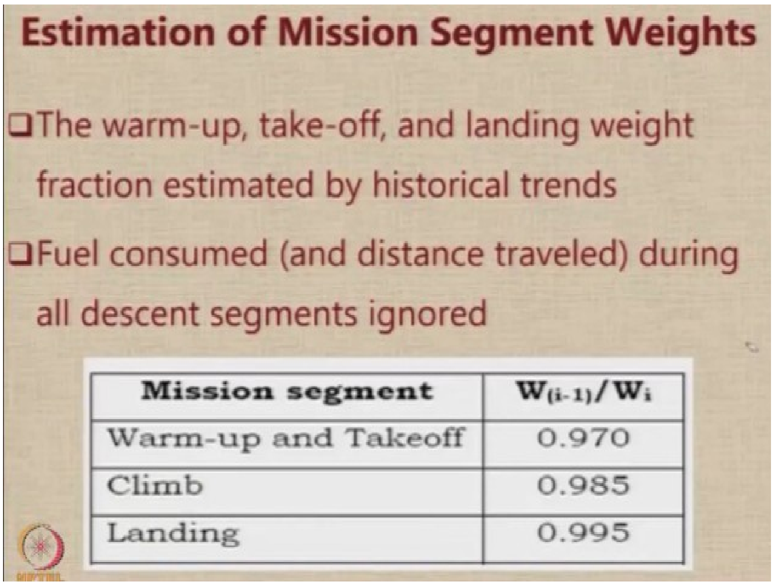

Taking this further now, we have to look at various segments can we get some estimate for these fractions. So, the warm up, the takeoff and landing weight tractions are estimated by historical trends and the fuel consumed and distance travel during these segments during the segments of descend is ignored, this is not really true because the aircraft can actually travel substantial distance during descent, but this distance may be a very small number as compared to the total mission that aircraft carries.

So, for example, an aircraft that carry that travels for 7000 kilometers may cover maybe 150 to 200 kilometers in the descent segment. So, in front of 7000, 100 can actually be neglected, but if it is a very short range mission, if the mission itself is 250 to 300 kilometers, then we cannot assume that the descent segments are ignored. So, the ratios of the mission segment for warm up and take off for the climb and for landing we for our typical transport aircraft, we can take it from past trends or historical data.

But here there is a word of caution these ratios are only true and meaningful when you look at a standard transport aircraft or an airliner we should not use these missions when we are designing let us say a UAV or even a small aircraft or regional or a commuter aircraft, we have to be very careful this example is basically meant for only airliners. So, therefore, these numbers should be used very carefully and with a lot of thought.

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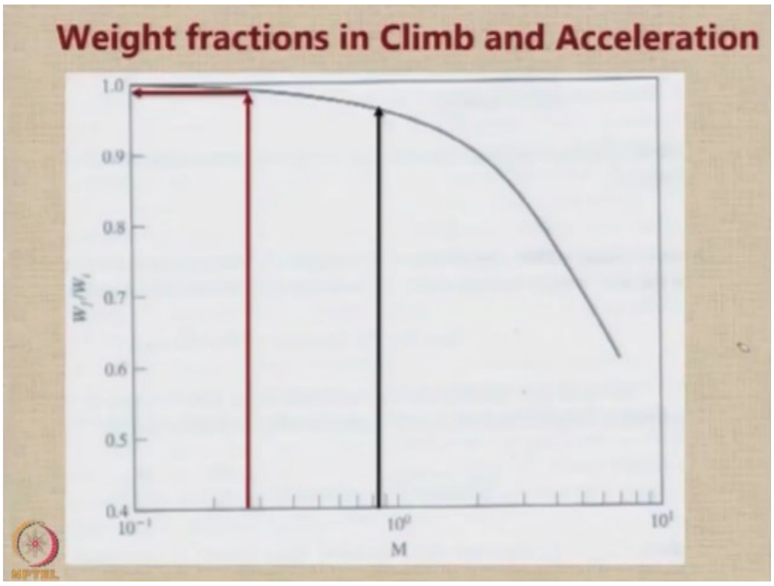

Now, in climb and acceleration, you can also use a slightly more sophisticated formulation. This particular formulation is important because many aircraft they have an accelerated climb this is especially true for military aircraft. So, they may go from you know a very small Mach number of approximately 0.1 or 0.2 during the takeoff to a Mach number of let us say 0.9 or even 1 in the climb, and when they do such kind of missions, substantial amount of fuel is consumed in climb.

In this graph, you have the X axis shows the Mach number at the end of the climb or at the end of the acceleration in a logarithmic scale and on the Y axis we have the fuel fraction of that segment in the linear scale. So, we notice that if you are accelerating up to around you know 0.2 Mach number or 0.15 to 0.2 Mach number, which is the typical value for a transport aircraft at the end of the climb, then the mission fuel fraction for that is indeed a very small number as shown in this particular graph.

But if your Mach number at the end of climb is something like 0.85 or so, then there is a much larger much larger fuel weight fraction.

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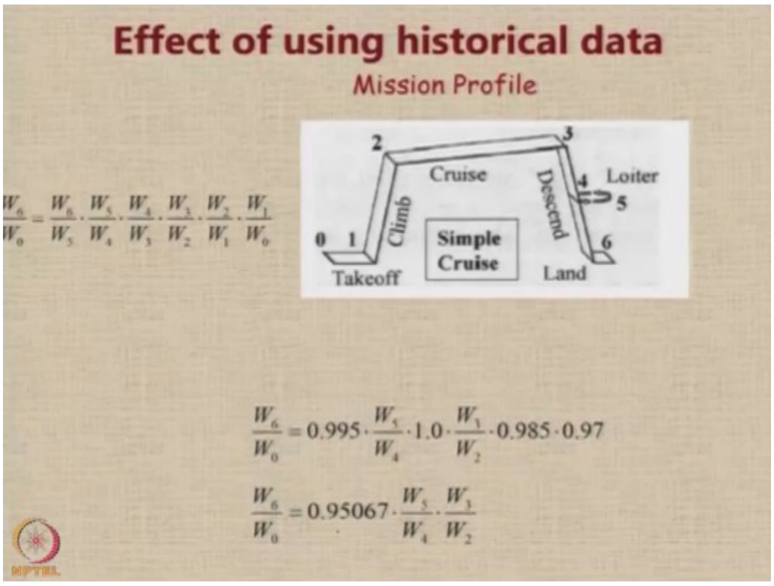

So, in the mission profile that we have chosen a simple mission profile, let us see what is the effect of using historical data, we were we had to take we had to do the estimate for 6 weight fractions. But out of those 6 weight fractions, 3 of them are going to be now available to you as an input data or as an assumed value purely from historical trends. The fuel fraction, during the warm up taxi out the fuel fraction during the descent and the fuel fraction during the landing are going to be available for historical data.

So, the problem of determining the empty weight, the fuel weight fraction $\frac{W_6}{W_0}$ for the whole mission is now converted into a problem of only finding out this value and this value. Now, we cannot assume fuel fractions for these values from historical data because if we do that, then we might as well take a fuel fraction from history and go ahead, that is not acceptable, because then we have not considered the requirements in our calculations.

The distance travelled in the cruise, the height at which you cruise and the Mach number at which you cruise these values strongly affect the ratio $\frac{W_3}{W_2}$. And similarly, the amount of time that which you have to loiter the height at which you have to loiter and maybe if it is specified the speed of loiter that will determine the ratio $\frac{W_5}{W_4}$. So, therefore, these 2 ratios we have to now calculate.

In other words, the problem of estimation of the mission fuel segments is now reduced to getting an estimate of these 2 only. And we need to do this because we need to look at the mission requirements to get to these numbers. So, if I just multiply these 3 numbers, I can get 1 number 0.95067. So, the total mission fuel fraction is equal to this number into the 2 ratios which we are going to now determine. Thanks for your attention we will now move to the next section.