: Assignment 2 :

AE461 - Aircraft Design

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Question [referred [1]]

Q.Do the Weight Estimation of the Proposed Aircraft

Ans: [1] ***has been referred to answer this question.***

$$W_{TO} = W_{pl} + W_c + W_f + W_E \tag{1a}$$

$$\implies W_{TO} = \frac{W_{pl} + W_c}{1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}} \tag{1b}$$

In Eq. (7a) $W_{TO} \rightarrow$ Max Takeoff Weight, $W_{pl} \rightarrow$ Payload Weight, $W_f \rightarrow$ Fuel Weight and $W_E \rightarrow$ Empty Weight

- Step1: Establishing the flight mission profile and identifying the mission segments

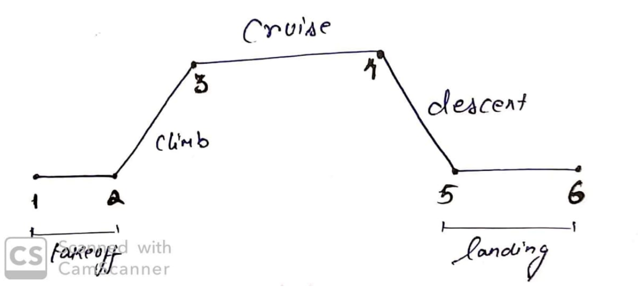

Figure 1: Flight Mission Profile

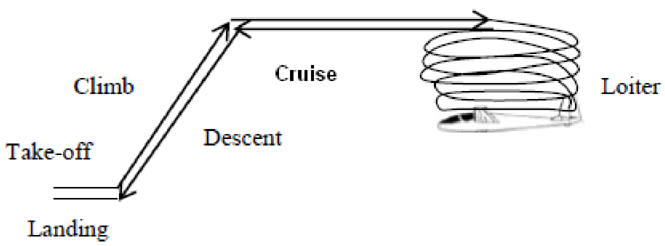

Figure 2: Flight Mission Profile (With Loitering)

		Weight of the Aircraft
1	Takeoff	W_1
2	Climb	W_2
3	Cruise	W_3
4	Descent	W_4
5	Landing	W_5

- Step2:

  Number of Flight Crew Members = 2

- Step3:

  Number of Flight Attendant = 0

- Step4:

  Weight of Flight Crew and Flight Attendant, $W_c = (2 * 80 + 0 * 80)\text{kg} = 160\text{kg}$

- Step5:

  Weight of Payload, W_{pl} = Weight of Passenger and their Luggage $= (5*80+7*25)$kg$=575$kg

- Step3: Determine weight ratios for the segments of take-off, climb, descent, and landing

Mission Segment	$\frac{W_{i+1}}{W_i}$ from[1]
Takeoff	$\frac{W_2}{W_1} \approx 0.98$
Climb	$\frac{W_3}{W_2} \approx 0.97$
Cruise	$\frac{W_4}{W_3}$ =To be determined from Mathematical Calculation
Loiter	$\frac{W_4}{W_3}$ = To be determined from Mathematical Calculation
Descent	$\frac{W_5}{W_4} \approx 0.99$
Landing	$\frac{W_6}{W_5} \approx 0.98$

- Step4:Determine weight ratios for the segments of range and loiter using the Following equations:

$$\frac{W_4}{W_3} = \exp^{-\frac{R_{max}C}{\eta_p (L/D)_{max}}} \tag{2a}$$

$$\frac{W_4}{W_3} = \exp^{-\frac{ECV_{E_{max}}}{0.866(L/D)_{max}\eta_p}} \tag{2b}$$

NOTE: Equation (8a) and (8b) are valid for Aircraft with Turboprop engines.

$R_{max} \rightarrow$ **Range** of the Aircraft (in Cruise)

$C \rightarrow$ Specific Fuel Consumption

$(L/D)_{max} \rightarrow$ Maximum Lift/Drag ratio

$\eta_p \rightarrow$ Efficiency of the Propeller

$v_{E_{max}} \rightarrow$ The speed for Max Endurance

$E \rightarrow$ **Endurance** of the Aircraft (in Loiter)

- Step8: Finding the overall fuel weight to Maximum Take off weight ratio $\frac{W_f}{W_{TO}}$

$$\frac{W_6}{W_1} = \frac{W_2}{W_1}\frac{W_3}{W_2}\left(\frac{W_4}{W_3}\right)\frac{W_5}{W_4}\frac{W_6}{W_5} \tag{3}$$

$$\frac{W_f}{W_{TO}} = 1.05(1 - \frac{W_6}{W_1}) \tag{4}$$

NOTE:

1. We need to decide C, η_p, $(L/D)_{max}$ empirically

   > C; Refer Table4.6 of [1]
   >
   > $\eta_p \approx 0.7$ to 0.85 when an aircraft is cruising with its maximum speed.
   >
   > $(L/D)_{max} \approx 10$ to 15 for General Aviation; Refer Table4.5 of [1]

2. (For a propeller driven Aircraft) The speed for Max endurance, $V_{E_{max}}$ = Aircraft flying with minimum speed, $V_{P_{min}} \approx 1.2V_{stall}$ to $1.4V_{stall}$

$V_{E_{max}} \approx 1.2V_{stall}$ to $1.4V_{stall}$

- *For calculation purpose we have considered*

C_R(C for (2a)) $= 0.65$

C_E (C for (2b)) $= 0.7$

$\eta_p = 0.8$

$(L/D)_{max} = 16$

$V_{E_{max}} = 356\text{kmph} = 98.889\text{ms}^{-1}$

$\frac{W_f}{W_{TO}}$ Fuel Weight to Max Take off Weight Calculated

- Step10: Put back $\frac{W_f}{W_{TO}}$ to (7b); we will obtain the following equation

$$W_{TO} = \frac{735kg}{1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}} \tag{5}$$

- Step10:Finding W_E/W_{TO} using the following Equation

$$\frac{W_E}{W_{TO}} = 0.9(aW_{TO} + b) \tag{6}$$

The factor 0.9 is because we are assuming that the Aircraft is made up of Composite material. (6) is from [1]; here a and b is determined from Table4.8 of [1]

- Step11: Solve the two equations (5) and (6) simultaneously and find the two unknowns of W_{TO} and $\frac{W_E}{W_{TO}}$.

Guessed WTO	Calculated WTO	Error Difference
10000	9674.987	-325.013
9349.974	9103.755	-246.219
8857.536	8670.093	-187.443
8482.65	8339.423	-143.227
8196.196	8086.447	-109.749
7976.698	7892.421	-84.2771
7808.144	7743.321	-64.8234
7678.497	7628.574	-49.9231
7578.651	7540.166	-38.4851
7501.681	7471.991	-29.6899
7442.301	7419.383	-22.9178
7396.466	7378.767	-17.6983
7361.069	7347.397	-13.6721
7333.725	7323.16	-10.5647
7312.595	7304.43	-8.16521

7296.265	7289.953	-6.31168
7283.642	7278.762	-4.87951
7273.882	7270.11	-3.77267
7266.337	7263.42	-2.9171
7260.503	7258.247	-2.25569
7255.992	7254.247	-1.74432
7252.503	7251.154	-1.34893
7249.805	7248.762	-1.04318
7247.719	7246.912	-0.80676
7246.105	7245.481	-0.62392

Conclusion:

We conclude with the result that $W_{TO} = 8430$ kg, $W_E = 4816$ kg, $W_f = 2879$ kg and $W_p = 735$ kg.

For the the above calculations we chose L/D as 16. However, we can see the variation of L/D with total and empty weights in the plot given below.

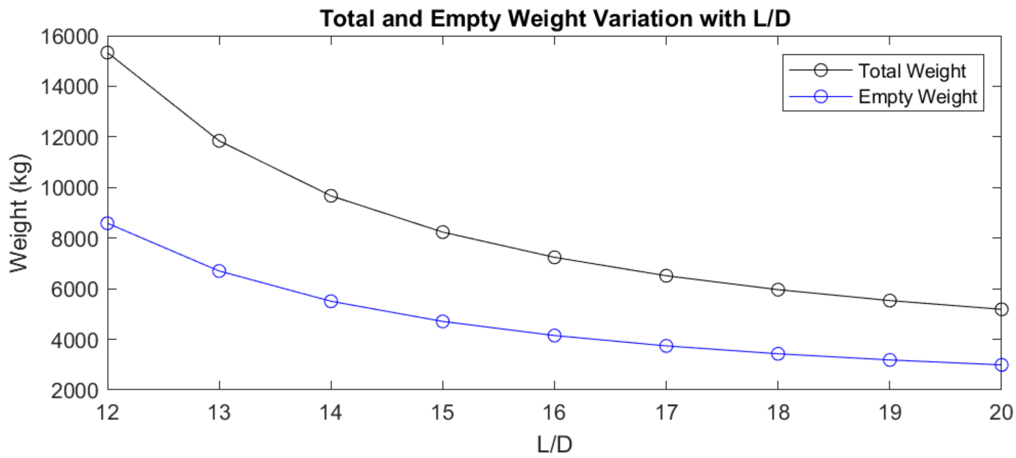

Figure 3: W_{TO} and W_E variation with L/D from 12 to 20

Question [referred [2]]

Q.Do the Weight Estimation of the Proposed Aircraft

Ans: [2] ***has been referred to answer this question.***

$$W_{TO} = W_{pl} + W_c + W_f + W_E \tag{7a}$$

$$\implies W_{TO} = \frac{W_{pl} + W_c}{1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}} \tag{7b}$$

$$\implies W_{TO} = \frac{W_p}{1 - \frac{W_f}{W_{TO}} - \frac{W_E}{W_{TO}}} \tag{7c}$$

In Eq. (7a) $W_{TO} \rightarrow$ Max Takeoff Weight, $W_{pl} \rightarrow$ Payload Weight, $W_f \rightarrow$ Fuel Weight and $W_E \rightarrow$ Empty Weight

$W_p \rightarrow$ **Total Payload Weight**

- Step1: Establishing the flight mission profile and identifying the mission segments

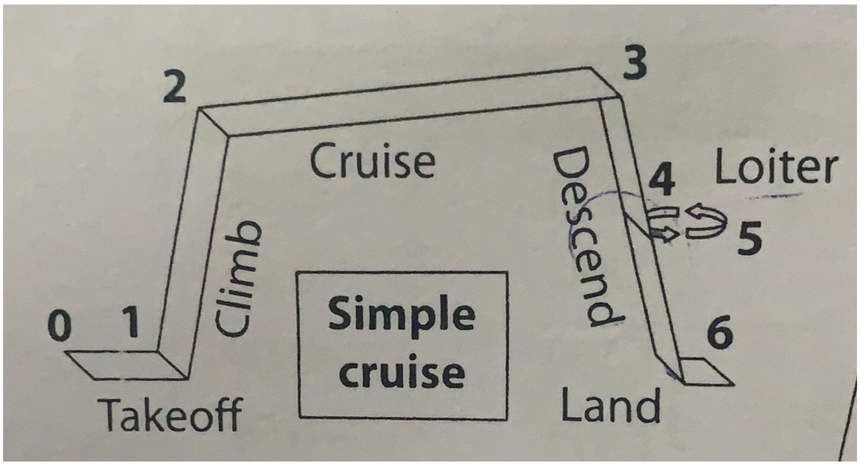

Figure 4: Flight Mission Profile

		Weight of the Aircraft
1	Takeoff	W_1
2	Climb	W_2
3	Cruise	W_3
4	Loiter	W_4
5	Descent	W_5
6	Landing	W_6

- Step2:

Total Payload Weight: $= 7 * 80 + 7 * 25$ **Kg** $=$ $W_p = 735$ **Kg**

- Step3: Determine weight ratios for the segments of take-off, climb, descent, and landing

Mission Segment	$\frac{W_{i+1}}{W_i}$ from[1]
Takeoff	$\frac{W_1}{W_0} \approx 0.970$
Climb	$\frac{W_2}{W_1} \approx 0.985$
Cruise	$\frac{W_3}{W_2}$ = To Calculate
Loiter	$\frac{W_4}{W_3}$ = To Calculate
Descent	$\frac{W_5}{W_4} \approx 0.995$
Landing	$\frac{W_6}{W_5} \approx 1.00$

- Step4:Determine weight ratios for the segments of range and loiter using the following equations:

$$\frac{W_4}{W_3} = \exp^{-\frac{R_{max}C}{\eta_p (L/D)_{max}}} \tag{8a}$$

$$\frac{W_3}{W_2} = \exp^{-\frac{ECV_{E_{max}}}{(L/D)_{max}\eta_p}} \tag{8b}$$

NOTE: Equation (8a) and (8b) are valid for Aircraft with Turboprop engines.

$R_{max} \rightarrow$ **Range** of the Aircraft (in Cruise)

$C \rightarrow$ Specific Fuel Consumption

$(L/D)_{max} \rightarrow$ Maximum Lift/Drag ratio

$\eta_p \rightarrow$ Efficiency of the Propeller

$v_{E_{max}} \rightarrow$ The speed for Max Endurance

$E \rightarrow$ **Endurance** of the Aircraft (in Loiter)

- Step5: Finding the overall fuel weight to Maximum Take off weight ratio $\frac{W_f}{W_{TO}}$

$$\frac{W_6}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\left(\frac{W_3}{W_2}\right)\left(\frac{W_4}{W_3}\right)\frac{W_5}{W_4}\frac{W_6}{W_5} \tag{9}$$

$$\frac{W_f}{W_{TO}} = (1 - \frac{W_6}{W_0}) \tag{10}$$

NOTE:

1. We need to decide C, η_p, $(L/D)_{max}$ using the historical data and equations provided in the book:

   - Using C_{bhp} = 0.5 lb/hr/bhp for Turboprops, we calculate the value of specific fuel consumption (C) in appropriate dimensions using the equation $C = C_{bhp}\frac{V}{550\eta_P}$
   - Using the above equation and V = 356 kmph (cruise speed of reference DA62 Aircraft [3]), we get $C = 0.3688\text{s}^{-1}$
   - $\eta_p = 0.8$
   - $(L/D)_{max}$: will vary L/D ratios in the code and check for appropriate W_{TO}.

$\frac{W_f}{W_{TO}}$ Fuel Weight to Max Take off Weight Calculated

- Step6: Using the equation (8b) and (8a) we obtain the $\frac{W_3}{W_2}$ and $\frac{W_4}{W_3}$ values. Based on the problem statement given, we need aircraft with endurance of 500 mins and additional loiter range of 25 km.

  So $\frac{W_3}{W_2} = 0.8252$ (endurance of 500 mins)
  and $\frac{W_4}{W_3} = 0.9984$ (additional range of 25 km)

  Using all the $\frac{W_{i+1}}{W_i}$ data we can calculate $\frac{W_6}{W_0}$ using equation (9). $\frac{W_6}{W_0} = 0.7833$
  Using equation (10), we get $\frac{W_f}{W_{TO}} = 0.2167$

- Step7:Finding W_E/W_{TO} using the following Equation

$$\frac{W_E}{W_{TO}} = AW_{TO}^C K_{vs} \tag{11}$$

  (11) is from [2]; here A and C is determined from Table3.1 of [2]. As we are choosing a fixed sweep $K_{vs} = 1$, A for twin turboprop is 0.92 and c = -0.05. Now we need to make a guess for W_{TO}, so let's take W_{TO} = 10,000 kg.
  We can subsequently calculate W_f and W_E using the guessed W_{TO} value. We obtain W_f = 2167.27 kg and W_E = 5804.81 kg. Now, using equation (7a) and payload weight as 735 kg. We get W_{TO} as 8707.08 kg. We obtain a error difference of 1292.92 kg.
  Using the iterative approach we take the next guess as current guess ± 2*(error difference).

- Step8: We use the iterative approach to reduce the error and obtain a correct estimate for empty weight fraction. The table obtained through the MATLAB code is shown below.

Guessed W_{TO}	Calculated W_{TO}	Error Difference
10000	8707.077	-1292.92
7414.154	6710.488	-703.666
6006.822	5613.687	-393.135
5220.552	4996.969	-223.584
4773.385	4644.754	-128.631
4516.122	4441.582	-74.5398
4367.043	4323.657	-43.3856
4280.271	4254.952	-25.3194
4229.633	4214.833	-14.7995
4200.034	4191.375	-8.65851
4182.717	4177.648	-5.0685
4172.58	4169.612	-2.96794
4166.644	4164.906	-1.73826
4163.167	4162.149	-1.01817
4161.131	4160.535	-0.59642
4159.938	4159.589	-0.34939
4159.239	4159.035	-0.20468

4158.83	4158.71	-0.1199
4158.59	4158.52	-0.07024
4158.45	4158.409	-0.04115
4158.367	4158.343	-0.02411

Conclusion:

We conclude with the result that $W_{TO} = 4158$ kg, $W_E = 2522$ kg, $W_f = 901$ kg and $W_p = 735$ kg.

For the the above calculations we chose L/D as 16. However, we can see the variation of L/D with total and empty weights in the plot given below.

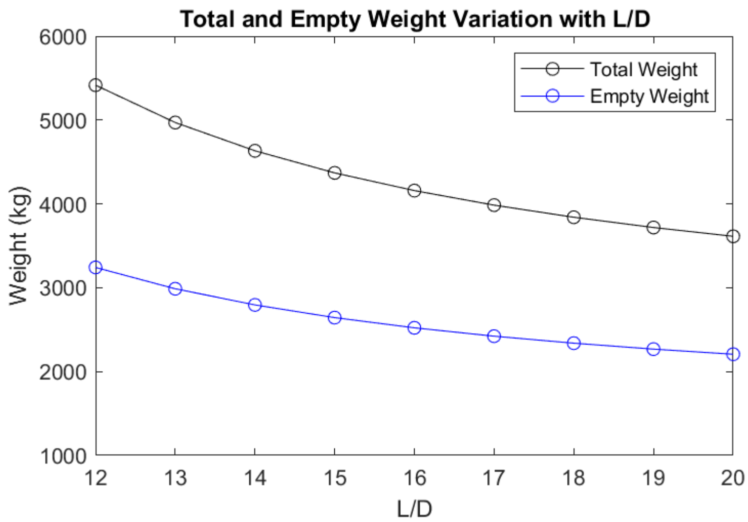

Figure 5: W_{TO} and W_E variation with L/D from 12 to 20

References

[1] M. H. Sadraey, *Chapter4 Preliminary Design*. Wiley, 2013.

[2] D. P. Raymer, *Chapter3 Sizing from a Conceptual Sketch*. American Institute of Aeronautics and Astronautics, 2021.

[3] https://www.diamondaircraft.com/en/private-owners/aircraft/da62/overview/.