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Weight Estimation of a Single Seater Home Built Air Craft

M. Venkatesan

Faculty of Marine Engineering,
College of Marine Science and Technology, Massawa, Eritrea

Abstract

The multitude of considerations affecting structural design, the complexity of the load distribution through a redundant structure, and the large number of intricate systems required in an airplane, makes weight estimation a difficult and precarious career. When the detail design drawings are complete, the weight engineer can calculate the weight of each and every part--thousands of them--and add them all up...and indeed this is eventually done. But in the advanced design phase, this cannot be done because there are no drawings of details. In the beginning, the advanced design engineer creates only a 3-view and some approximate specifications. The rest of the design remains undefined.

One may start the design process with only very simple estimates of the overall empty weight of the aircraft based purely on statistical results. Some of these correlations are not bad, such as the observation that the ratio of empty weight to gross weight of most airplanes is about 50%. Of course, this is a very rough estimate and does not apply at all to aircraft such as the Voyager or other special purpose designs.

Estimate the gross weight of aircraft by using various historical data for the specified mission profile.

Keywords: Weight estimation – Home based Aircraft – “C” program.

Introduction
The gross weight of aircraft will be given by equation,

$$W_o = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$$

Empty weight includes structure, landing gear, lift equipment avionic instruments.

To simplify fuel weight and empty weight calculation take fraction of them based on total weight.

$$W_o = W_{crew} + W_{payload} + \left(\frac{W_f}{W_o} + \frac{W_E}{W_o}\right)W_o$$

$$W_{crew} + W_{payload} = W_o - \left(\frac{W_f}{W_o}\right)W_o - \left(\frac{W_E}{W_o}\right)W_o$$

$$W_o = \frac{W_{crew} + W_{payload}}{1 - \frac{W_f}{W_o} - \frac{W_E}{W_o}} \rightarrow A$$

This is the equation for the gross weight of an aircraft.

Procedure

Step1: In the first step we consider the pay load and crew weight. It is given as

$$W_{payload} + W_{crew} = 80 + 30 = 110Kg$$

Step2: In the second step we can guess the total weight of the aircraft from the various historical data as 800Kg.

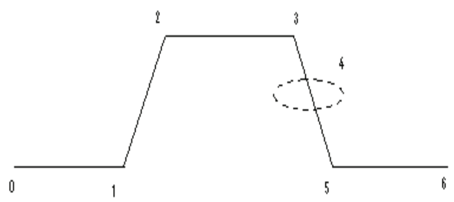
$$W_{total} = 800Kg$$

Step3: The fuel weight includes mission fuel and fuel reserved for emergency purpose.

$$W_f = W_{fuelmission} + W_{fuelreserved}$$

Mission fuel weight can be calculated from the fuel fractions for various mission segments.

Mission Profile



0-1 $\rightarrow$ WARM UP& TAKE-OFF
1-2 $\rightarrow$ CLIMB
2-3 $\rightarrow$ CRUISE
3-4 $\rightarrow$ LOITER
4-5 $\rightarrow$ DESCEND
5-6 $\rightarrow$ LANDING

Mission 0-1
The mission 0-1 is the engine start, warm up and the take-off. From the historical data, it is found to be,

$$\frac{W_1}{W_0} = 0.995$$

Mission 1-2
The mission 1-2 is the climb. The fuel fraction from historical data was

$$\frac{W_2}{W_1} = 0.995$$

Mission 2-3
The mission 2-3 is cruise. The fuel fraction for this mission was found from the range equation (i.e.) Brequet equation,

$$R_{cr} = 375\left(\frac{\eta_{propeller}}{C_p}\right)_{cr}\left(\frac{L}{D}\right)_{cr}\ln\left(\frac{W_2}{W_3}\right)$$

From the historical data,

$$\eta_{propeller} = 0.7$$

$$C_p = 0.7 lba/hp/hr$$

$$\frac{L}{D} = 9$$

The range from historical data is 900Km,

$$900 = 375\left(\frac{0.7}{0.7}\right)\times 9\times\ln\left(\frac{W_2}{W_3}\right)$$

$$\frac{W_3}{W_2} = 0.7659$$

Mission 3-4

The mission 3-4 is the loiter. The fraction for the mission is found from the Endurance equation,

$$E_{loiter} = \left(\frac{1}{C_p}\right)_{loiter} \left(\frac{L}{D}\right)_{loiter} \ln\left(\frac{W_3}{W_4}\right)$$

From the historical data,

$$E_{loiter} = 20\,\text{min}$$

$$C_p = 0.6$$

$$\frac{L}{D} = 11$$

$$0.33 = \left(\frac{1}{0.6}\right) \times 11 \times \ln\left(\frac{W_3}{W_4}\right)$$

$$\frac{W_4}{W_3} = 0.981$$

Mission 4-5

The mission 4-5 is the descent. The fraction of fuel for this fraction from historical data is found to be,

$$\frac{W_5}{W_4} = 0.995$$

Mission 5-6

The mission 5-6 is the landing. Taxing and shut-off. The fuel fraction of this mission was found to be,

$$\frac{W_6}{W_5} = 0.998$$

The fuel fraction is found from product of all the values,

$$m_{ff} = \frac{W_6}{W_5} \times \frac{W_5}{W_4} \times \frac{W_4}{W_3} \times \frac{W_3}{W_2} \times \frac{W_2}{W_1} \times \frac{W_1}{W_0}$$

$$m_{ff} = 0.995 \times 0.995 \times 0.7659 \times 0.981 \times 0.995 \times 0.998$$

$$m_{ff} = 0.7386$$

$$\frac{W_f}{W_o} = 1 - m_{ff}$$

$$\frac{W_f}{W_o} = 1 - 0.7386$$
$$W_f = 0.2613 \times 800$$
$$W_f = 209.077\text{Kg}$$

Reserved Fuel

The reserved fuel is the fuel which is used for the emergency purpose.

$$W_{reservedfuel} = 0177 \times 0.25 \times 800$$
$$W_{reservedfuel} = 34\text{Kg}$$

Operating Empty Weight

The operating empty of aircraft is calculated from equation,

$$W_{OE} = W_{total} - W_{fuel} - W_{crew}$$
$$W_{OE} = 800 - 209.07 - 110 = 480.93\text{Kg}$$

Trapped Fuel

The trapped fuel is considered to be 0.5% of the total weight,

$$W_{trapped} = 0.005 \times 800$$
$$W_{trapped} = 4\text{Kg}$$

Gross Weight

The gross weight of aircraft can be determined by formula,

$$W_o = \frac{W_{crew} + W_{payload}}{1 - \frac{W_f}{W_o} - \frac{W_E}{W_o}}$$
$$W_o = 771.72\text{Kg}$$

%Error

The percentage of error from the gross weight can be calculated from formula,

$$\%ERROR = \frac{W_{actual} - W_{assumed}}{W_{actual}} \times 100$$
$$\%ERROR = \frac{800 - 771.72}{771.72} \times 100$$
$$\%ERROR = 3.6\%$$

Conclusion

Thus by the various calculation we can determined the weight of aircraft as 771.72Kg

$$W_{payload} = 110Kg$$

$$W_f = 209.07Kg$$

$$W_{OE} = 476.93Kg$$

Weight Configuration

Sl. No.	Aircraft Name	Empty Weight (Kg)	Take-Off Weight (Kg)
1	Su-26	736	789.5
2	Su-31	756	805.12
3	ZIVKO EDGE 540	531	703
4	YAK 50	765	900
5	CAP 232	590	820
6	YAK 54	769	990
7	ALBATROS L79	405	640
8	Z 242	730	970
9	AEROCAM SLICK	450	645
10	ZUIN Z-50	510	650

Symbols Used

W	Weight of aircraft
W_o	Overall weight
W_f	weight of fuel
W_e	Empty weight
L_f	fuselage length
D_f	diameter of fuselage
S_w	wing area
T_w	wing thickness
b_w,b	wing span
S_{ht}	horizontal tail area
t_{ht}	horizontal tail thickness
b_{ht}	horizontal tail span
AR	aspect ratio
S	Surface area
S_{vt}	vertical tail area
t_{vt}	vertical tail thickness
b_{vt}	vertical tail span
Cd_o	drag polar
Cd	coefficient of drag
C_L	coefficient of lift
F, T	thrust

T/W	Thrust loading
W/S	Wing loading
A.R	Aspect ratio
C_r,C_t	Chord length of root,tip
T_r,T_t	Thickness of root,tip
S_p	Wetted surface area
C_{Dp}	Coefficient of drag of wetted surface area
a	Angle of attack
C.G	Center of gravity
β	Dihedral angle
R	Range
E	Endurance
μ	Ground friction
$V\infty$	Free stream velocity
C	Chord
Lf	Length of fuselage
VT	Vertical tail
HT	Horizontal tail
ℓ	Density(kg/m^3)
g	Gravity
s	Distance
H	Height
h	altitude
ROC	rate of climb
V, u	velocity
D	Drag
L	Lift
H	Altitude
g	Acceleration of gravity
W_o	optimum weight
Λ	sweep angle
C_r	root chord

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