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Fuselage Weight Estimation in Conceptual Design Phase for Tactical Unmanned Aerial Vehicles

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Abstract

Fuselage weight Estimation of an Unmanned Aerial Vehicle (UAV) during the conceptual design phase has been demonstrated to be an important challenge because of its unconventional configuration. Investigation of the development of a new suggested formula for fuselage weight estimation of UAV is done for UAVs having takeoff weight ranging from 100 to 500 kg, and which have similar characteristics. Based on statistical trends, obtained from analyzed existing UAVs, takeoff weight is estimated from mission specification, and it is derived for a tactical unmanned aerial vehicle (TUAV). Software tools are developed in MATLAB to facilitate takeoff and component weight calculations. The least square method is applied to analyze statistical data in order to develop trend functions which correlate TUAVs takeoff weight. Existing formulas, developed for general aviation, for fuselage and takeoff weight estimations are applied to TUAV and promising one are selected and adjusted to TUAV conceptual design phase. Fuselage weight estimation is related to geometrical parameters and takeoff weight of TUAVs.

Keywords: Conceptual Design Phase, Fuselage Weight Estimation, TUAV.

Introduction

A fuselage of aircraft is essentially a hollow shell designed to carry a payload, and an engine. Many parameters control the fuselage weight such as; its average diameter, length, skin area or wetted area, shell volume, pressurization, aircraft load factor, maximum possible speed which is dive speed, fuselage configuration, and construction material. High aircraft velocity and load factors require more material for structural integrity. Additional reinforcement weight is needed for the installation of engines and the landing gear on the fuselage. Pressurization of the cabin raises the fuselage-shell hoop stress level that requires more weight for reinforcement, and a rear-mounting cargo door is also a large increase in weight.

Fuselage Weight Estimation Methods

A fuselage is defined as a hollow shell designed to accommodate a payload. The size of the fuselage is obviously controlling the mass of the body, The drivers for the fuselage group mass are its length, L; diameter, Dave; shell area and volume, and additionally, the mass of the body depends on the aircraft layout (e.g. engine and undercarriage positions). Many methods of weight estimation in the conceptual design phase are studied in this research to contribute for getting best formula for fuselage weight estimation.

Jenkinson Method:

Jenkinson suggested the following formula (1) which is recommended for civil aircrafts (50-300 seats).

$$W_b = 0.039 \times \left(2 \times L \times D \times \sqrt{V_d}\right)^{1.5} \quad (1)$$

W_b – Fuse. weight, D – Equivalent diameter, V_d – dive speed, L – Fuse. Length,

It is recommended that the above mass be amended as follows:

Increased 8% for pressurized cabin.

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Increased 4% for fuselage mounted engines.

Increased 7% for fuselage mounted main undercarriage.

Increased 10% for large cargo door.

Reduced 4% if the fuselage is free from structural discontinuity.

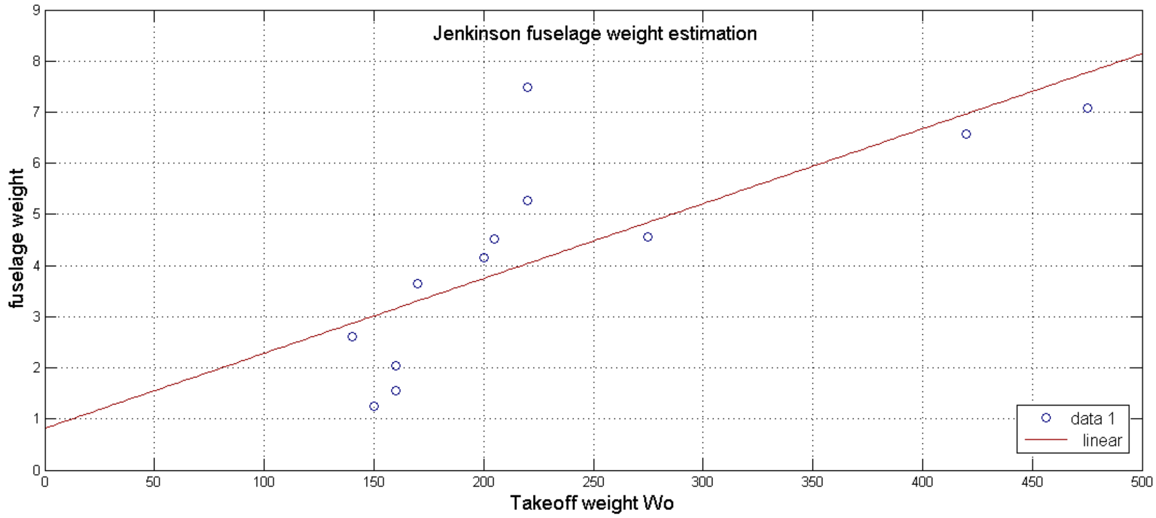

Figure (1): Diagram of Fuselage Weight Estimation for Jenkinson Formula

Howe Method:

Howe has modified his equation for fuselage mass estimation to be:

$$W_b = 0.044 \times \left(L \times (B + H) \times \sqrt{V_d}\right)^{1.5} \quad (2)$$

B – Fuselage maximum width, H – Fuselage maximum depth, V_d – dive speed, L-Fuselage length

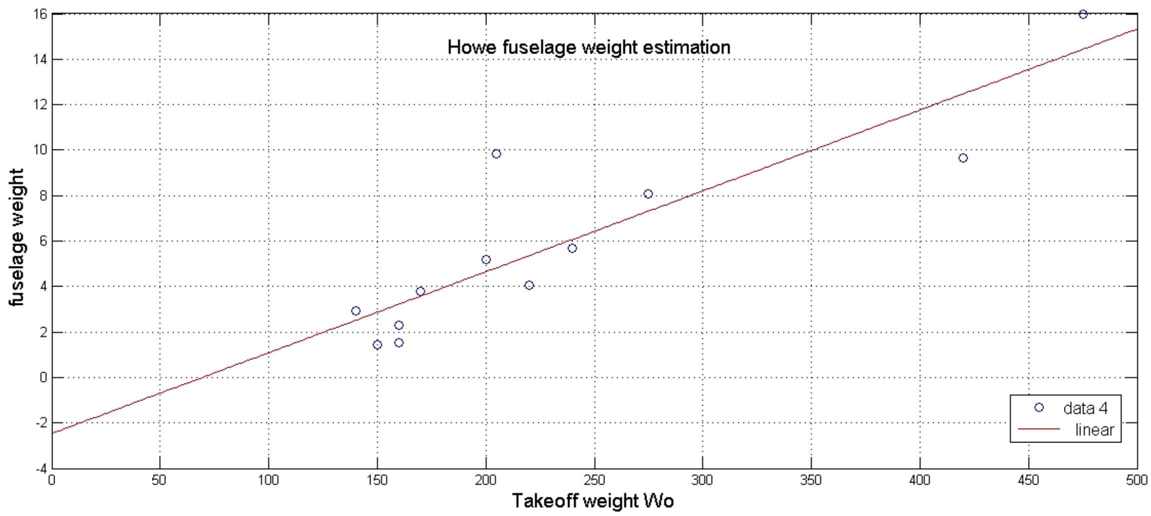

Figure (2): Diagram of Fuselage Weight Estimation for Howe Formula

Kundu Method:

Kundu suggested the formula below for a fuselage weight with a fixed undercarriage which is written as follow:

$$W_b = 0.038 \times k_u \times k_e \times (W_o \times N_z)^x \left(2 \times L \times D \times \sqrt{V_d}\right)^{1.5} \quad (3)$$

D – Average diameter, V_d – dive speed, ke - for fuselage-mounted engines = 1.05 to 1.07, W_o - Takeoff weight, L – Fuselage length, ku - for fuselage undercarriage, Nz - Ultimate load factor

The value of index x depends on the aircraft size: 0 for aircraft with an ultimate load (nult) < 5 and between 0.001 and 0.002 for ultimate loads of (nult) >5 (i.e., lower values for heavier aircraft). In general, x = 0 for civil aircraft; therefore, (MTOM × nult) x = 1. The value of index y is very sensitive. Typically, y is 1.5, but it can be as low as 1.45.

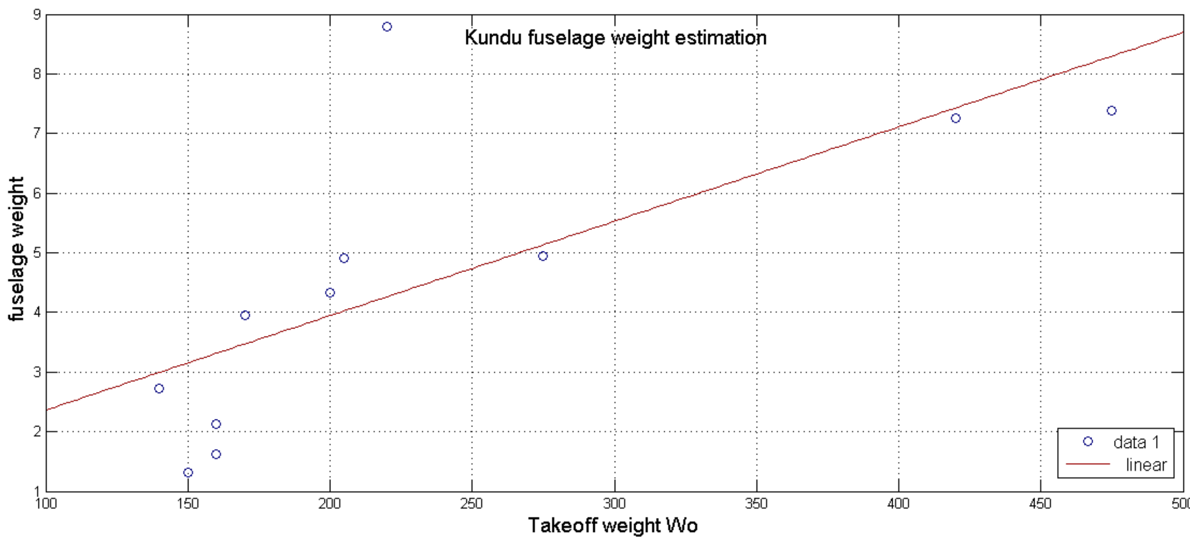

Figure (3): Diagram of Fuselage Weight Estimation for Kundu Formula

Roskam Method:

Suggested Roskam formula (4) for estimating fuselage weight, which is called the General Dynamic method:

$$W_b = 10.43 \times k_{in}^{1.42} \times (q/100)^{0.283} \times (W_o/1000)^{0.95} \times (L/H)^{0.71} \qquad (4)$$

W_b - Estimated fuselage weight in [lb], q - dynamic pressure in psf, L - fuselage length, H - Fuselage height, K_{inlet} - for inlets in or on the fuselage, Wo - Takeoff weight

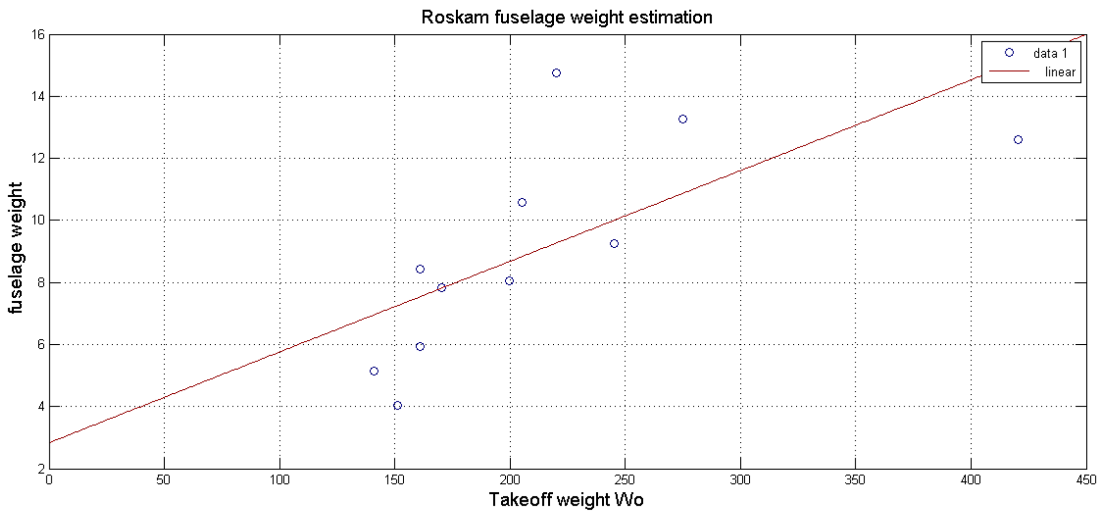

Figure (4): Diagram of Fuselage Weight Estimation for Roskam Formula

Raymer Method:

Raymer formula (5) for general aviation aircrafts to estimate fuselage weight is introduced as follow:

$$W_b = 0.052 \times (W_o \times N_z)^{0.177} \times q^{0.241} \times S_f^{1.086} \times L^{-0.051} \times (L/D)^{-0.072} \qquad (5)$$

Sf - fuselage surface area [ft^2], L - fuselage length [ft], q - Dynamic pressure [lb/ft2], D - Fuselage diameter [ft], Nz - Ultimate load factor, Wo - Takeoff weight. lb

Usaf Method:

Usaf formula (6) for general aviation aircrafts to estimate fuselage weight is introduced as follow:

$$W_b = 200 \times \left(\left(W_o \times \frac{N_z}{10^5} \right)^{0.286} \times \left(\frac{L_f}{10} \right)^{0.857} \times \left(\frac{(B+H)}{10} \right) \times (V_{cr}/100)^{0.338} \right)^{1.1} \qquad (6)$$

L_f - fuselage length (ft), H - Max fuselage hight, B - Max fuselage width, Vcr - design cruise speed (knots), Nz - Ultimate load factor, Wo - Takeoff weight. lb

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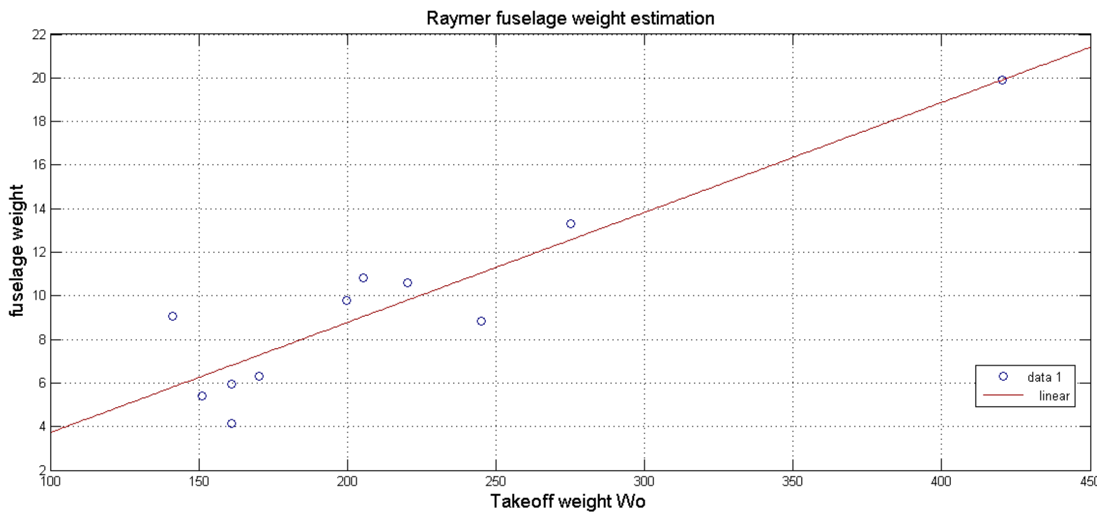

Figure (5): Diagram of Fuselage Weight Estimation for Raymer Formula

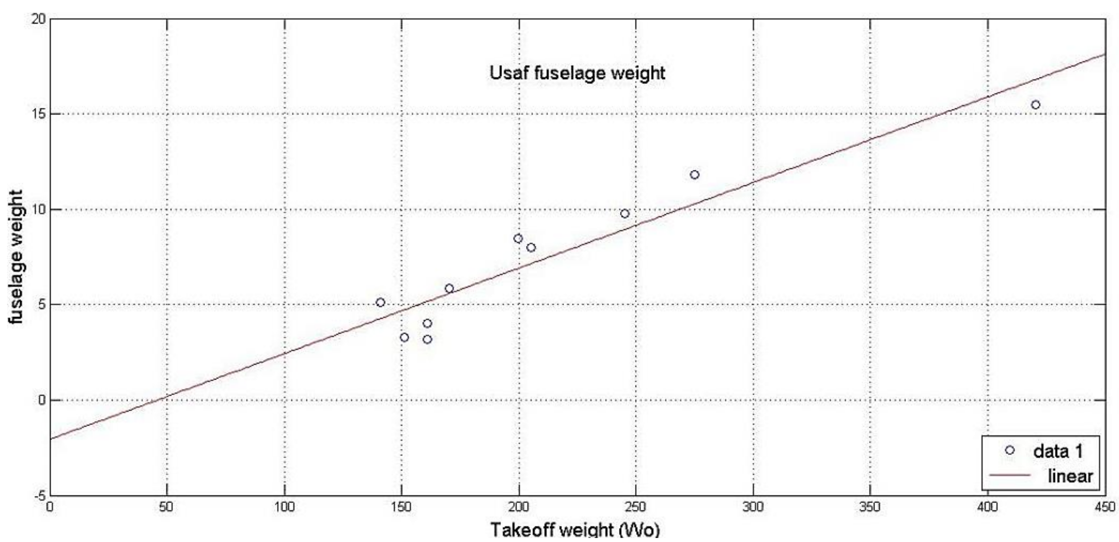

Figure (6): Diagram of Fuselage Weight Estimation for Usaf Formula

Kroo Method:

Fuselage weight is based on gross fuselage wetted area (without cutouts for fillets or surface intersections) and upon a pressure-bending load parameter.

Kroo suggested Desktop Aeronautics formula to be used for fuselage weight estimation and it is introduced as follow:

$$W_b = (1.051+0.102\times I_{\text{fuse}})\times S_f \quad (7)$$

W_b - Estimated fuselage weight in [lb], I_{fuse} - fuselage index, w_o - takeoff weight.
S_f - Fuselage wetted area, I_p When fuselage is not pressure-dominated: $I_{fuse} = 5\times10^{-7}$

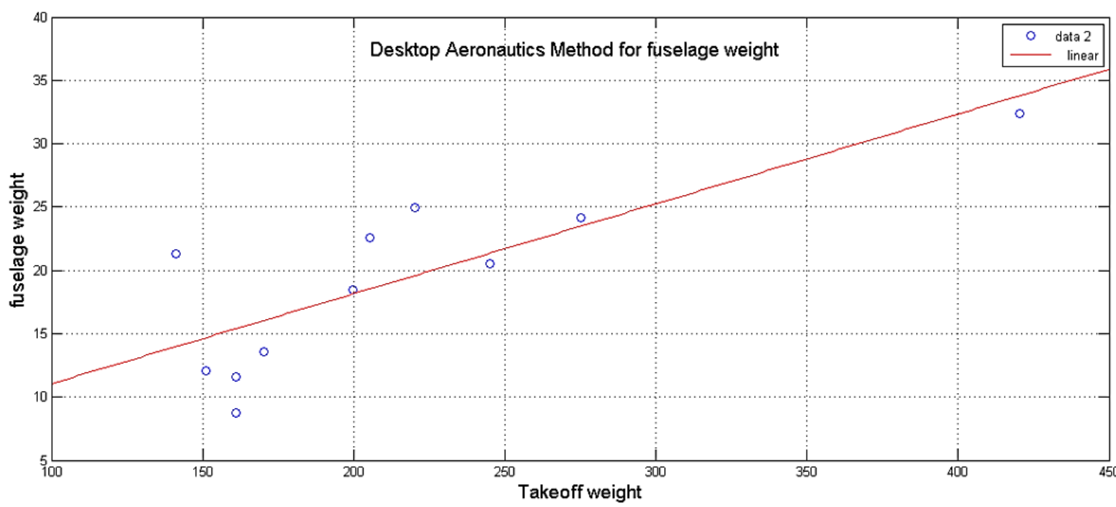

Figure (7): Diagram of Fuselage Weight Estimation for Kroo Formula

Jay Gundlach Method:

Jay suggested a general fuselage structural weight formula for a structure of a semi monocoque or composite shell fuselage for subsonic or transonic UAVs weigh from 1 to 800,000 lb is introduced as follow:

$$W_b = 0.5257 \times fm \times fn \times fp \times fv \times ft \times L^{0.3796} \times (Wc \times Nz)^{0.4863} \times (1.3 \times Vd./100)^2 \quad (8)$$

W_b - Estimated fuselage weight in lb, F_n - Nose gear on the fuselage factor,
w_c - weight of the components carried within the structure in pounds
V_d - design dive speed in knots equivalent air speed,
F_P - Pressurized fuselage factor
F_M - Main gear on the fuselage factor, FV- Vertical tail on the fuselage factor
Ft - Materials factor, L - fuselage length, w_o - max equivalent weight,
fm=1.07; fn=1.04; fv=1; ft=1; fp=1;

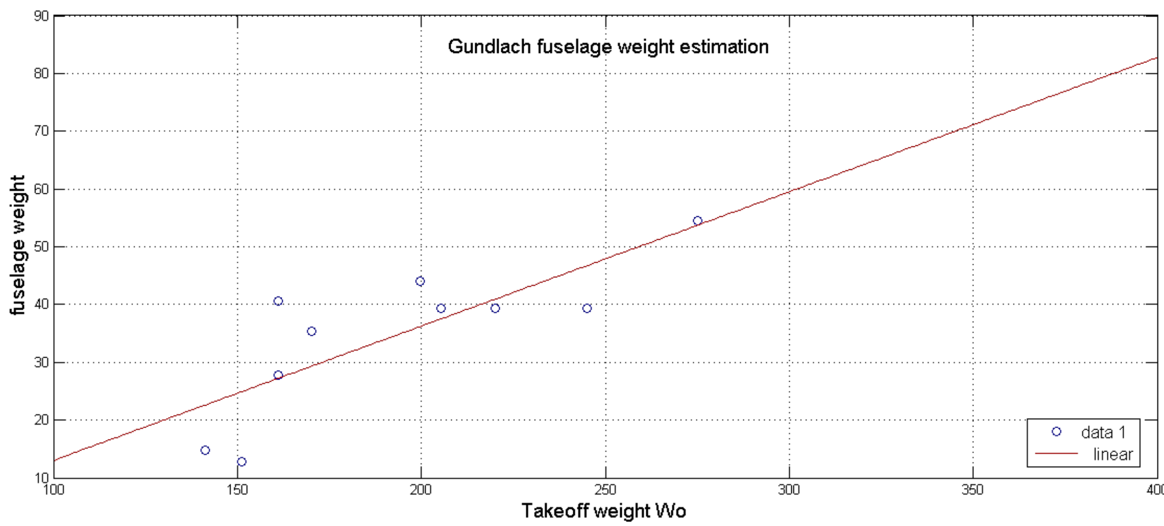

Figure (8): Diagram of Fuselage Weight Estimation for Gundlach Formula

Analysis of Fuselage Weight Results:

All the results extracted from the formulas for fuselage weight estimation are not satisfied. The best result for our case is gotten by Gundlach, this attributed to that all the other formulas are established for manned aircraft fuselage. The most obvious difference between the components of manned and unmanned aircrafts is that the fuselage shape and configuration. For UAV, there is no human inside it, so there is no need for crew or passengers' equipment, seats, and doors. Some parameters are neglected within fuselage weight design for UAVs such as; pressurization

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reinforcement weight, and doors weight. The fuselage diameter, depth, or width in UAV's is much lower than in manned aircrafts. All of these factors have clear effect on the UAV fuselage weight.

Suggested formula for fuselage weight estimation for TUAVs:

Gundlach formula results are almost satisfied in some cases. But it is still inaccurate for others as shown in Figure (8). Random samples of UAVs for fuselage weight estimation gave weights ranging from 12 to 21% of takeoff weight. This wide range makes it unreliable for many cases.

Introducing the aircraft speed in the formulas of fuselage weight estimation is not practically effective, especially for low speed aircrafts. At low speeds of aircrafts, the drag is reduced and doesn't have high effect on the thrust. So introducing the aircraft speed in these formulas may not be effective.

In this research a new suggested formula for fuselage weight estimation in conceptual design phase is established. This formula is founded for tactical unmanned aerial vehicles. It is valid for TUAVs having takeoff weight ranges from 100 to 500 Kg, and maximum speed less than 300 Km/hr, and altitude does not exceed 6000 m.

This formula is experimented just for the previous parameters. However, it may be valid to use for higher or lower takeoff weights, and higher altitude, but in subsonic speeds range.

This formula first mainly relies on the aircraft takeoff weight, whereas the fuselage of the aircraft connects and carries all the components of the aircraft together, (wing, empennage, landing gear, and engine). Dimensions of the fuselage are a main part of the formula represented by fuselage length, diameter and indirectly fuselage surface area.

$$W_b = 0.55 \times (L^{0.3} \times D^{0.3} \times W_o^{0.478})^{1.5} \quad \text{Kg} \qquad (9)$$

W_b- Fuselage weight Kg, L – Fuselage length m, D – Equivalent diameter m.

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From figure (9), the results of this formula for different UAVs sizes have takeoff weights ranging from 100 to 500 Kg lying between 11 – 15 %.

Slope line shows same value all along the line which is approximately 12.7% of takeoff weight.

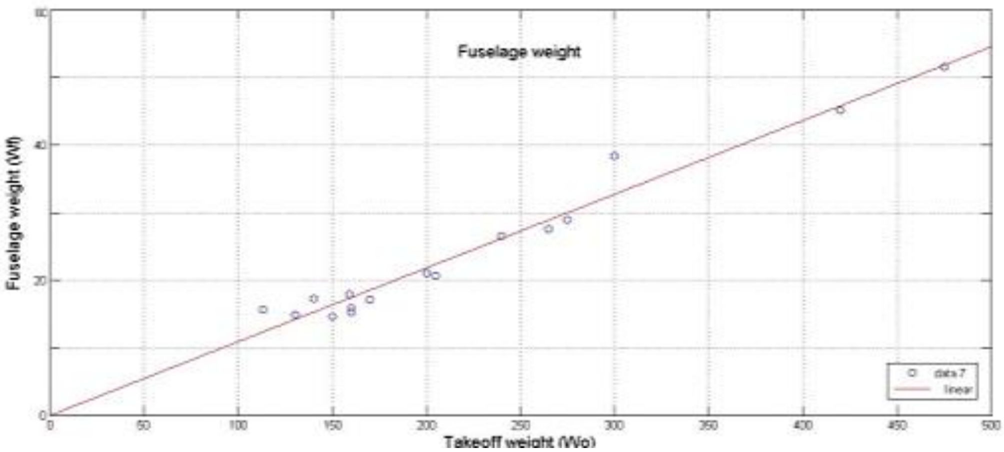

Figure (9): Diagram of Fuselage Weight Estimation for New Suggested Formula

Conclusion

Modification in available formulas is done in order to get better fit fuselage design process. These modified formulas are the main contribution of this research. Application of these formulas estimates more accurately fuselage weight of the UAVs. This leads to more reliable and accurate conceptual design phase. The suggested fuselage weight estimation formula by this research is introduced as follows:

$$W_b = 0.55 \times (L^{0.3} \times D^{0.3} \times W_o^{0.478})^{1.5} \quad Kg$$

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