A STUDY OF STRUCTURE WEIGHT ESTIMATING FOR HIGH ALTITUDE LONG ENDURENCE (HALE) UNMANNED AERIAL VEHICLE (UAV)

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Abstract

In this paper, the estimating formulas for the structure weight of High-Altitude Long-Endurance (HALE) ummanned Aerial Vechicles (UAVs) are deduced by means of the liner regression method on the basis of the analysis about the statistical data of the overall parameters of HALE UAVs. The structure weight of the "global hawk" is evaluated by means of this method to examine the justification and availability of those estimating formulas. The authors also establish the mathematic formulas for the variation rules of the structure weight that vary with overall structure parameters variation on the basis of estimating formulas of structure weight. The sensitivity of each overall parameter which has influence on each component of the structure weight of HALE UAVs is also analyzed. The results indicate that this method can be applied in the estimation of structure weight of High-Altitude Long-Endurance (HALE) Unmanned Aerial Vehicles (UAVs).

1 Introduction

High Altitude Long Endurance (HALE) Unmanned Aerial Vehicles (UAVs) are those that have an endurance of at least 24 hours and an operating altitude of above 18000 meters [1].In the future war, HALE UAV will be the important supplementation and strengthen means of the scout satellites and manned strategy scouts, and become one of the most important methods of gaining strategy information. As a significant branch of UAV, it has many special requirements to the overall configuration for its service characteristics. In general, the HALE UAVs usually configured with high aspect ratio airfoil, which can produce high- lift and low-drag .For its high operating altitude and long endurance, the requirement of structure weight of HALE UAV is very rigid, which require the estimation of structure weight more accurate and reasonable. The values of structures weight are directly affected by the values of overall parameters, so it has a significant meaning to the estimation of structure weight and the relationship between the structure weight and the overall configuration parameters. The aim of this paper is to establish estimating formulas of structure weight by means of the liner regression method, which consider the statistical data of the overall parameters which have influence on the structure weight of HALE UAVs. The structure weight of the "global hawk" is evaluated using this method to examine the justification and availability of those estimating formulas. Based on the estimating formulas of structure weight, we analyze and establish the mathematic formulas of the variation rules of the structure weight variation according to overall structure parameters variation, which would make the estimation of structure weight more accurate and reasonable and provide direct and useful information for the design and selection of the overall parameters.

2 Estimating Formulas of Structure Weight

In this paper, we respectively deduce the structure weight estimating formulas for the wing, the fuselage, the v-type tail and the landing gear of HALE UAVs using the liner regression method and combining with engineering practice, taking into account of the statistical data of the overall parameters which have influence on the structure weight from all the High-Altitude Long-Endurance and Medium- Altitude Long-Endurance Unmanned Aerial Vehicles in the world. The estimating formulas will established in the sequent section.

2.1 The wing

In general, the HALE UAVs usually configured with high aspect ratio (about 20~30), little sweepback (about 0~10°) airfoil, and the wing thickness ratio is big (about 14%~18%). The wing is usually made by three spars or four spars solidify carbon fiber material structure. Some overall parameters which have influence on the wing structure weight are chosen to construct the estimating formula, such as wing area, wing aspect ratio, flight mach number, take-off weight, wing thickness ratio, load factor, wing taper ratio and wing $1/2$ chord sweep back angle. The wing structure weight estimating formula is as below:

$$W_{wing} = 0.0118 \frac{S_w^{0.48} AR \cdot Ma^{0.43} \cdot W_{to}^{0.84} \cdot n_y^{0.84} \cdot \lambda^{0.14}}{(t/c)^{0.76} \cos(0.0175 \Lambda_{1/2})^{1.54}} \tag{1}$$

2.2 The fuselage

The fuselage fineness ratio of HALE UAV is big. The mostly part of fuselage is made of aluminum alloy material. We choose some of overall parameters which have influence on the fuselage structure weight, such as air intake pattern parameter, fuselage structure length, dynamic pressure, fuselage structure height and take-off weight. The fuselage structure weight estimating formula is available:

$$W_{fuse} = 0.0025 K_{inlet}^{1.42} \cdot q^{0.283} \cdot W_{to}^{0.95} \cdot \left(\frac{L}{H}\right)^{0.71} \tag{2}$$

2.3 V-tail

The V-tail is made of composite material. The structure weight of this part is much lighter than other structures. We choose some of overall parameters which have influence on the structure weight of the V-tail, such as load factor, V-tail area, arm of force of V-tail, V-tail root chord thickness, wing mean aerodynamic chord length, V-type tail span and take-off weight. The structure weight of this part is given by:

$$W_{ht} = 0.022 \left(W_{to}^{0.813} \cdot n_y^{0.813} \cdot S_{ht}^{0.584} \cdot \left(\frac{b_{ht}}{T_{rht}}\right)^{0.033} \cdot \left(\frac{C_{cwing}}{L_t}\right)^{0.28} \right)^{0.915} \tag{3}$$

2.4 Landing gear

The structure weight of landing gear is affected by the take-off weight .The structure weight of this part can be obtained:

$$W_{ld} = 0.165 W_{to}^{0.84} \tag{4}$$

Where

S_w: wing area（m^2）

AR: wing aspect ratio

M_a: mach number

W_{to}: take-off weight（kg）

t/c: wing thickness ratio

n_y: load factor

λ : wing taper ratio

L: fuselage structure length （m）

q: dynamic pressure（kg/m^2）

H: fuselage structure height （m）

S_{ht}: V-tail area（m^2）

L_t: arm of force of V-tail （m）

T_{rht}: V-tail root chord thickness （m）

C_{wing}: wing mean aerodynamic chord length （m）

K_{inlet}: air intake pattern parameter （such as: nose intake K_{inlet} is 1.0, abdomen intake K_{inlet} is 1.05, back intake K_{inlet} is 1.2, both sides intake K_{inlet} is 1.3）

$\Lambda_{1/2}$: wing $1/2$ chord sweep back angle（°）

b_{ht}: V-tail span （m）.

2.5 Example

The structure weight of the "global hawk" [2] is evaluated by means of this method to examine the justification and availability of those estimating formulations. The results are tabulated in Table 1:

Table1. structure weight and structure weight fraction of each component of the "global hawk"

	wing	fuselage	V- tail	Landing gear
Structure weight/kg	968.15	826.53	98.646	429.97
structure weight fraction	0.0834	0.0712	0.0085	0.0370

From the results, we can draw a conclusion that the structure weight fraction of the "global hawk" basically accords with the analysis results. So these equations can provide a reasonable estimate of the structure weight and also can be applied in engineering practice during preliminary design for the HALE UAV.

3 Sensitivity analysis of overall parameters

On the basis of the estimating formulas of structure weight, the writers analyze the sensitivity of every overall parameter which has influence on each component of the structure weight of HALE UAV by means of analyzing the values of structure weight changing rate of each part of HALE UAV while each overall parameter has the same changing rate. With the above analysis, the mathematical formulas which can reflect the overall parameters sensitivity are established.

3.1 The wing parameters

If Δi is the percentage of parameter change, ΔW_{wing} is the corresponding percentage of the wing structure weight change. Using the Eq. (1), one can obtain the formulas and the sensitivity analysis graph:

1. take-off weight W_{to}:

$$\Delta W_{wing} = (1+\Delta W_{to})^{(\frac{21}{25})} - 1 \qquad (5)$$

2. load factor n_y:

$$\Delta W_{wing} = (1+\Delta n_y)^{(\frac{21}{25})} - 1 \qquad (6)$$

3. wing area S_w:

$$\Delta W_{wing} = (1+\Delta S_w)^{(\frac{12}{25})} \qquad (7)$$

4. wing aspect ratio AR:

$$\Delta W_{wing} = \Delta AR \qquad (8)$$

5. wing taper ratio λ:

$$\Delta W_{wing} = (1+\Delta\lambda)^{(\frac{7}{50})} - 1 \qquad (9)$$

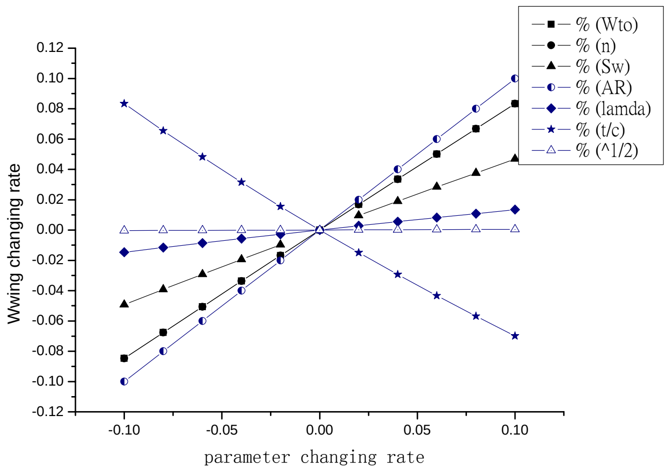
6. wing thickness ratio t/c:

$$\Delta W_{wing} = 1 - \frac{(1+\Delta_{t/c})^{(\frac{19}{25})}}{(1+\Delta_{t/c})^{(\frac{19}{25})}} \qquad (10)$$

7. wing $1/2$ chord sweep back angle $\Lambda_{1/2}$:

$$\Delta W_{wing} = \frac{\cos(0.017\Lambda_{1/2})^{(\frac{77}{50})}}{\left(\cos(0.017\Lambda_{1/2} + 0.017\Delta_{\Lambda 1/2}\cdot\Lambda_{1/2})\right)^{(\frac{77}{50})}} - 1 \qquad (11)$$

Fig.1. The Sensitivity Analysis of The Wing Structure Weight



From Fig.1, it can be concluded that different overall parameters have different influence on the wing structure weight. The value of curvilinear slope represents the sensitivity of every overall parameter which has influence on the structure weight of wing. The bigger the value of curvilinear slope is, the more sensitive it is. If the value of curvilinear slope of the overall parameter is positive, it means that the wing structure weight will increase with the overall parameter increasing and if the value of curvilinear slope is negative, it means that the wing structure weight will decrease with the overall parameter increasing. It is easy to see that the increasing of W_{to}, n_y, S_w, AR, λ and $\Lambda_{1/2}$ will lead to the increase of the wing structure weight, while the increasing of t/c will lead to the opposite influence on the wing structure weight . The changing rate of the wing structure weight is different while the overall parameters changing rate is the same i.e. the change of n_y, W_{to} have the same influence on the wing structure weight, the change of $\Lambda_{1/2}$, λ have very little influence on it, the change of t/c has big influence on it, the changing rate of the wing structure weight is the same as the changing rate of AR which has the most signaficant influence on the wing structure weight among them.

3.2 The fuselage parameters

Denoting Δi as the percentage of parameter change and ΔW_{fuse} as the corresponding percentage of the fuselage structure weight. From Eq.(2), the formulas for sensitivity analysis can be expressed as follow:

1. dynamic pressure q:

$$\Delta W_{fuse} = (1+\Delta q)^{(\frac{283}{1000})} - 1 \tag{12}$$

2. fuselage structure height H:

$$\Delta W_{fuse} = (1/_{1+\Delta H})^{(\frac{71}{100})} - 1 \tag{13}$$

3. fuselage structure length L:

$$\Delta W_{fuse} = (1+\Delta L)^{(\frac{71}{100})} - 1 \tag{14}$$

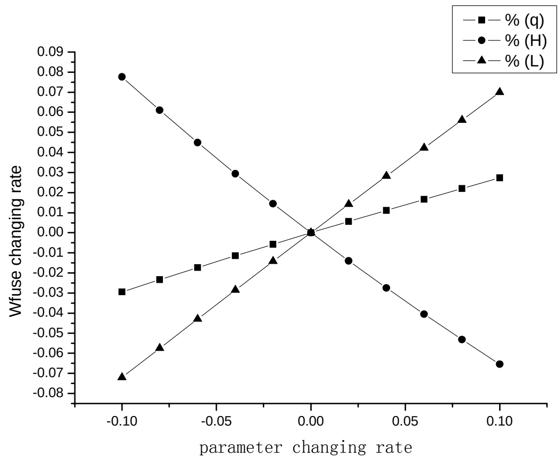


Fig.2. The Sensitivity Analysis of The Fuselage Structure Weight

From Fig.2, it can be concluded different overall parameters have different influence on the fuselage structure weight. It is easy to see that the increasing of q and L will lead to the increase of the fuselage structure weight, but the increasing of H will lead to the decrease of the fuselage structure weight. The changing rate of the fuselage structure weight is different while the parameters change rate is the same: the change of the three overall parameters all have big influence on the fuselage structure weight and the change of H has the most prominent influence on the fuselage structure weight among them.

3.3 The V-tail parameters

Using the notation Δi represent the percentage of parameter change and ΔW_{ht} represent the corresponding percentage of the V-tail structure weight. From the Eq.(3), the sensitivity analysis formulas are as follow:

1. V-tail area S_{ht}:

$$\Delta W_{ht} = 0.28 \times (10.76 + 10.76\Delta S_{ht})^{0.53} - 1 \tag{15}$$

2. V-tail span b_{ht}:

$$\Delta W_{ht} = (1+\Delta b_{ht})^{0.03} - 1 \tag{16}$$

3. V-tail root chord thickness T_{rht}:

$$\Delta W_{ht} = (1/_{(1+\Delta T_{rht})})^{0.03} - 1 \tag{17}$$

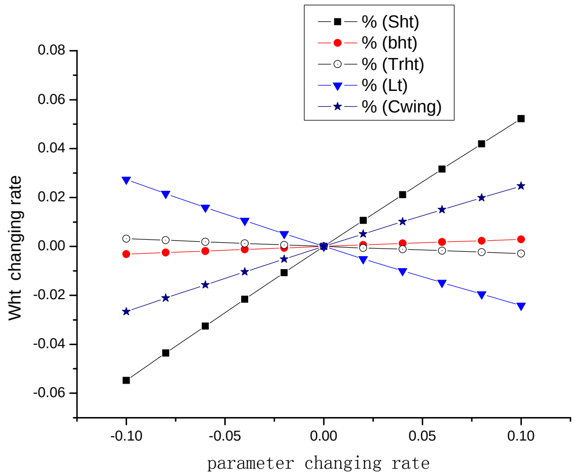
4. arm of force of V-tail L_t:

$$\Delta W_{ht} = (1/_{(1+\Delta L_t)})^{0.26} - 1 \tag{18}$$

5. wing mean aerodynamic chord length C_{wing}:

$$\Delta W_{ht} = (1 + \Delta C_{wing})^{0.26} - 1 \quad (19)$$

Fig.3. The Sensitivity Analysis of The V-tail Structure Weight



From Fig.3, one can see that different overall parameters have different influence on the V-tail structure weight. It is easy to see that the increasing of S_{ht}, C_{wing} and b_{ht} will lead to the increase of the V-tail structure weight, but the increasing of L_t and T_{rht} will lead to the decrease of the V-type tail structure weight. The change rate of the V-type tail structure weight is different while the parameters change rate is the same: the change of b_{ht} and T_{rht} has little influence on the V-tail structure weight; the change of L_t and C_{wing} has big influence on the V-tail structure weight and the change of S_{ht} has the most prominent influence on the V-tail structure weight among them.

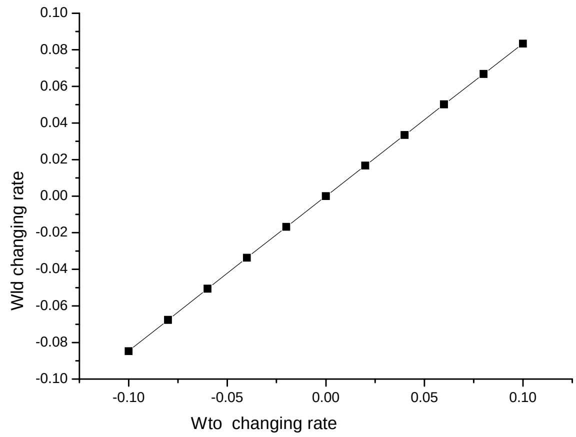
3.4 The landing gear parameter

If Δi is the percentage of parameter change, ΔW_{ld} is the corresponding percentage of the landing gear structure weight. Based on Eq.(4), the sensitivity analysis formula for the landing gear can be written as:

take-off weight W_{to}:

$$\Delta W_{ld} = 170.439 \times (0.002 + 0.002\Delta W_{to})^{0.84} - 1 \quad (20)$$

Fig.4. The Sensitivity Analysis of The Landing Gear Structure Weight



From Fig.4, it can be known that the increase of W_{to} will lead to the increase of the landing gear structure weight. The changing rate of the landing gear structure weight is different from changing rate of W_{to}, and the changing rate of the landing gear structure weight is smaller than that of W_{to}.

From the formulas (5)~(20), it is easy to known that the relationship between the changing rate of each overall parameter and the each part structure weight is mostly nonlinear. But in this paper, the curvilinears in the figures look like straight lines because the changing rate of each overall parameter is small (the range of Δi is between $\pm 10\%$).

3.5 Sensitivity analysis

From the above analysis, one can draw a conclusion that : wing aspect ratio, take-off weight, wing thickness ratio, load factor, fuselage structure height, wing mean aerodynamic chord length, fuselage structure length, V-tail area and arm of force of V-tail have the prominent influence on the structure weight of HALE UAV while wing taper ratio, wing $1/2$ chord sweep back angle, V-tail root chord thickness and V-tail span have smaller influence on it than other parameters.

4 Conclusions

Based on the results presented in this paper, the following conclusions can be made.

(1) The structure weight estimating formulas which are deduced in this paper can be applied in engineering practice during preliminary design of the HALE UAV.

(2) The analysis of the sensitivity of each overall parameter, which has influence on the structure weight, and the established mathematical formulas, which can directly reflect the relationship between the changing rate of overall parameters and the changing rate of the structure weight, can decrease the difficulty of the selection of overall parameters during the preliminary design. If fully considerating these rules while evaluating the structure weight of the HALE UAV, one can make decision more precisely and reasonable.

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