Chapter 5

Wing design - selection of wing parameters - 4

Lecture 22

Topics

5.3.9 Ailerons

5.3.10 Other aspects of wing design

Example 5.1

5.3.9 Ailerons

The main purpose of the ailerons is to create rolling moment and provide adequate rate of roll. Subsection 6.10.1 of Ref.3.1 be referred for discussion on different types of ailerons, subsection 6.10.2 to 6.10.4 for steps to obtain the rate of roll for given parameters of wing and aileron. Federal Aviation Regulations prescribe rates of roll for different types of airplanes. Chapter 12 of Ref.1.24 also gives some data. However, these calculations can be done at a later stage. At this stage of preliminary design, guidelines from similar airplanes can be taken regarding (i) ratio of aileron chord to wing chord (c_a / c_w) and (ii) extent of aileron span to wing span (b_a / b).

5.3.10 Other aspects of wing design

(i) Chapter 4 of Ref.1.18 be consulted for shapes of wing tips. Section 3.2.21 of Ref.3.3 gives brief information on winglets. Websites (www.google.com) be referred to for information on topics like a) wing strakes, b) double delta wings and c) behavior of delta wings at high angles of attack.

(ii) The fuel is mostly stored in the wings. Adequate space inside the wing should be available for storage of fuel. Section 6.5 presents the guidelines in this regard. Chapter 8 of Ref. 4.1 presents the calculations of fuel tank space required and its location in wings for the case of a propeller - driven airplane.

Example 5.1

In example 2.1, the preliminary estimates of wing parameters were obtained for a 60 seater turboprop airplane. Obtain, for the same airplane, the refined estimates of the following wing parameters (a) airfoil section, (b) aspect ratio, (c) sweep, (d) taper ratio, (e) twist, (f) incidence, (g) dihedral and (h) vertical location.

Solution :

From example 3.1: weight of the airplane = W_0 = 21,280 kgf = 208,757 N

From section 4.10.5: W/S = 3570 N/m^2

Hence, wing area = W_0/(W/S) = 208757/3570 = 58.48 m^2

I) Airfoil selection

Since, the airplane under consideration is a commercial airplane, the cruising flight is considered as the design condition.

V_{cr} = 500 kmph = 138.9 m/s

h_{cr} = 4.5 km ; Hence, ρ_{cr} = 0.7768 kg/m^3

Speed of sound at 4.5 km : 322.57 m/s; M_{cr} = 138.9 / 322.57 = 0.431

Consequently,

$$C_{Lcruise} = \frac{2W/S}{\rho V^2} = \frac{2\times 3570}{0.7768\times 138.9^2} = 0.476$$

An airfoil with C_{lopt} between 0.4 to 0.5 would be near optimum. However, from the discussion in subsection 5.2.4, it is noted that the airfoil NASA MS(1)-0317 has been specifically designed keeping in view, the application to medium speed airplanes. This airfoil has $C_{lmax} \approx 2.0$ (Fig.5.5a), C_{dmin} occurs for C_l from 0 to about 0.6. Further, this airfoil has been used on IPTN-N-250-100 airplane. Hence, this airfoil is selected.

It has been pointed out in remark (ii) of subsection 5.2.6 that using a thinnner airfoil at tip is advantageous.

Following the choices in IPTN-N-250-100 airplane, the value of (t/c) at root is taken as 17% and that near the wing tips as 13%.

II) Aspect ratio

At the present stage of preliminary design, A = 12 is chosen as this value is close to that of some airplanes in this category (Table 2.1).

III) Sweep

Since, the value of M_{cr} is only 0.431, an unswept wing ($\Lambda = 0$) would appear to be an appropriate choice. However, from table 2.1 it is observed that the wings of airplanes in this category, which are similar to the configuration shown in Fig.2.1, have small amount of quarter chord sweep ($\Lambda_{\frac{c}{4}}$) in the outboard portion.

Observing the trends in table 2.1, an average value of $\Lambda_{\frac{c}{4}} = 3.9^o$ is tentatively chosen for the outboard wing of the airplane under design. This results in a leading edge sweep (Λ_{le}) of 6.07^o for the outboard wing. This is shown in Fig. E 5.1a. It is seen that with this sweep angle the rear spar of the wing, to which the flaps and ailerons are attached, has a simpler shape without any bend.

IV) Taper ratio

In subsection 5.3.3 it is pointed out that a wing with constant chord central section and outer panels tapered, combines the advantages of ease of fabrication and lower structural weight. This type of planform is also observed in XAC-YC-7, IPTN-N-250-N, ATR-72-250 and DASH-8-Q300. The straight section is chosen to extend upto 35% of semispan on either side of the root chord. A taper ratio of 0.5 for the outer panels appears to be a preferred choice.

With these choices the root chord (c_r) and tip chord (c_t) can be worked out as follows.

S = 58.48 m^2 , A = 12, Hence, b = $\sqrt{AS} = \sqrt{58.48 \times 12} = 26.49$ m

Hence,

$$58.48 = 0.35 \times 26.49\, c_r + 2\left(\frac{c_r + 0.5\, c_r}{2}\right)\frac{0.65}{2} \times 26.49$$

Or c_r = 2.636 m and $c_t = 1.318$ m

The final planform of the wing will be arrived at after the optimisation procedure which will result in low drag and weight of the wing.

The wing planform is shown in Fig.E 5.1.

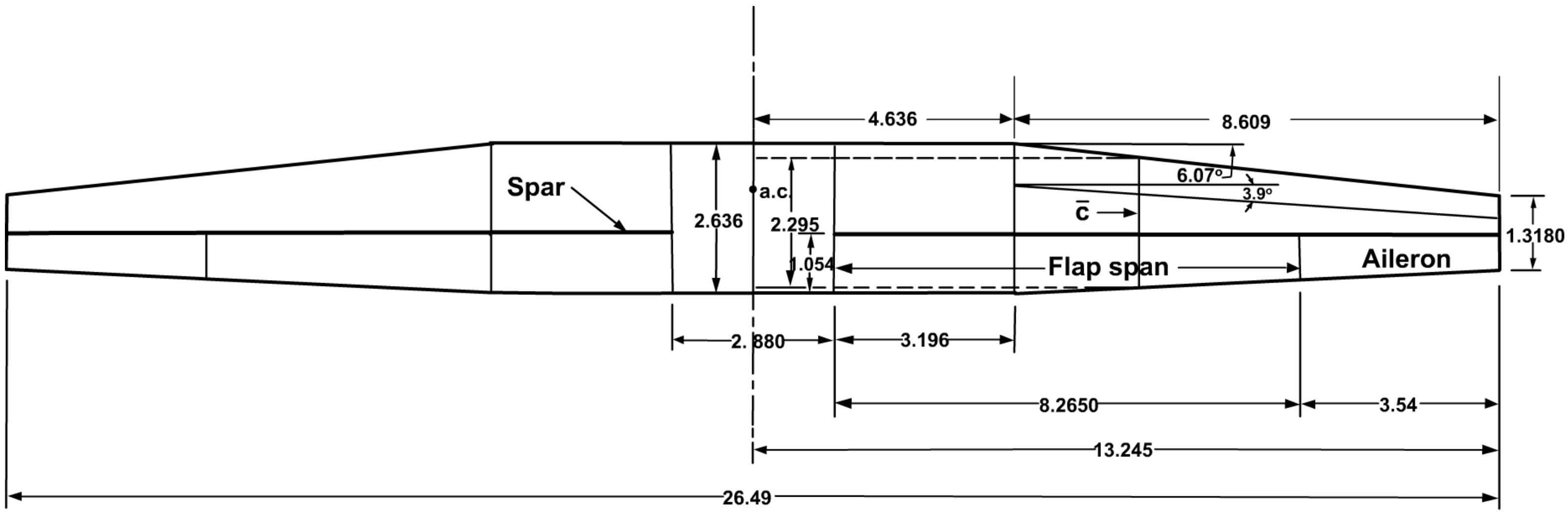

Fig. E 5.1a Wing planform

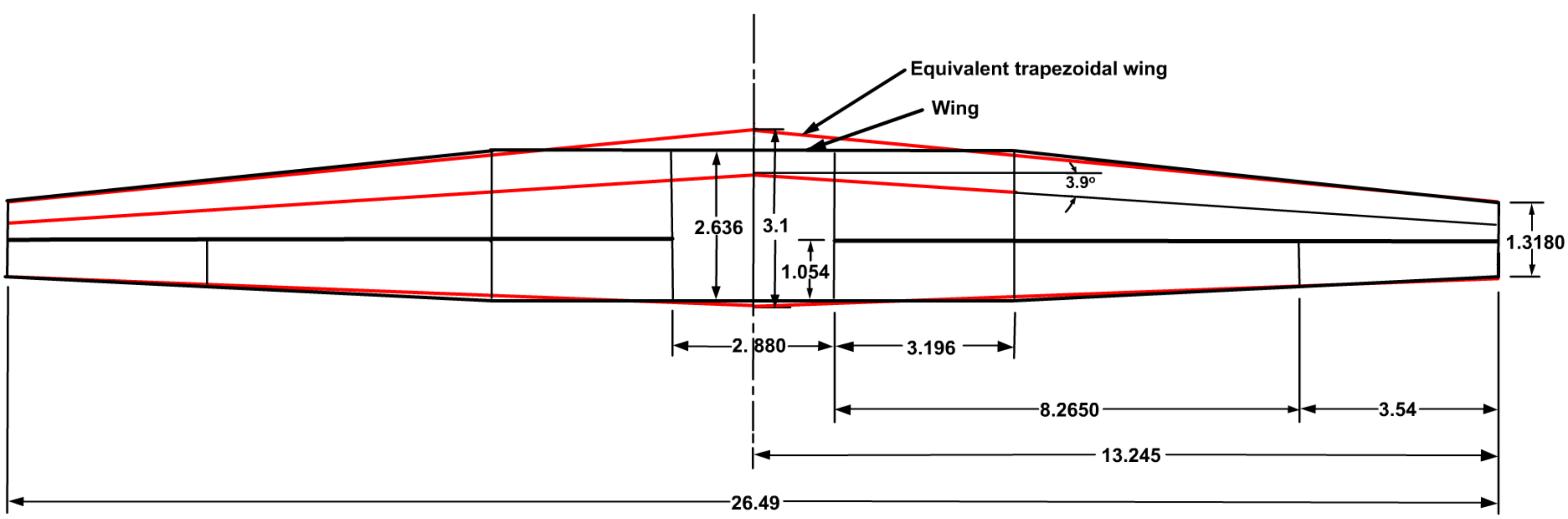

Fig.E 5.1b. Wing and equivalent trapezoidal wing

Remark :

The value of the mean aerodynamic chord of the wing $(\bar{c}_w)$ and the location of the aerodynamic centre would be needed in chapter 6. These are worked out below.

For a wing which is symmetric about the root chord, $\bar{c}_w$ is given by :

$$\bar{c}_w = \frac{2}{S_W}\int_0^{b/2} c^2\,dy$$

In the present case :

c = 2.636 m for $0 \le y \le 4.636$

$$= 2.636 - \frac{(2.636-1.318)}{8.609}(y-4.636) \text{ for } 4.636 \le y \le 13.245$$

$$= 3.3458 - 0.1531\,y \text{ for } 4.636 \le y \le 13.245 \qquad (5.11)$$

Consequently,

$$\bar{c}_W = \frac{2}{58.48}\left\{\int_0^{4.636} 2.636^2\,dy + \int_{4.636}^{13.245}(3.3458 - 0.1531y)^2\,dy\right.$$

$$= \frac{2}{58.48}\left\{2.636^2 \times 4.636 + \int_{4.636}^{13.245}(11.194 + 0.02344\,y^2 - 1.0245\,y)dy\right.$$

$$= \frac{2}{58.48}\left\{32.211+11.194(13.245-4.636) + \frac{0.02344}{3}(13.245^3-4.636^3) - 1.0245(13.245^2-4.636^2)\right\}$$

= 2.295 m

Location of aerodynamic centre

From Eq.(5.11) the spanwise location (y_{mac}) where a chord of 2.295 m is located is given by :

2.295 = 3.3458 – 0.1531 y_{mac}

Or y_{mac} = 6.863 m

To obtain the location of a.c. of the wing, the wing chord at y_{mac} is projected on to the root chord. The quarter chord of this is the a.c. of the wing. (Fig. E 5.1 a).

The leading edge sweep of the outboard wing is 6.07^o. Hence, the location of a.c. from the leading edge of the root chord is given by :

$$(6.863-4.636)\tan 6.07+\frac{2.295}{4}=0.811\,\text{m}$$

V) Twist

Taking guidelines from the value of wing twist in IPTN-N-250-100, a value of $\varepsilon = 3^0$ (wash-out) is chosen at this stage of preliminary design.

VI) Incidence (i_w)

This angle is chosen such that during cruise, the fuselage is horizontal and wing with $\alpha = i_w$ produces the desired lift. From item(I) above, $C_{Lcruise} = 0.476$

From Eq.(5.6)

$$C_{L\alpha}=\frac{2\pi A}{2+\sqrt{4+\frac{A^2\beta^2}{\eta^2}\left(1+\frac{\tan^2\Lambda_{\frac{1}{2}}}{\beta^2}\right)}}$$

$A = 12$, $\beta = \sqrt{1-M^2} = \sqrt{1-0.4312} = 0.902$

η = (average slope of lift curve of airfoil on wing) / 2π .

Generally, η is taken as unity.

This quantity $\Lambda_{\frac{1}{2}}$ depends, A, λ and $\Lambda_{\frac{1}{4}}$. The taper ratio and $\Lambda_{\frac{1}{4}}$ are those of an equivalent trapezoidal wing (ETW). The steps to obtain the dimensions of ETW are given below.

Equivalent trapezoidal wing :

It may be pointed out that the procedures to obtain the aerodynamic data and stability derivatives are generally available for straight tapered wings. Reference 5.6, section 2 suggests that the geometrical parameters of practical wings can be approximated by an ETW. A certain amount of judgement is involved to obtain ETW. The procedure is as follows.

(a) The actual wing and the ETW have the same span and area.

(b) The length and location of tip chord is the same for the two wings. The swept back portion of the two wings are nearly the same.

In the present case the actual wing has the following values.

Area of wing = 58.48 m^2 ; wing span = 26.49 m; root chord (c_r) = 2.636 m; tip chord(c_t) = 1.318 m ; the constant chord (2.636 m) extends upto 4.636 m on either side of the root chord ; leading edge sweep of the outboard wing is 6.07^o ; quarter chord sweep of the outboard wing is 3.9^o through out the .

The ETW is taken as having area of 58.48 m^2, span of 28.49 m, tip chord of 1.318 m and quarter chord sweep of 3.9^o through out the same-span.

Consequently, the root chord (c_{re}) of ETW is given by :

$$58.48 = \frac{26.49}{2}(c_{re} + 1.318) \text{ or } c_{re} = 3.1\,\text{m}$$

Taper ratio of (λ_e) of ETW = 1.318 / 3.1 = 0.425

The ETW as superposed over actual wing is shown in Fig.E5.1b.

The quarter chord sweep $\left(\Lambda_{\frac{1}{4}}\right)_{ETW}$ is chosen to be 3.9^o. The value of $\left(\Lambda_{\frac{1}{2}}\right)_{ETW}$ can be worked out by geometry. However, from section 1 of Ref.5.6, the value of $\tan \Lambda_{\frac{1}{2}}$ is given by :

$$\tan \Lambda_{\frac{1}{2}} = \tan \Lambda_{\frac{1}{4}} - \frac{4}{A}\left[(0.5 - 0.25)\frac{1-\lambda_e}{1+\lambda_e}\right]$$

$$= 0.06817 - 0.0336 = 0.03454$$

$$\Lambda_{\frac{1}{2}} = 1.98^o$$

With the above data, the value of $C_{L\alpha}$ of the wing is obtained as :

$$C_{L\alpha} = \frac{2\pi \times 12}{2 + \sqrt{4 + \frac{12^2 \times 0.902^2}{1}\left(1 + \frac{0.03454^2}{0.902^2}\right)}}$$

$$= 5.793 \text{ rad}^{-1} = 0.1011 \text{ deg}^{-1}$$

From Fig.5.5 a, α_{ol} of the airfoil is -3^o

Since, the wing has a twist of 3^o (wash-out), from Eq.(5.10) the angle of zero lift of the wing (α_{oL}) is :

α_{oL} = 0.4(-3) = -1.8^o

Hence, wing incidence (i_W) is given by :

0.476 = 0.1011 (i_W + 1.8) or i_W = 2.9^0

Remark :

IPTN-N-250-100 which also uses NASA MS (1)-0317 airfoil has $i_w = 2^0$

This value would have been obtained after wind tunnel tests on the model of the final configuration of the airplane.

VII) Dihedral (Γ)

At this stage of the preliminary design a value of $\Gamma = 3^0$ is chosen based on Table 2.1.

VIII) Vertical location

For airplanes with propellers mounted on wings, the preferred vertical location is the high wing configuration. This is chosen in the present case.

Flaps and ailerons

As mentioned in example 4.11, a double slotted flap, similar to ATR-72-200 has been chosen. Based on this airplane, the flap span is chosen as 70% of the exposed wing span (i.e. wing span minus the fuselage width). The flap chord is 40% of the wing chord in the constant chord section. The ailerons start from the spanwise location where the flap ends and extend upto the wing tip.

Figure E 5.1a shows the tentative locations of flaps and ailerons.

Answers :

The wing parameters, at this stage of preliminary design, are :

Wing area (S) = 58.48 m^2, span (b) = 26.49 m

Root chord (c_r) = 2.636 m, constant chord central section upto 4.636 m from root on either side.

Tip chord (c_t) = 1.318 m.

Airfoil : NASA MS(1) – 0317 at root, t/c = 17%

NASA MS(1) – 0313 at tip, t/c = 13%

Aspect ratio = 12

Quarter chord sweep of outboard panel = 3.9^o

Mean aerodynamic chord = 2.295 m

Twist (ε) = 3^o (wash-out)

Wing incidence (i_w) = 2.9^o

Dihedral angle (Γ) = 3^o