Chapter 6

Fuselage and tail sizing - 5

Lecture 27

Topics

Example 6.2 (part I)

Example 6.2 (part I)

In example 2.1 the preliminary estimates of the parameters of the horizontal and vertical tails were obtained for a 60 seater turboprop airplane. Obtain, for the same airplane, the refined estimates of the following parameters.

(a)Estimated values of tail volume ratios for horizontal and vertical tails (C_{ht} and C_{Vt}). (b) Tail arms l_{ht} and l_{vt} .(c) Areas of horizontal and vertical tails.(d) Aspect ratio, taper ratios and sweep of horizontal and vertical tails. (e) Span of horizontal tail and height of vertical tail. (f) Estimated areas of elevator and rudder.

Solution :

In part I of this example the calculations of the parameters of wing and empennage are illustrated for the case of XAC YC-7-100 airplane.

Table 2.1, under the section on empennage, presents overall data for eight airplanes, in the category of regional transport airplanes with turboprop engines. This information along with additional data is presented in Table 6.2. To generate the additional data, certain dimensions of the parts of the airplanes were needed. These have been obtained from the three view drawings in Ref.1.21 (1999-2000 edition). These data are marked as “estimated”.

As suggested in section 6.3, the first step is to obtain, the tail volume ratios (C_{ht} and C_{vt}) of similar airplanes. The values of S, S_{ht} and S_{vt} are directly available in Ref.1.21. The mean aerodynamics chords of the wing and tails and the locations of their aerodynamic centres need to be calculated. This calculation is described below for the case of XAC YC – 7 -100 airplane.

I) Location of a.c. of wing for XAC YC – 7 -100

The span of the wing (29.67 m) is prescribed as that over the winglets.

The span of the wing is estimated as 28.93 m from the three-view drawing. The root chord (3.5 m) tip chord (1.1 m) span (28.93 m) and the area of the wing (75.26 m^2) are mentioned (Ref.1.21). From these data the spanwise extent of the constant chord portion of the wing is estimated as follows.

Let, this extent be 'y_{cc}'

Consequently,

$$3.5 \text{ x } y_{cc} \text{ x } 28.93 + (1-y_{cc})\left(\frac{28.93}{2}\right)(3.5+1.1) = 75.26$$

Or y_{cc} = 0.25

In the present case, the estimated / given values for the wing can be summarized as follows. Figure 6.10a also shows the values.

Area of wing = 75.26 m^2

Wing span = 28.93 m

Root chord = 3.5 m

Tipchord = 1.1 m

Constant chord (3.5 m) portion extends upto (28.93 x 0.5 x 0.25) 3.615 m on either side of the root chord. Leading edge sweep of the outboard wing is 9.4°.Quarter chord sweep of the outboard wing is 6°

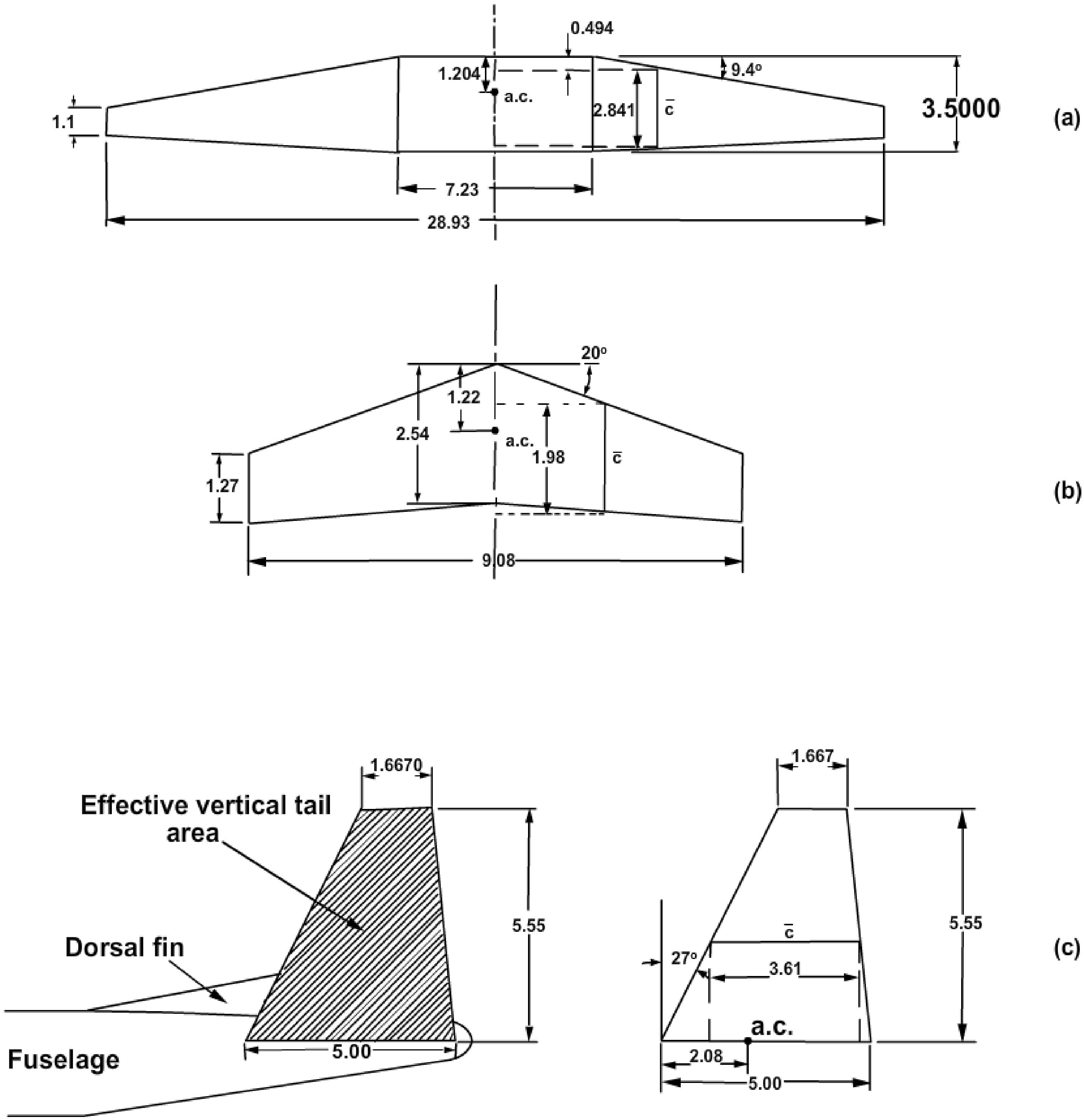

Fig.6.10 Parameters of wing, h.tail and v.tail of XAC-Y-7-100

(a) Wing (b) Horizontal tail (c) Vertical tail

The mean aerodynamic chord $(\bar{c})$ and the location of aerodynamic centre of the wing are obtained as follows.

The m.a.c. for a symmetric wing is defined as:

$$\bar{c} = \frac{2}{5}\int_0^{b/2} c^2 dy \qquad (6.13)$$

From Fig.6.10a :

For $0 \le y \le 3.615$: c = 3.5 m

For $3.615 \le y \le 14.465$: $c = 3.5 - \frac{(3.5-1.1)}{(14.465-3.615)}(y-3.615)$

$$= 4.3 – 0.2212\ y \qquad (6.14)$$

Consequently, Eq(6.13) gives :

$$\bar{c}_w = \frac{2}{75.26}\left\{\int_0^{3.615} 3.5^2\, dy + \int_{3.615}^{14.465}(4.3-0.2212y)^2\, dy\right\}$$

$$= \frac{2}{75.26}\left\{3.5^2 \times 3.615 + \int_{3.615}^{14.465}\left(18.49+0.04893y^2-1.9023y\right)dy\right\}$$

$$= \frac{2}{75.26}\left\{44.28+\left[18.49y+\frac{0.04893}{3}y^3-\frac{1.9023}{2}y^2\right]_{3.615}^{14.465}\right\}$$

$= 2.841$ m

From Eq.(6.14), the spanwise location(y_{mac}) where the wing chord is 2.841 m, is given by :

$2.841 = 4.3 – 0.2212\ y_{mac}$ or $y_{mac} = 6.596$ m

To get the a.c. of the wing, the chord at y_{mac} is projected on to the root chord (Fig.6.10a). The quarter chord point of this projection is the a.c. of the wing. From Fig.6.10a the location of the a.c. of wing behind the leading edge of the root chord is :

$$(6.596-3.615)\tan 9.4+\frac{2.814}{4}=1.204\,\text{m}$$

The distance of the leading edge of the root chord of the wing, from the nose of the fuselage is estimated as 8.71 m.

Hence, the location of the a.c. of the wing, from the nose of the fuselage, is :

8.71 + 1.204 = 9.91 m .

II) Location of a.c. of horizontal tail for XAC YC – 7 -100.

The data from Ref.1.21 (1999 – 2000 edition) about h.tail are:

Area of h.tail = 17.3 m^2

Span of h.tail = 9.08 m

The following date are estimated from the three-view drawing in Ref.1.21.

The taper ratio (c_{tt} / c_{rt}) = 0.5

The h.tail has trapezoidal planform.

The leading edge sweep of h.tail = 20^0

The distance of the root chord of h.tail from the nose of the fuselage = 21.33 m.

Based on the given and estimated values, the following values are deduced for the horizontal tail.

$$S_t=\frac{b_t}{2}(c_{rt}+c_{tt})$$

Or $17.3 = \frac{9.08}{2}(c_{rt} + 0.5 \times c_{rt})$

Hence, c_{rt} = 2.54 m, c_{tt} = 1.27 m

The mean aerodynamic chord of a trapezoidal shape is given as :

$$\bar{c} = \frac{2}{3} c_r \left(\frac{1+\lambda+\lambda^2}{1+\lambda} \right); \lambda = \text{taper ratio}$$

Hence, mean aerodynamic chord of h.tail ($\bar{c}_t$) is :

$$\bar{c}_t = \frac{2}{3} \times 2.54 \left(\frac{1+0.5+0.5^2}{1+0.5} \right) = 1.98 \text{ m}$$

The location of the a.c. of the h.tail can be obtained in a manner similar to the steps to obtain a.c. of the wing. The location of the a.c. of h.tail, behind the leading edge of the root chord of h.tail, is at 1.22 m.(Fig.6.10b)

Hence, distance of a.c. of h.tail from the nose of the fuselage = 21.33 + 1.22 = 22.55 m.

Consequently, horizontal tail arm (l_{ht}) is :

(distance of a.c. of h.tail from nose) – (distance of a.c. of wing from nose)

= 22.55 – 9.91 = 12.64 m.

Hence,

$l_{ht} / \bar{c}_w$ = 12.64/2.841 = 4.45

l_{ht} / l_f = 12.64/24.22 = 0.522

$$C_{ht} = \frac{S_{ht}}{S} \frac{l_{ht}}{\bar{c}_w} = \frac{17.3}{75.26} \times \frac{12.64}{2.841} = 1.023$$

Figure 6.10b shows the planform of the h.tail.

III) Location of a.c. of vertical tail

Ref.1.21 (1999-2000 edition) gives:

Area of fin = 13.38 m^2

Area of rudder = 5.105 m^2

Hence, area of vertical tail = S_{vt} = 18.49 m^2

The following data are estimated from the three-view drawing in Ref.1.21.

The surface of fuselage, on which the v.tail is located is slightly curved. Hence, the root chord of the v.tail is taken on a line parallel to FRL and passing through the rear end of the fuselage.The left side of Fig.6.10c shows the configuration.

Root chord of the V.tail = c_{rvt} = 5.0 m

Tip chord of the V.tail = c_{tvt} = 1.667 m

Height of V.tail = h_{vt} = 5.55 m

Incidently, these values of c_{rvt}, c_{tvt} and h_{vt} give S_{vt} of 18.50 m which is close to the actual value of S_{vt}.

Leading edge sweep of v.tail = Λ_{vle} = 27°

Distance of the leading edge of the root chord of v.tail from nose is estimated to be 19.40 m. From these data the following quantities are evaluated.

Taper ratio of v.tail = 1.667 / 5 = 0.333.

Mean aerodynamic chord of v.tail = $\bar{c}_{vt} = \frac{2}{3} \times 5 \frac{\left(1+0.333+0.333^2\right)}{1+0.333} = 3.61\,m$

Taking into account c_{rvt}, c_{tvt} and Λ_{vle}, the location of the leading edge of the mean aerodynamic chord is at a height of 2.31 m above root chord and 1.177 m behind the leading edge of the root chord.(Fig.6.10c)

Hence, the distance of the a.c. of vertical tail from the leading edge of the vertical tail = 1.777 + (3.61/4)= 2.08 m

Hence, the distance of the a.c. of v.tail from the nose of the fuselage is:

19.40 + 2.08 = 21.48 m

Noting that, the a.c. of the wing is at 9.91 m from the nose of the fuselage, the distance between a.c. of wing and that of v.tail is :

l_{vt} = 21.48 – 9.91 = 11.57 m

Consequently, l_{vt} / b = 11.57 / 28.93 = 0.400 and l_{vt}/l_f = 11.57 / 24.22 = 0.478

$$C_{vt} = \frac{S_{vt}}{S_w}\frac{l_{vt}}{b} = \frac{18.49}{75.26}\times\frac{11.57}{28.93} = 0.0983$$

Similar calculations were carried out for IPTN – N – 250 – 100, ATR-72-200 and Dash-8-Q300 airplanes which have T-tail configuration. The values of various parameters and the required quantities are included in Table 6.2 given below.

Designation	**XAC Y-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYU-SHIN Il-114**	**SAAB 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
				Wing				
Wing span(m)	28.93 (29.67 over winglets)	28.00	27.05	27.05	30.00	24.76	24.73	27.43
Wing gross area (m^2)	75.26	65.00	61.00	61.00	81.9	55.74	90.00	56.21
Aspect ratio	11.7	12.1	12	12	11	11		13.4
Wing chord at root c_r (m)	3.5	2.8	2.57	2.57				2.46*
Wing chord at tip c_t(m)	1.1	1.45	1.59	1.59				1.23*
Taper ratio c_t/c_r (wing)	0.31	0.52	0.62	0.62			0.36	0.50
Constant chord central section	Upto 0.25 of semi-span*	Upto 0.29 of semi-span*	Upto 0.36 of semi-span*					Upto 0.323 of semi-span*
Quarter chord sweep of outboard wing	6.9^{o}	4.8^{o}	3.1^{o}		3.1^{o}			3.6^{o}
$\bar{c}_w$ or $\bar{c}$ = mean aerodynamic chord of wing (m)	2.89	2.406	2.3					2.13
l_{ntacw} (m) $	9.91	11.30	11.39					10.67

* : Estimated value $: l_{ntacw} = location of the a.c. of wing from nose of fuselage

Table 6.2 Geometric and other parameters of wing, fuselage and empennage of similar airplanes (Contind..)

Designationn	XACY-7-100	IPTN-250-100	ATR-72-200	ATR-72-500	ILYU-SHIN Il-114	SAA-B 2000	ANTONOV AN-140	De Havilland Dash 8 Q300
Wing								
l_{ntacw} / l_f	0.409	0.422	0.419					0.437
Type of flap		Fowl-er flap	Two segme-nt double slotted	Two seg me-nt doub le slott ed		Single slotted		Fowler Flap
Fuselage								
Length of fuselage(l_f) (m)	24.22	26.78	27.17	27.17	26.88	27.28	22.61	24.43*
$l_{overall}$/l_f	1	1.05	1.0					1.06

Table 6.2 (Contd….)

Designationn	**XACY-7-100**	**IPTN-250-100**	**ATR-72-200**	**ATR-72-500**	**ILYU-SHIN Il-114**	**SAA-B 2000**	**ANTONOV AN-140**	**De Havilland Dash 8 Q300**
				Empennage				
Configuration	Con-ventio-nal	T-tail	T-tail	T-tail	Con-ventio-nal	Con-venti-onal	Con-ventio-nal	T-tail
H.tail area(m^2)	17.3	16.31	11.73	11.73		18.35		13.94
S_{ht} / S	0.23	0.25	0.19			0.33		0.248
H.tail span (m)	9.08	9.04	7.31 Elev-ator with horn balance		11.1	10.36		7.92 Elevator with horn bala-nce
H.tail aspect ratio (A_t)	4.77	5.01	4.56			5.85		4.5
Elevator area (m^2)	5.14	6.34	3.92	3.92				4.97
S_e / S_{ht}	0.30	0.39	0.33					0.36
Leading edge sweep($\Lambda_{h/e}$)	20^0*	6.8^0*	11.4^o*					9.5^0*
c_{rht} (m)	2.54*	2.34*	2.08*					2.7*
c_{tht} (m)	1.27*	1.27*	1.11*					1.45*
H.tail taper ratio	0.5	0.54	0.54				0.483	0.70
Mean aerodynamic chord of h.tail ($\bar{c}_t$) (m)	1.98	1.855	1.649					1.78
l_{ht} = dist. between wing a.c.and h.tail a.c.(m)	12.64	14.43	13.31					13.03
l_{ht} / l_f	0.522	0.539	0.49					0.533
$C_{ht} = \frac{S_{ht}}{S}\frac{l_{ht}}{\bar{c}_w}$	1.013	1.505	1.113					1.52
$l_{ht} / \bar{c}_w$	4.45	6.0	5.79					6.12

Table 6.2 (Contind…)

Designationn	XACY-7-100	IPTN-250-100	ATR-72-200	ATR-72-500	ILYUSHIN Il-114	SAAB 2000	ANTONOV AN-140	De Havilland Dash 8 Q300
Empennage (contd..)								
V.tail area (S_{vt}) (m^2)	18.49 (fin = 13.38)	14.72	16.48			13.01		14.12
S_{vt} / S	0.246	0.226	0.27			0.233		0.251
Rudder area (m^2)	5.11	4.41*	4.0					4.31
S_r / S_{vt}	0.276	0.3	0.243					0.31
Dorsal fin area (m^2)	2.88	3.08*	1.05*					2.64*
Leading edge sweep(Λ_{vle})	27^{o*}	31.3^{o*}	45.2£* (near root)					32^{o*}
c_{rvt} (m)	5.0*	3.3*	6.29*£					3.9*
c_{tvt} (m)	1.667*	2.2*	1.71*					2.73*
V.tail taper ratio	0.333	0.667	0.27£					0.70
V.tail height h_{vt} (m)	5.55*	5.36*	4.79*					4.26*
$A_{vt} = \frac{h^2_{vt}}{S_{vt}}$	1.67	1.95	1.392					1.285
$\bar{c}_{vt}$ (m)	3.61	2.787	4.052					3.35
l_{vt} (m)	11.57	13.49	10.16					11.25
l_{vt}/l_f	0.481	0.504	0.374					0.46
C_{vt}	0.0983	0.109	0.101					0.103
$\frac{l_{ht} - l_{vt}}{l_f}$	0.041	0.035	0.116					0.0729
$(l_{ht}-l_{vt})$ / b		0.0335	0.116					

£ Note the cranked shape of v.tail in Fig.6.7a

Table 6.2 Geometric and other parameters of wing, fuselage and empennage of similar airplanes

(Continued in Lecture 28)