

AE 451 Aeronautical Engineering Design I

Geometry Sizing & Configuration

Prof. Dr. Serkan Özgen
Dept. Aerospace Engineering
November 2015



Fuselage

- The fuselage must be large enough to contain the engine, the occupants and the fuel.
- Disadvantages of storing the fuel in the fuselage:
 - Safety of the occupants is risked,
 - If the fuel is stored in the wings, the shift in the CG of the airplane as the fuel is consumed is minimized $\Rightarrow$ it is preferable to design the wing with enough internal volume to hold the fuel.

Fuselage

- Size the fuselage according to the length, width and height of the engine (or diameter and length for a jet engine).
- There should be sufficient and comfortable space for the pilot(s) and the occupant(s).

Fuselage

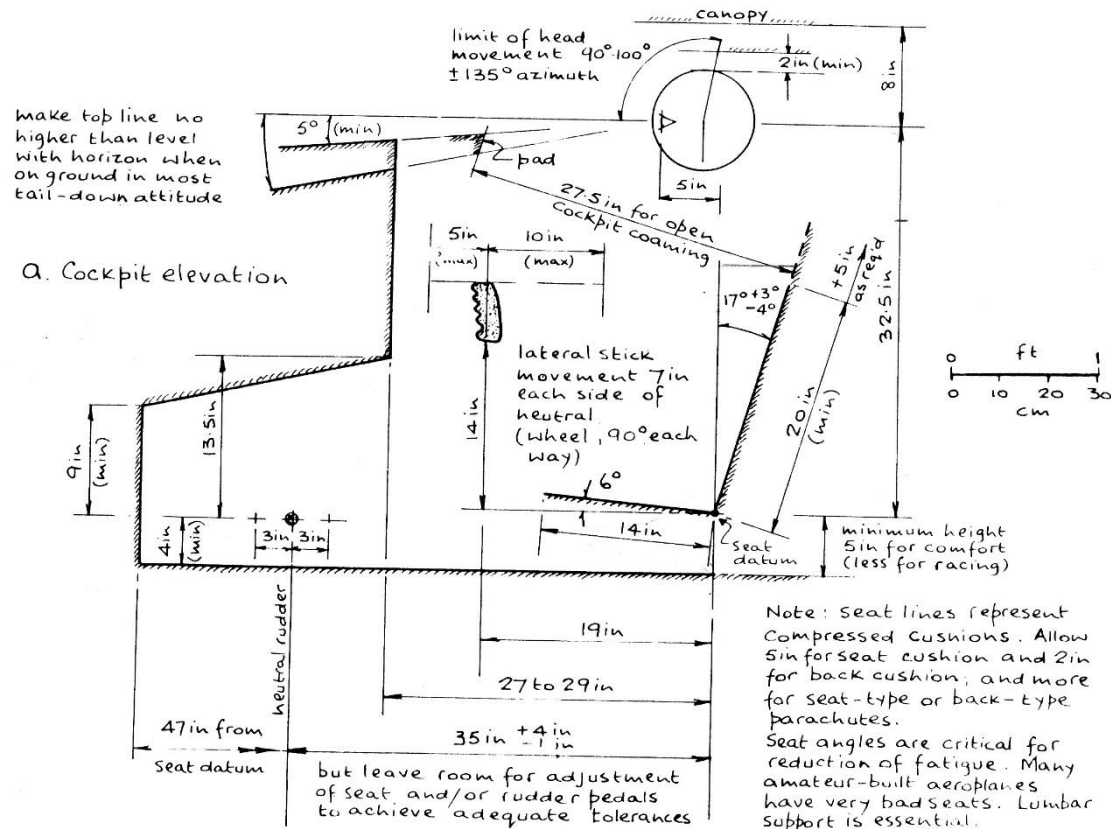
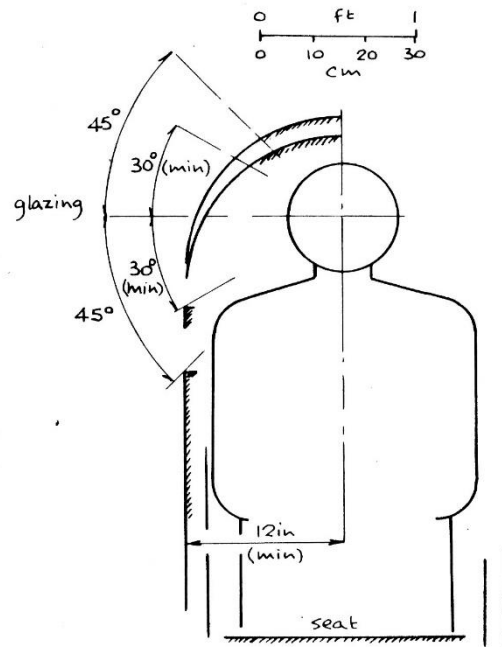


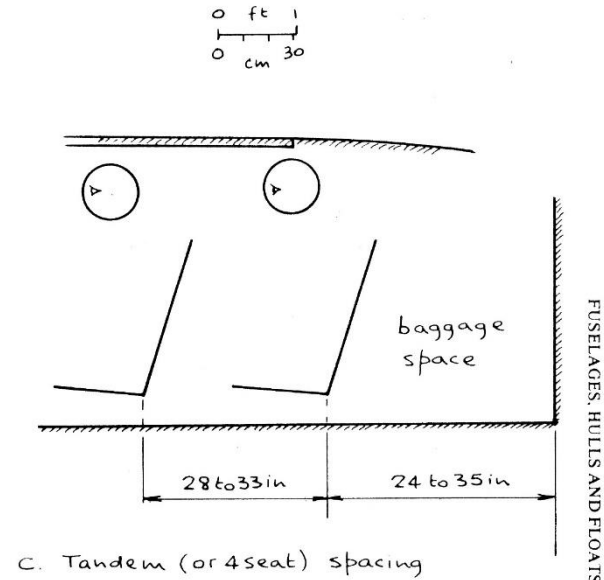
Fig. 9.3a Cockpit elevation.

Fuselage



b. Extent of glazing and cockpit sills to enable the pilot to look out sideways in 30° and 45° banked turns. It is essential to be able to look inwards during any turn, with an unobstructed view in the plane of a manoeuvre.

Fig. 9.3b and c Cockpit and cabin dimensions.



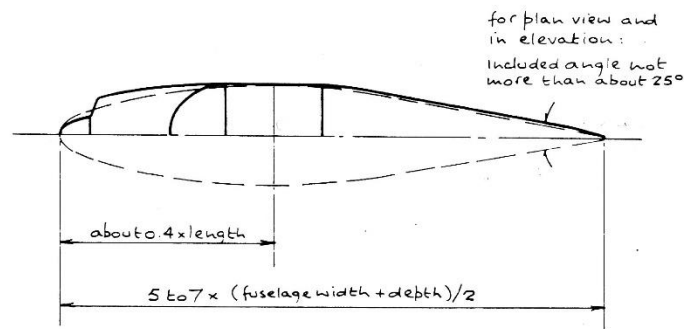
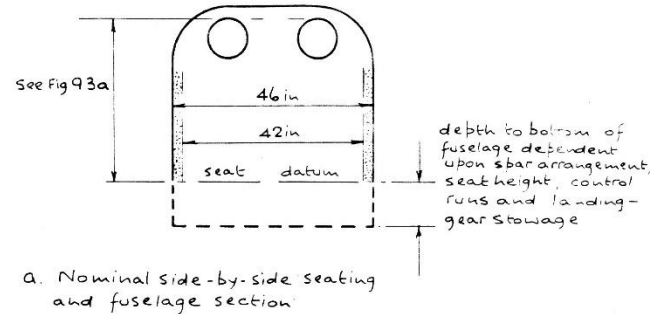
FUSELAGES, HULLS AND FLOATS

347

Fuselage

352

THE DESIGN OF THE AEROPLANE



- b. General planform of fuselage should have lines comparable with an aerofoil section. The same should be true for the side view, but this is much harder to achieve because of other considerations. The slope of surfaces towards the tail should not be too steep for the air to negotiate, so causing premature separation in normal flight. A Reynolds number and, hence, fuselage thickness ratio can be worked out using Fig 3.4.

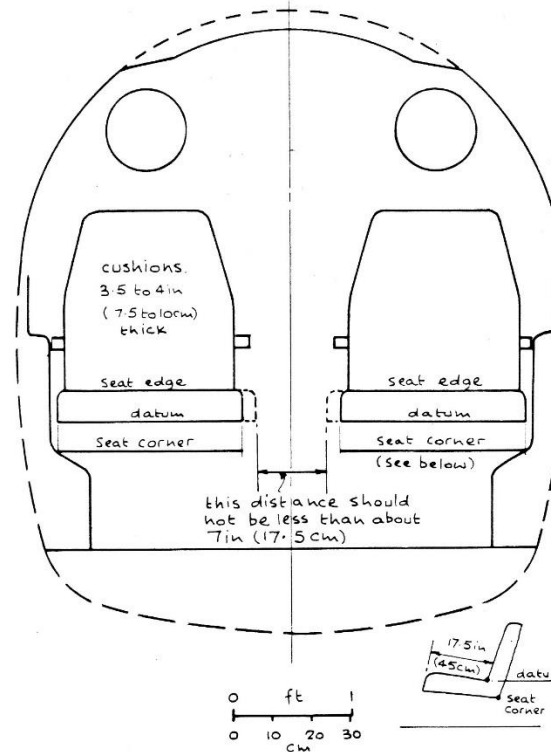
Fig. 9.5a, b and c Fuselage proportions and inboard profile.

Fuselage

FUSELAGES, HULLS AND FLOATS

353

Surrounding cockpit structure should be strong enough to resist penetrating the enclosed volume shown below. The floor and supporting structure should be able to resist deformation which, in turn, distorts the seats, causing injury.



c. Generalised inboard profile of cabin or cockpit section of light business-executive aeroplane.

Fig. 9.5c.

Fuselage

- The fairing at the rear of the fuselage must gently reduce to zero cross-section to minimize back pressure drag.
- For subsonic aircraft, the taper angle $< 15^\circ$, otherwise flow separation may occur.
- The length of the fuselage behind the CG should be long enough to provide sufficient moment arm for the horizontal and vertical tails.
- Historical data may be used as a first estimate:

$$l_f = aW_o^C$$

Fuselage

Table 6.3 Fuselage length vs W_0 (lb or {kg})

Length = aW_0^C (ft or {m})	a	C
Sailplane—unpowered	0.86 {0.383}	0.48
Sailplane—powered	0.71 {0.316}	0.48
Homebuilt—metal/wood	3.68 {1.35}	0.23
Homebuilt—composite	3.50 {1.28}	0.23
General aviation—single engine	4.37 {1.6}	0.23
General aviation—twin engine	0.86 {0.366}	0.42
Agricultural aircraft	4.04 {1.48}	0.23
Twin turboprop	0.37 {0.169}	0.51
Flying boat	1.05 {0.439}	0.40
Jet trainer	0.79 {0.333}	0.41
Jet fighter	0.93 {0.389}	0.39
Military cargo/bomber	0.23 {0.104}	0.50
Jet transport	0.67 {0.287}	0.43

Wing

- Wing location with respect to the fuselage is determined by:
 - Wing incidence,
 - Dihedral,
 - Wing vertical location.

Wing

- Wing incidence: is the pitch angle of the wing with respect to the fuselage.

For an untwisted wing, incidence is the angle between the fuselage axis and the wing chord.

If the wing is twisted, incidence is the angle between the fuselage axis and the chord of the root section of the exposed wing.

Wing incidence angle is chosen to minimize drag at some operating condition, usually cruise.

The incidence is chosen such that when the wing is at correct angle of attack for the selected design condition, the fuselage is at the correct angle of attack for minimum total drag.

For a circular, straight fuselage, this is a few degrees nose-up, allowing fuselage to contribute to lift.

Wing

- Typical incidence values for untwisted wings:
 - General aviation and homebuilt: 2°
 - Transport aircraft: 1°
 - Military aircraft: 0°

For twisted wings, average incidence should equal these values.

Wing

- Dihedral: is the angle of the wing with respect to the horizontal when seen from the front.

Positive (tips higher) dihedral provides a strong roll stiffness. Wing sweep also produces a stabilizing roll moment.

Roughly, 10° sweep $\approx 1^\circ$ dihedral.

The position of the wing on the fuselage also has an influence on the effective dihedral, the greatest effect provided by a high wing.

The stabilizing effect of wing sweep and position may be so strong that, negative dihedral may be necessary like in most military transports.

Wing



© Deltaweb



MIDDLE EAST TECHNICAL UNIVERSITY

Wing

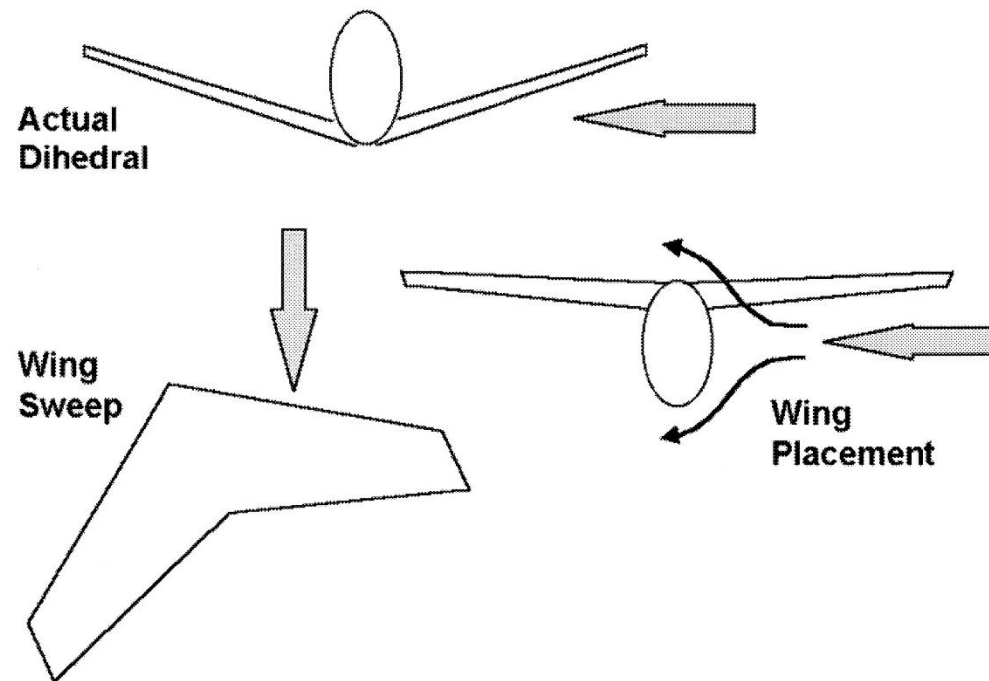


Fig. 4.25 Increased angle of attack and lift.

Wing

Table 4.2 Dihedral guidelines

	Wing position		
	Low	Mid	High
Unswept (civil)	5 to 7	2 to 4	0 to 2
Subsonic swept wing	3 to 7	-2 to 2	-5 to -2
Supersonic swept wing	0 to 5	-5 to 0	-5 to 0

Wing

- Wing vertical location:
 - i. High wing configuration: major benefit of a high wing is that it simplifies loading and unloading for a military transport airplane with minimum ground handling equipment.

With a high wing configuration, jet engines and propellers will have sufficient ground clearance without high landing gears and the associated weight.

There is a structural benefit because the wingbox is carried over the top of the fuselage rather than passing through it.

Wing



Wing

- The fuselage weight is heavier since it must be strengthened to support the landing gear loads.
- The fuselage is flattened at the bottom, which is heavier than the optimal circular cross-section.

Wing

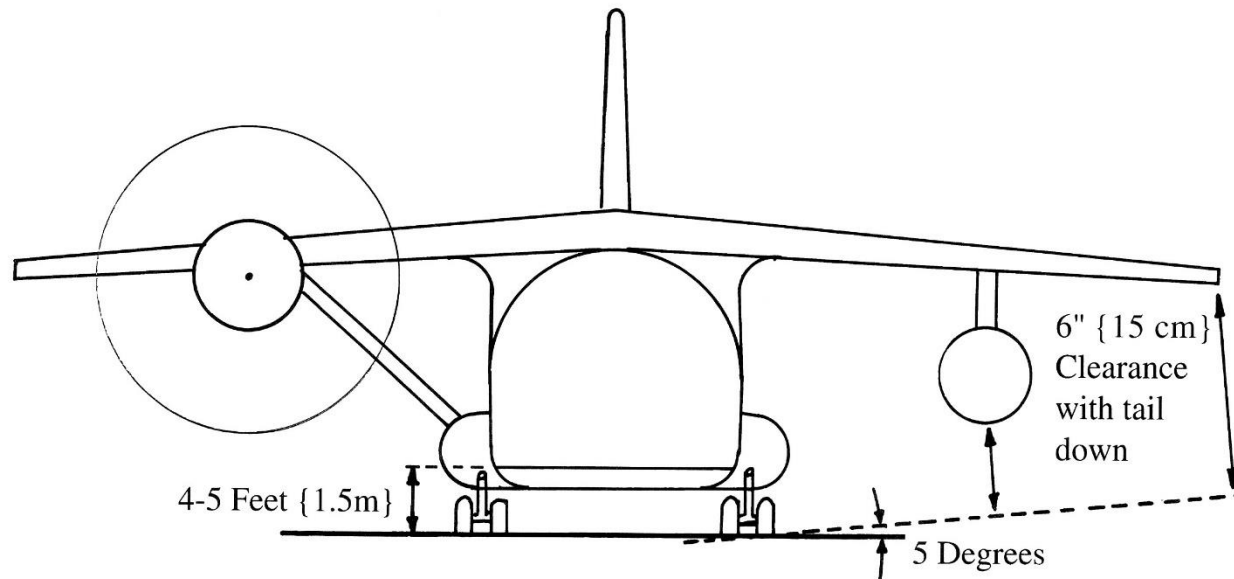


Fig. 4.26 High wing.

Wing

- Wing vertical location:
 - ii. Mid-wing configuration: produces the lowest drag of the three configurations because of reduced wing-body interaction.

High and low wing configurations require fillets to decrease interference drag.

Mid-wing is the most advantageous configuration for aerobatic maneuvering (inverted flight).

Wing

A major disadvantage is structural:

- The bending moment of the wing must be carried by the fuselage, which must be stiffened $\Rightarrow$ extra weight.
- The bending moments can be transmitted accross the fuselage by a series of heavy ring frames or bulkheads, which increase the empty weight of the aircraft.

Wing



Wing

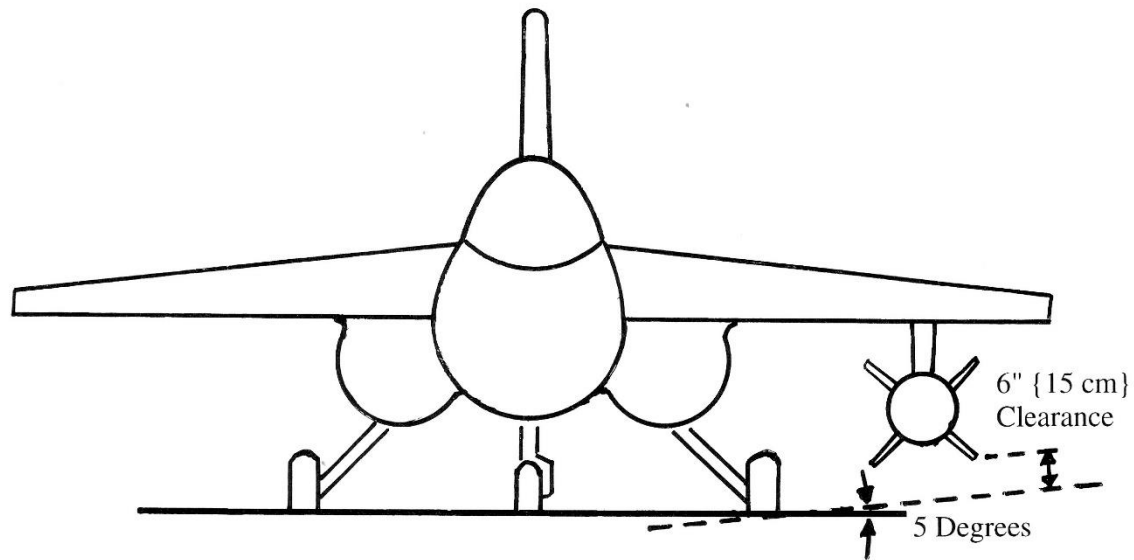


Fig. 4.27 Mid wing.

Wing

- Wing vertical location:

iii. Low-wing configuration: major advantage is in the design of the landing gear. The landing gear is attached and retracted into the wing, which is structurally the strongest component of the airplane.

Disadvantages:

- Fuselage requires some ground clearance for the engines and propellers $\Rightarrow$ the landing gear must be designed longer and heavier.
- For lateral stability, low wing configurations need dihedral. This may require an increase in vertical tail size in order to avoid Dutch-roll.
- Undesirable aerodynamic interference at the wing-body interface. A fillet is required to reduce this effect.

Wing



Wing

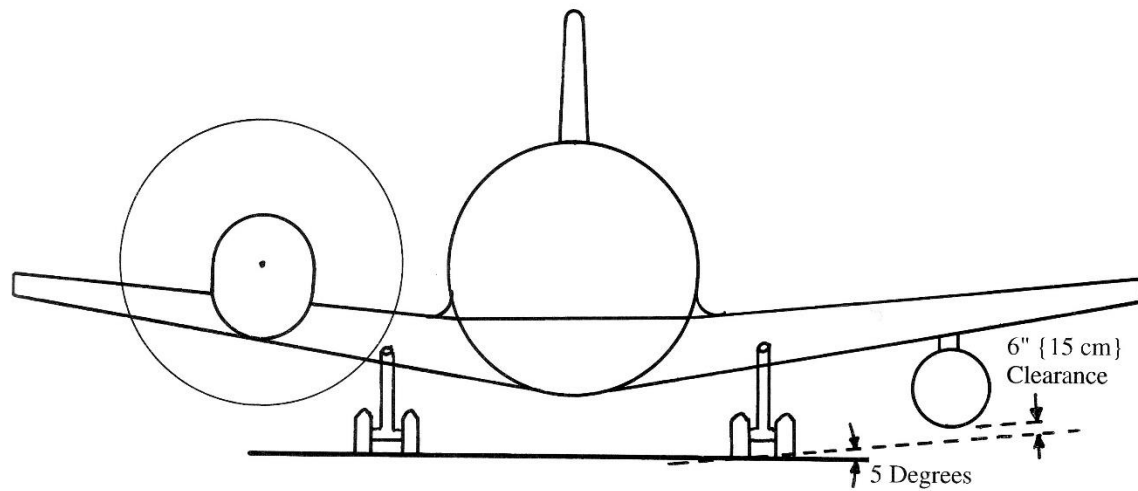


Fig. 4.28 Low wing.

Tail arrangement and sizing

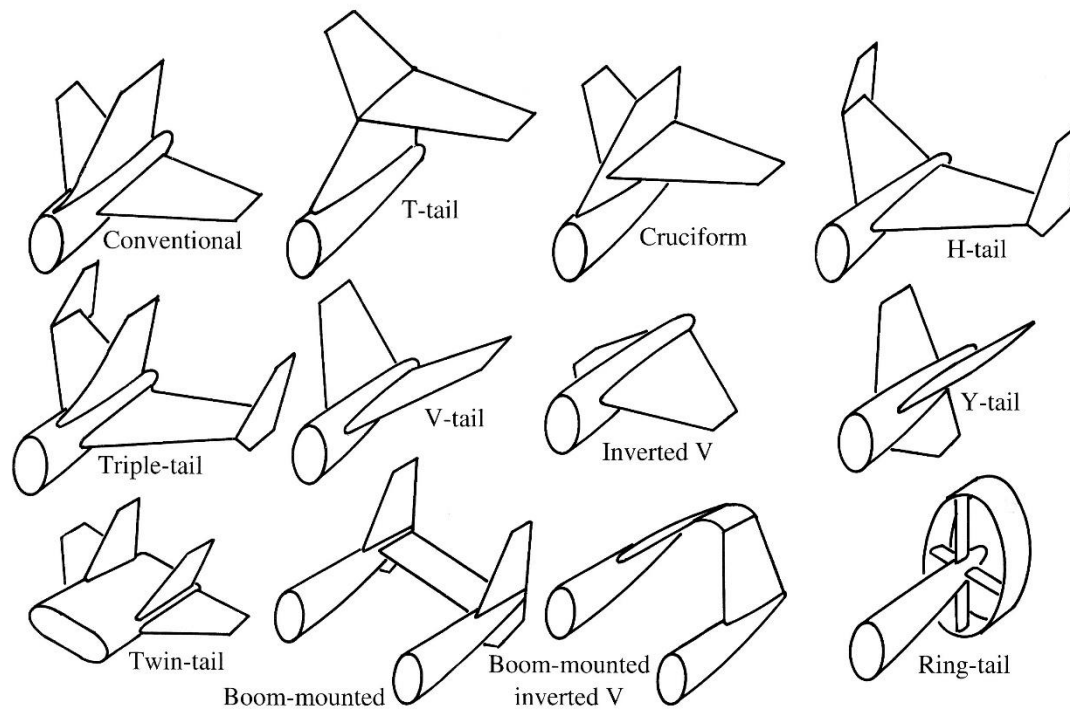


Fig. 4.30 Aft tail variations.

Tail arrangement and sizing

- Conventional tail: provides adequate stability and control at low weight. However, the horizontal tail must be positioned behind the vertical so that its wake does not mask the rudder at high α , important for spin recovery. As a rule of thumb, 1/3 of the rudder area should be out of the wake.

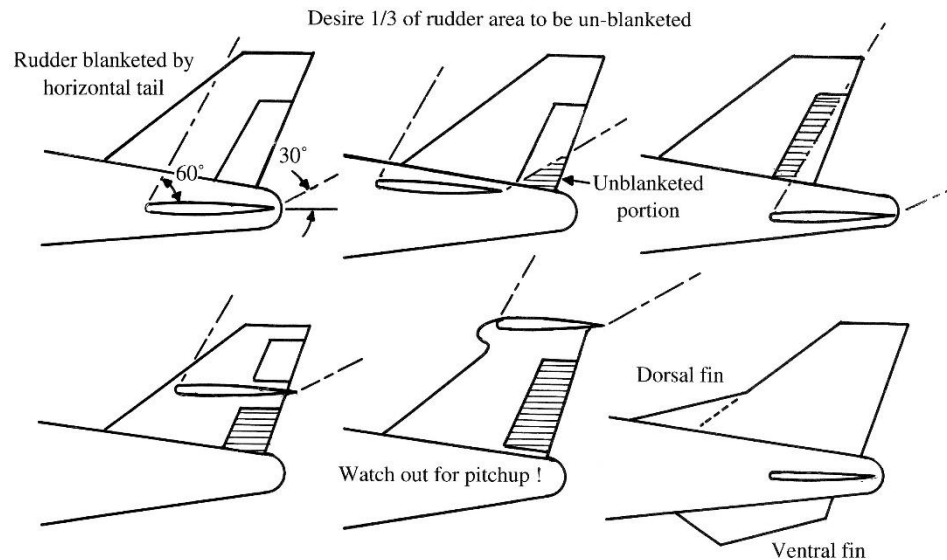


Fig. 4.33 Tail geometry for spin recovery.

Tail arrangement and sizing

- T-tail: is heavier than a conventional tail because the vertical tail must be strengthened to support the horizontal tail. Due to endplate effect, induced drag is less and the vertical tail can be sized smaller.

Tail arrangement and sizing

- The location of the horizontal tail w.r.t. wing is critical for the stall characteristics. If the tail remains in the wing wake during stall, control will be lost and pitch-up may be encountered (deep stall).

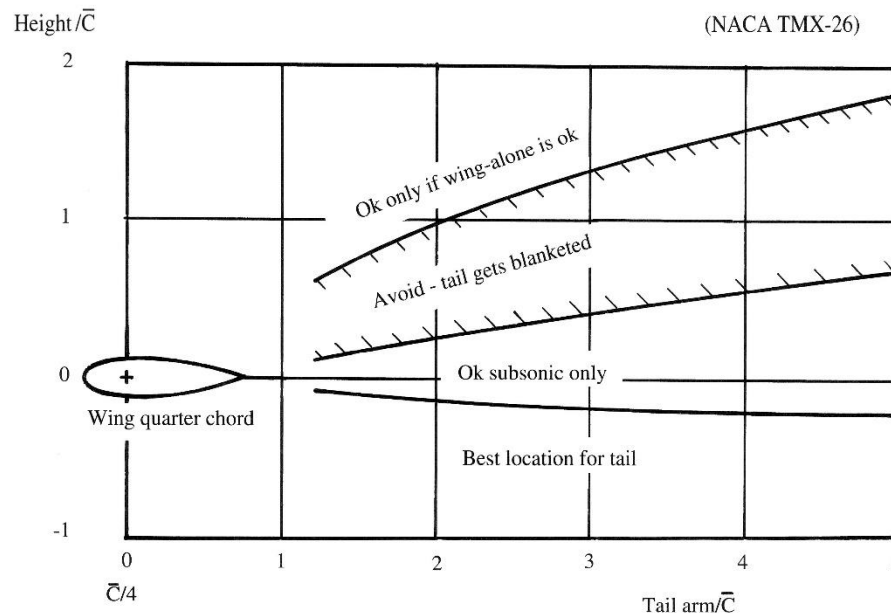


Fig. 4.31 Aft tail positioning.

Tail arrangement and sizing

- Cruciform tail: is a compromise between a conventional tail and a T-tail.

It avoids proximity to jet exhausts or exposes the lower part of the rudder to undisturbed air during high α flight or spins.

- An H-tail is used to position vertical tails in undisturbed air during high α flight or to position the rudders in the propwash in order to increase their effectiveness.

It is heavier than a conventional tail but the endplate effect results in a lighter horizontal tail.

Tail arrangement and sizing

- In a V-tail, the wetted area is reduced.

In theory, horizontal and vertical tail surfaces are found from the Pythagorean theorem. Research shows that the total wetted area of a V-tail is the same as that for separate horizontal and vertical tails.

- When the right rudder pedal in a V-tail is pressed, the right «ruddervator» deflects downward and the left ruddervator deflects upward.

The resulting force pushes the tail to the left and the nose to the right as desired.

However, the same force produces a roll moment towards the left $\Rightarrow$ adverse roll-yaw coupling.

Tail arrangement and sizing

- In an inverted V-tail, the adverse roll-yaw coupling problem is solved.
- In a Y-tail, the additional surface contains the rudder, while V surfaces provide only pitch control.

Avoids the complexity of the ruddervators and reduces the interference drag compared to the conventional tail.

Tail arrangement and sizing

- Twin tails position the rudders away from the aircraft centerline avoiding being blanketed by the wing or the fuselage at high α .

Twin tails reduce the height of the vertical tail. Twin tails are usually heavier than conventional tails but are often more effective.

- Other configurations like control-canard, lifting canard, tandem wing, flying wing are also possible.

Tail arrangement and sizing

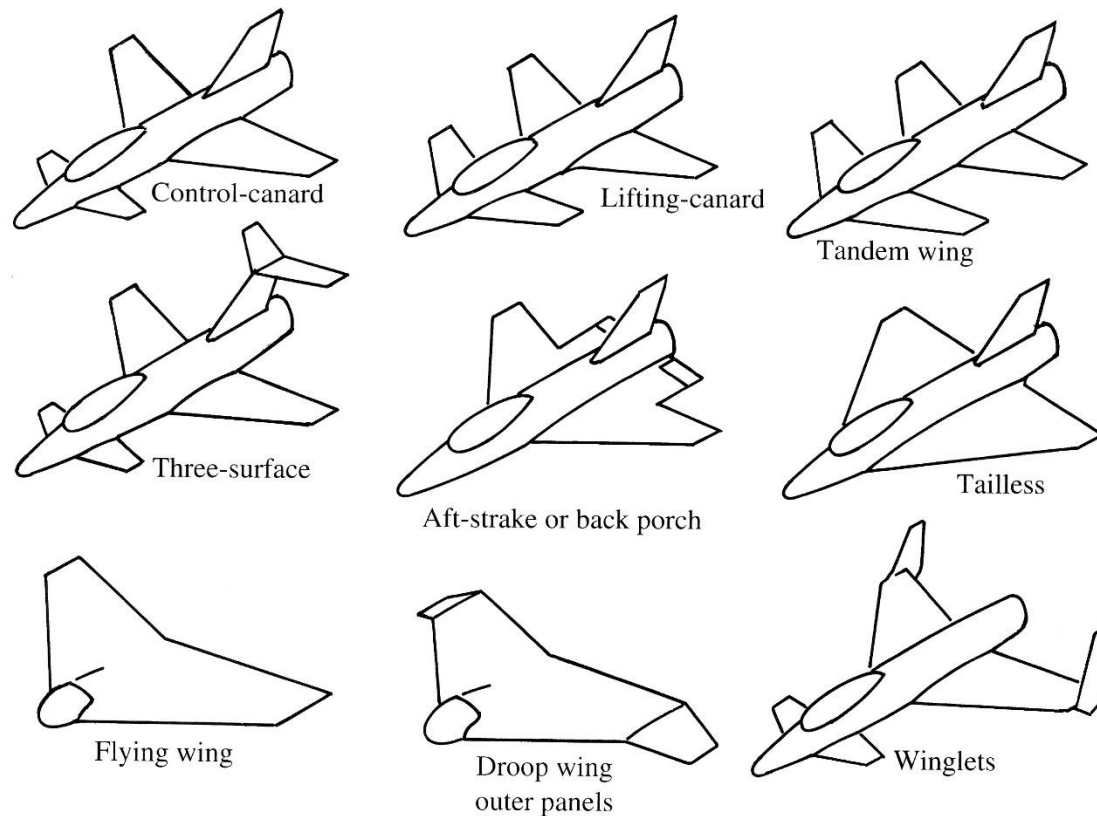


Fig. 4.32 Other tail configurations.

Tail arrangement and sizing



Tail arrangement and sizing



Tail volume ratio

- Horizontal tail volume ratio:

$$V_{HT} = \frac{l_{HT} S_{HT}}{\bar{c} S}$$

- Vertical tail volume ratio:

$$V_{VT} = \frac{l_{VT} S_{VT}}{b S}$$

Tail volume ratio

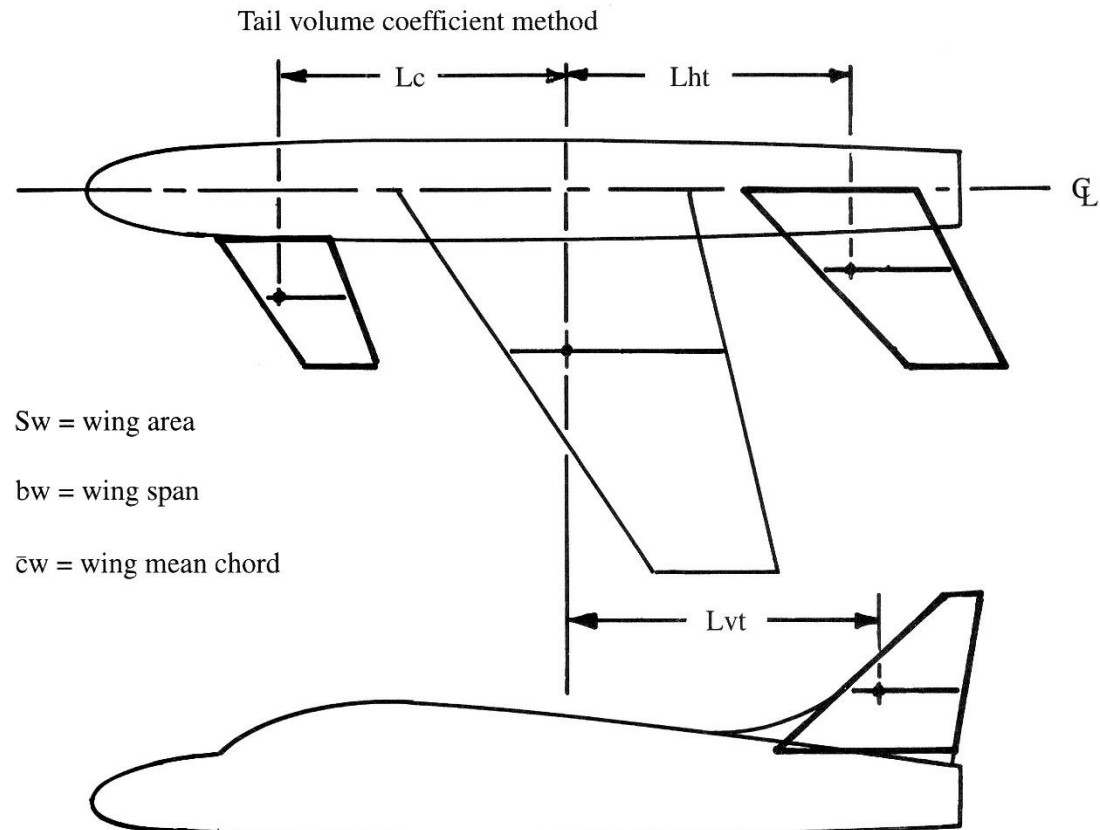


Fig. 6.2 Initial tail sizing.

Tail volume ratio

Table 6.4 Tail volume coefficient

	Typical values	
	Horizontal c_{HT}	Vertical c_{VT}
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
General aviation—single engine	0.70	0.04
General aviation—twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

Tail volume ratio

- Moment arm for different configurations:
 - Front mounted propeller engines: $0.6l_f$,
 - Aircraft with wing mounted engines: $0.5 - 0.55l_f$,
 - Aft mounted engines: $0.45 - 0.5l_f$,
 - Sailplane: $0.65l_f$,
 - Canard: $0.3 - 0.5l_f$.

Tail volume ratio

- For an all-moving tail, the volume coefficient can be reduced by about 10-15%.
- For T-tail, the vertical tail volume coefficient can be reduced by 5% due to endplate effect.
- For H-tail, horizontal tail volume coefficient can be reduced by 5% due to endplate effect.
- In a V-tail, the required horizontal and vertical tail sizes can be estimated normally. Then the V-surfaces are sized to provide the same total surface area.

$$\Lambda_{HT} = \tan^{-1} \frac{S_{VT}}{S_{HT}} \approx 45^\circ.$$

Tail volume ratio

- For control type canards $V_{HT} \approx 0.1$.
- For lifting canard aircraft, tail volume ratio method does not work. Approximately, 25% of total wing area is the canard, 75% is the wing.

Tail volume ratio

Methodology to size the horizontal (and vertical) tail:

- Locate the mean aerodynamic center of the horizontal tail with respect to the wing.
- Calculate S_{HT} .
- Unlike the wings, aerodynamic forces generated by the tail surfaces are small, they only need to be large enough to maintain stability and control
- $\Rightarrow$ no need to use a cambered airfoil, use symmetric airfoils like NACA 0009, 0012, 0015 or biconvex airfoils, etc.

Tail aspect ratio

- Low AR wings stall at higher angles of attack compared to those with high AR.

If the tail has a lower AR compared to wings, even when the wing stalls, horizontal tail will still have attached flow and control authority $\Rightarrow$ use a lower AR than the wing.

- Taper ratios and sweep angles are usually chosen close to those of the wing.

Tail aspect ratio

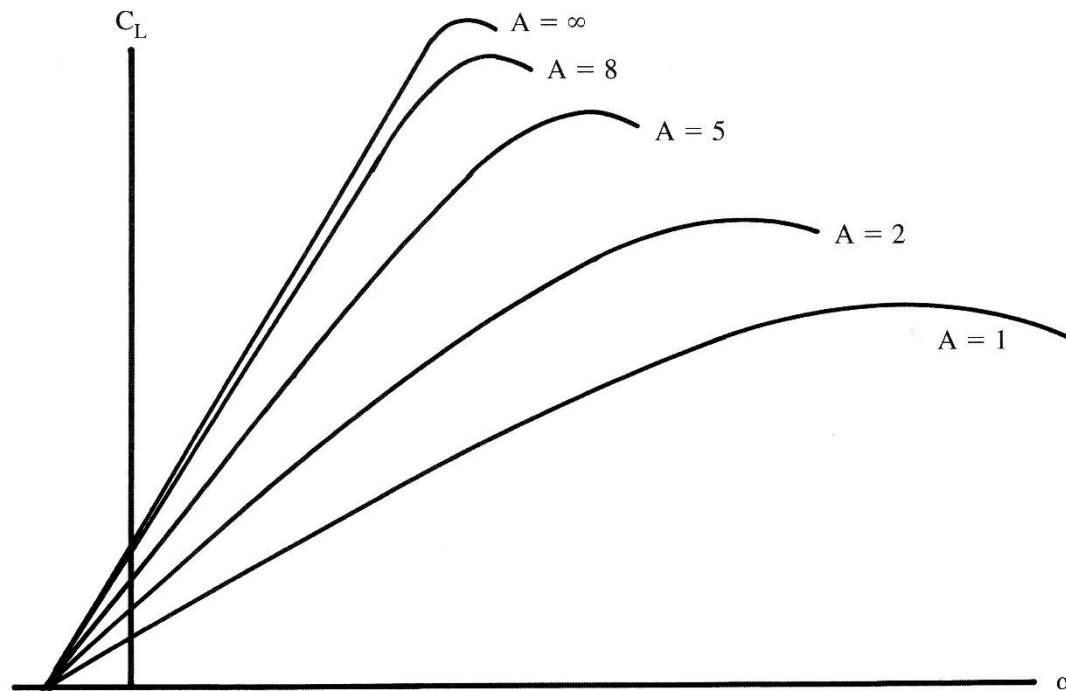


Fig. 4.19 Effect of aspect ratio on lift.

Tail aspect ratio and taper ratio

Table 4.3 Tail aspect ratio and taper ratio

	Horizontal tail		Vertical tail	
	A	λ	A	λ
Fighter	3–4	0.2–0.4	0.6–1.4	0.2–0.4
Sail plane	6–10	0.3–0.5	1.5–2.0	0.4–0.6
Others	3–5	0.3–0.6	1.3–2.0	0.3–0.6
T-Tail	–	–	0.7–1.2	0.6–1.0

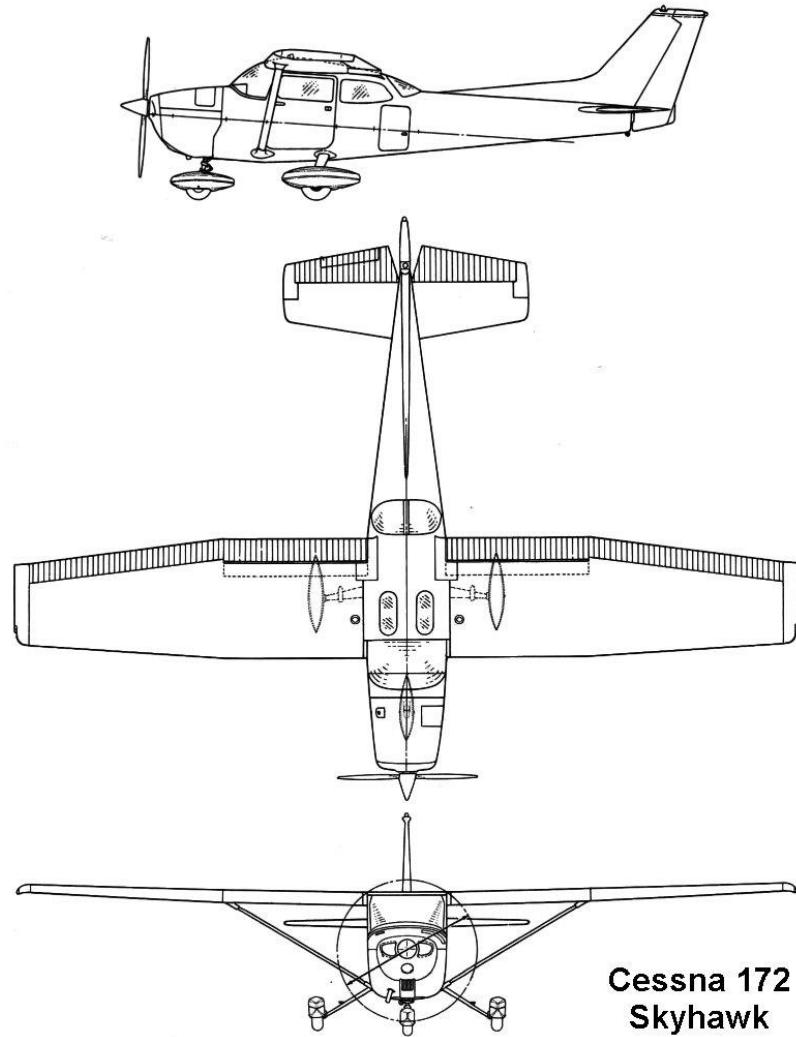
Vertical tail

- The vertical tail is sized in the same way, except that the aspect ratio is defined differently.
- Leading edge sweep of the horizontal tail is usually 5° more than the wing sweep.

This makes the tail stall after the wing and increases the critical Mach number of the tail, eliminating the loss of elevator effectiveness due to shock formation and flow separation.

- For low speed airplanes, the horizontal tail sweep is such that the elevator has a straight hinge line.
- Vertical tail sweep is between 35° - 45° .

Tail sizing



CG estimation methodology

- The major weight components that we know the weight or size: engine, crew, wing, fuselage, payload, tail surfaces.
- Methodology:
 - Calculate the effective CG of the engine, crew, payload and fuselage. Take the engine weight as the weight with accessories lubricants, etc., not the dry weight.

$$W_{\text{engine}} = 1.3 - 1.4 * W_{\text{engine,dry}}$$

- Locate the mean aerodynamic center of the wing close to the CG of the airplane.

CG estimation methodology

- Estimate the weight of the wing as a function of geometry, g-limit, etc.

Wing mean aerodynamic center is at 25% of the mean aerodynamic chord measured from the leading edge.

Wing CG is $\approx 40\%$ of mean aerodynamic chord.

- Find a new cg location for the airplane, adding the weight of the wing to the previous calculations.



CG estimation methodology

Table 15.2 Approximate empty weight buildup

Item	Fighters		Transports and bombers		General aviation		Multiplier	Approximate location
	lb/ft ²	{kg/m ² }	lb/ft ²	{kg/m ² }	lb/ft ²	{kg/m ² }		
Wing	9.0	{44}	10.0	{49}	2.5	{12}	$S_{\text{exposed planform}}$	40% MAC
Horizontal tail	4.0	{20}	5.5	{27}	2.0	{10}	$S_{\text{exposed planform}}$	40% MAC
Vertical tail	5.3	{26}	5.5	{27}	2.0	{10}	$S_{\text{exposed planform}}$	40% MAC
Fuselage	4.8	{23}	5.0	{24}	1.4	{7}	$S_{\text{wetted area}}$	40–50% length
Landing gear ^a	0.033	—	0.043	—	0.057	—	TOGW	—
	Navy: 0.045	—						
Installed engine	1.3	—	1.3	—	1.4	—	Engine weight	—
“All-else empty”	0.17	—	0.17	—	0.10	—	TOGW	40–50% length

^a15% to nose gear; 85% to main gear.

WEIGHTS

Wetted area determination - wing

- The exposed planform area of the wing is to be considered.

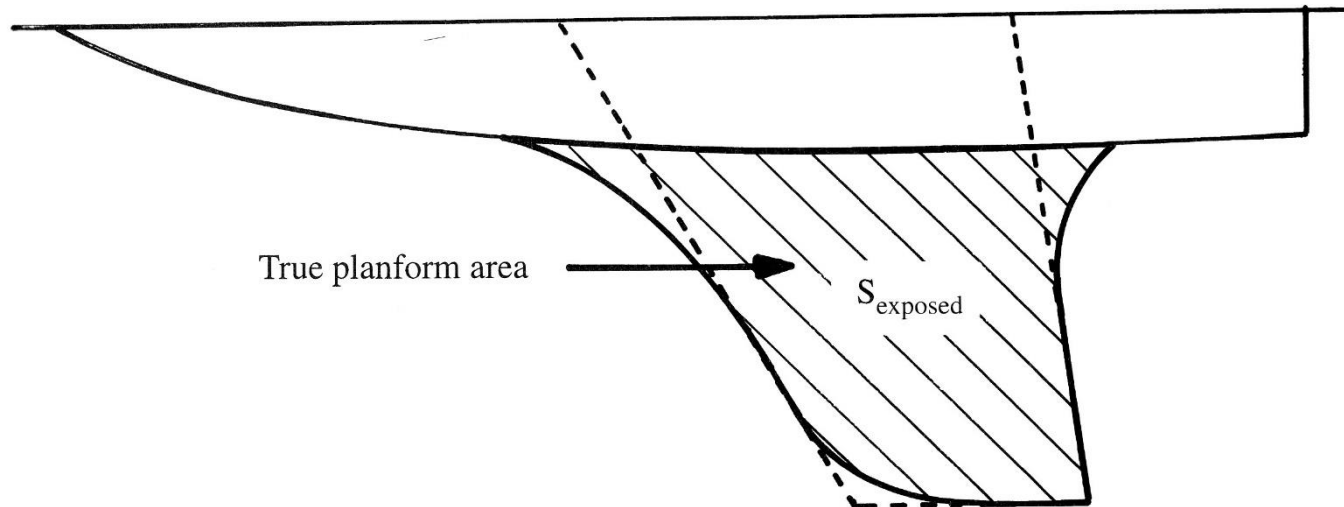


Fig. 7.35 Wing/tail wetted area estimate.

Wetted area determination - wing

- $S_{exposed} = \frac{S_{exposed,planview}}{\cos\Gamma}$, Γ : dihedral angle of the wing
- If $t/c < 5\%$: $S_{wet} = 2.003S_{exposed}$
- If $t/c > 5\%$: $S_{wet} = S_{exposed}[1.977 + 0.52(t/c)]$

Wetted area determination - fuselage

- As an approximate method, S_{wet} can be estimated by using only the side and top views of the fuselage.

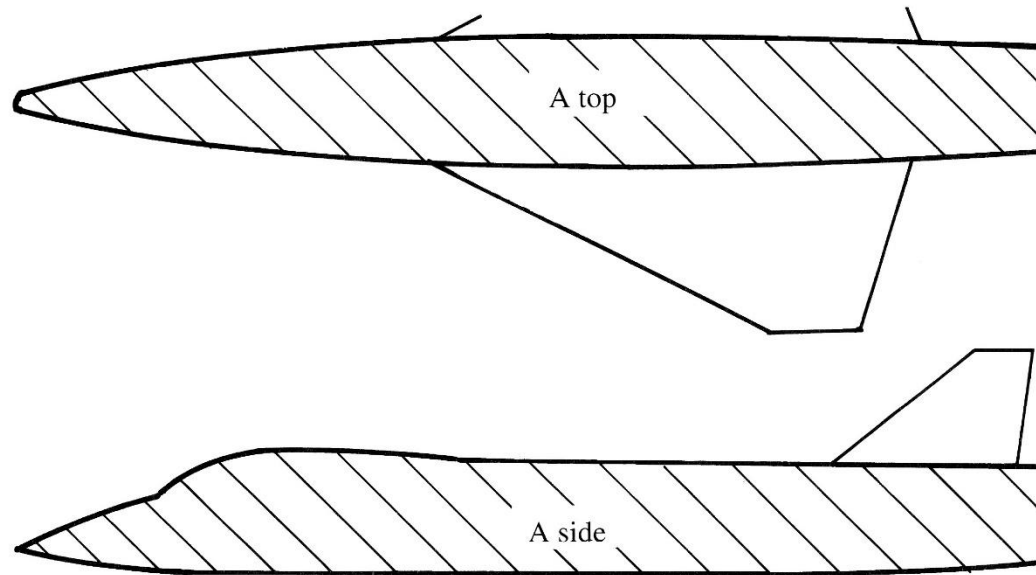


Fig. 7.36 Quick fuselage wetted area estimate.

Wetted area determination - fuselage

- $S_{wet} \approx 3.4 \left(\frac{A_{top} + A_{side}}{2} \right)$
- Fuselage volume can be determined in the same way:
- $V \approx 3.4 \left(\frac{A_{top} + A_{side}}{4l_f} \right)$

CG estimation methodology

cg estimation					
Item	W	x	z	xW	zW
Wing	1056	16,615	3,6	17545,44	3801,6
Fuselage	958,6	15,85	4,7	15193,81	4505,42
Engine	1217	4,5	4,74	5476,5	5768,58
Student pilot	198,2	13	5,5	2576,6	1090,1
Instructor pilot	198,2	17	6	3369,4	1189,2
Baggage	44	19	6	836	264
Fuel	640	15,77	3,6	10092,8	2304
Landing gear	218	14,586	1,4	3179,748	305,2
Horizontal tail	128	29,49	5,96	3774,72	762,88
Vertical tail	79,6	28,56	8,75	2273,376	696,5
All else empty	942,4	22,19	4,4	20911,86	4146,56
	5680			85230,25	24834,04
x_cg=	15,00533				
z_cg=	4,37219				

Control surface sizing

- Primary control surfaces: ailerons (roll), elevator (pitch), rudder /yaw).
- Typically, ailerons extend from 50-90% of span.

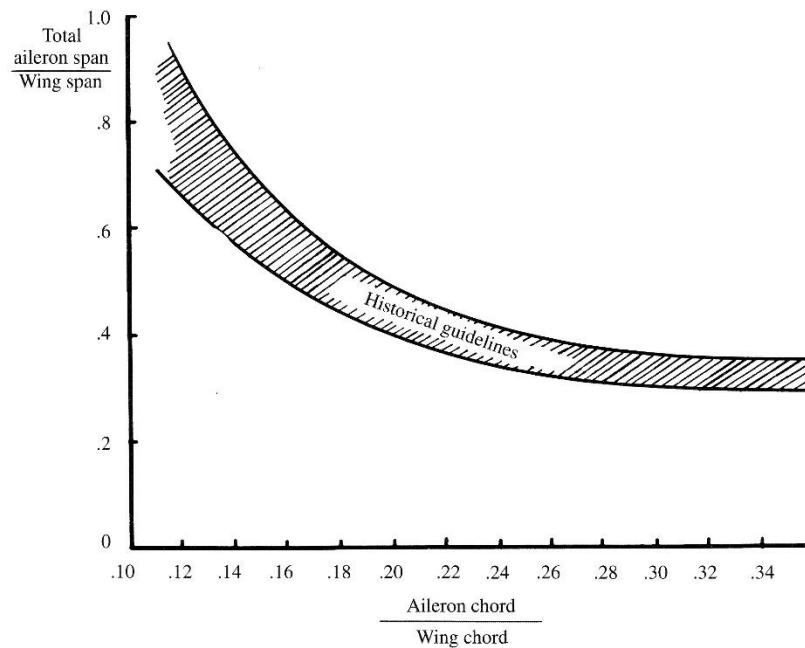


Fig. 6.3 Aileron guidelines.

Control surface sizing

- Wing flaps are inboard of the ailerons. For high $C_{L,max}$, flap span should be as large as possible $\Rightarrow$ use spoilers for roll control.
- Spoilers are located at the top of the wing, just aft of the maximum thickness point. Spoilers reduce lift, add drag.
- In order to avoid aileron reversal, inboard ailerons or rolling tails may be used.
- Elevators and rudders span 90% of the span of the respective surface.
- Control surfaces are usually tapered in chord by the same ratio as their respective surfaces.

Control surface sizing

- Ailerons and flaps are typically 15-25% of wing chord, rudders and elevators are about 25-50% of the tail chord.

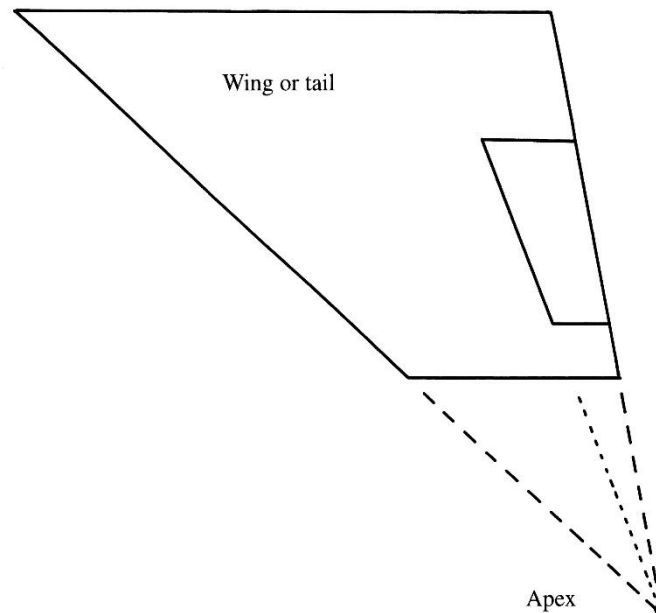


Fig. 6.4 Constant-percent chord control surface.

Control surface sizing

- Aerodynamic balancing can minimize flutter.
- The hinge axis should not be further aft than about 20% of the average chord of the control surface.

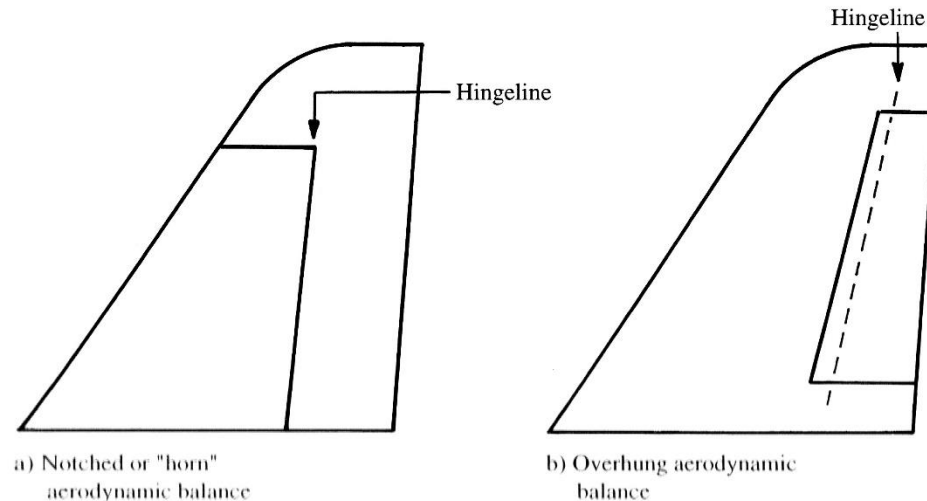


Fig. 6.5 Aerodynamic balance.

Control surface sizing

- The horizontal tail for a manually controlled airplane usually has a hinge line perpendicular to the airplane centerline.
- All moving tails are common for supersonic airplanes, where it can be used to trim the rearward shift of the aerodynamic center and to avoid control surface reversal.