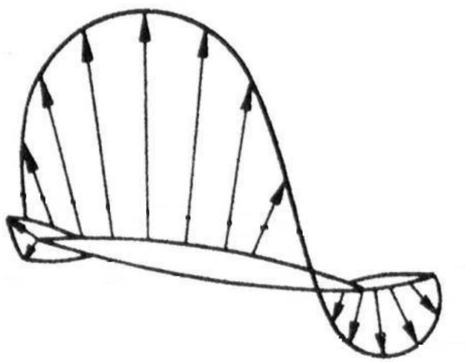
Aircraft Design I
Tail loads

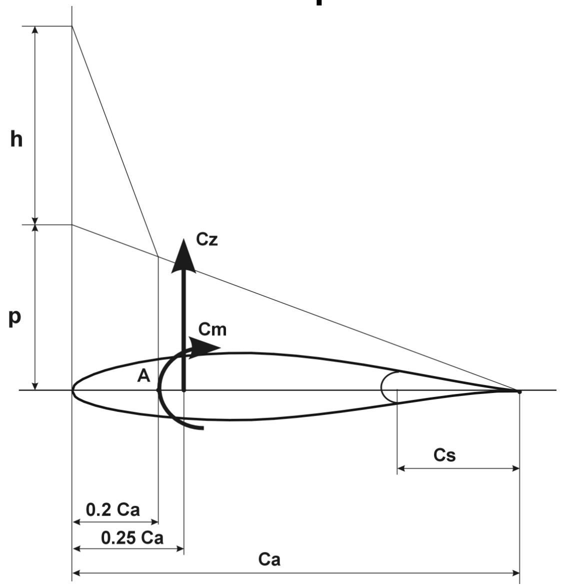
Horizontal tail loads

- What is the source of loads ?
- How to compute it ?
- What cases should be taken under consideration?

Tail – small wing but strongly deflected



Hot to compute it ?



Linearized pressure distribution on the not deflected airfoil (clean configuration)

Hot to compute it ?

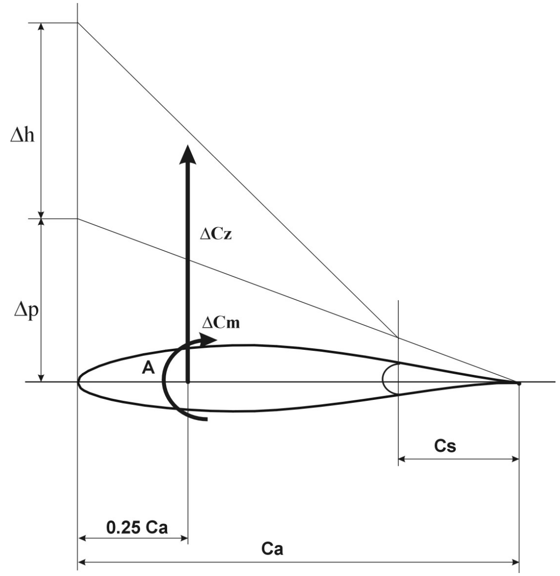
Assuming unit chord length the we obtain the following formulas to compute *p* and *h*

$$p = \frac{1}{8} q (11 C_z - 60 C_m)$$
$$h = \frac{1}{8} q (25 C_z + 300 C_m)$$

where:

q – dynamic pressure ($0.5\ \rho V^2$)

Hot to compute it ?



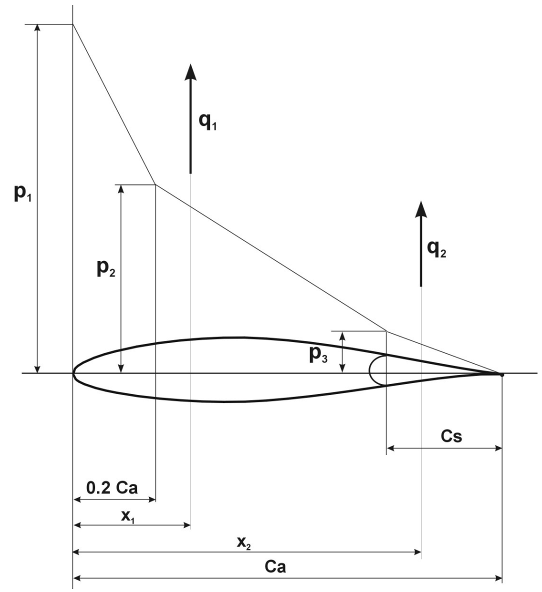
Linearized pressure distribution on the deflected airfoil

Hot to compute it ?

If the control surface chord ratio is $\varphi = C_S/C_a$ and increments of the lift and pitching moment due to control surface deflection are ΔC_z and ΔC_m the following formulas are obtained:

$$\Delta p = \frac{q}{2\varphi}\left[(4\varphi - 1)\Delta C_z - 12\,\Delta C_m\right]$$
$$\Delta h = \frac{q}{2\varphi(1-\varphi)}(\Delta C_z + 12 \Delta C_m)$$

Hot to compute it ?



Hot to compute it ?

Values p_1, p_2, p_3 are the results of summing of distributions from previous slides:

$$p_1 = (p + \Delta p) + (h + \Delta h)$$

$$p_2 = 0.8(p + \Delta p) + \frac{0.8 - \varphi}{1 - \varphi}\Delta h$$

$$p_3 = \varphi(p + \Delta p)$$

The loads (forces) q_1, q_2 and their coordinates x_1, x_2 can be derived from the following relations:

$$q_1 = \frac{1}{10}[p_1 + 5p_2(1-\varphi) + p_3(4 - 5\varphi)]$$

$$q_2 = \frac{1}{2}\varphi\, p_3$$

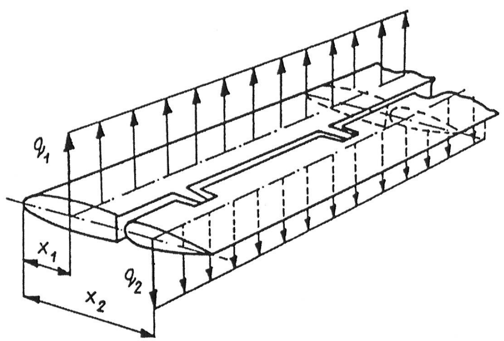
$$x_1 = \frac{1}{150\, q_1}\left[p_1 + 2p_2 + 15(0.8-\varphi)(p_2 + p_3) + 25(0.8-\varphi)^2(p_2 + 2p_3)\right]$$

$$x_2 = 1 - \frac{2}{3}\varphi$$

Remarks:

The linearized pressure distribution is not good to compute the hinge moments. The force acting on the control surface is closer than x_2 to rotation axis in fact. However the torque (torsion moment) computed in this way is greater only a little and the structure is heavier not much.

Load distribution



Aerodynamic load of a horizontal tail:
q_1 – continuous load of a tailplane,
q_2 – continuous load of an elevator,
x_1, x_2 – coordinates of the loads

What is the source of the loads?

To derive the critical cases to size the horizontal tail, the following sources should be taken into account:

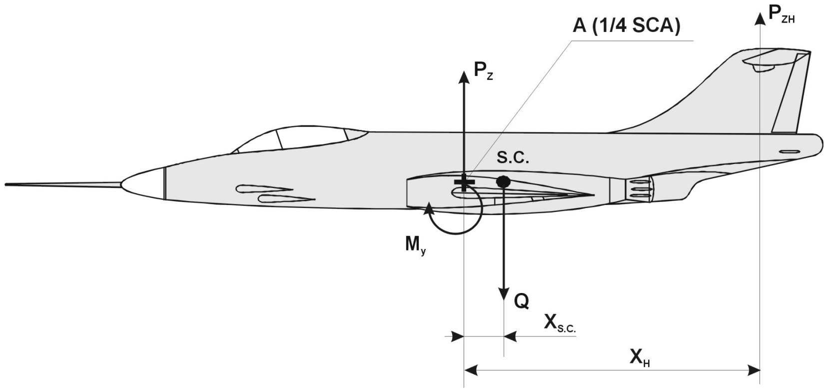
- loads to satisfy equilibrium,
- loads due to control,
- loads due to gusts,
- nonsymmetrical loads (sideslip, propeller downwash, etc.)

The analysis of such cases depends on the regulations.

Generally, we have to compute:

- lift coefficient due to angle of attack on the horizontal tail,
- lift coefficient increment due to elevator deflection ,
- pitching moment coefficient due to angle of attack on the horizontal tail,
- pitching moment coefficient increment due to elevator deflection ,
- hinge moments

Equilibrium problem



$$\sum M_{SC} = M_Y + P_Z x_{SC} - P_{ZH}(x_H - x_{SC}) = 0$$

Loads to satisfy equilibrium

This load of tailplane is required to satisfy equilibrium conditions during straight level flight, with constant airspeed. This load (angle of attack, elevator deflection and lift and pitching moment coefficients) have to be computed for all characteristic points of flight envelope V_A, V_F, V_C, i V_D. These loads are only initial to compute other cases.

The results should be:

- angle of attack on the tailplane (α_H)
- elevator deflection (δ_H),
- lift force coefficient ($a_1\alpha_H$) on the tail due to angle of attack,
- lift force coefficient increment ($a_2\delta_H$) due to elevator deflection,

Manoeuvring loads

Manoeuvring loads are computed according to the following criteria defined in regulations:

- max. control forces (eg. CS 23.397),
- max. pitching accelerations (eg. CS 23.423).

The result of this part of analysis, should be the max. possible increment of forces and hinge moments (and their dimensionless coefficients) due to control, computed for each characteristic point of flight envelope. The increments have to be computed for both (up and down) elevator deflection, for each value of airspeed and load factor.

Look at CS-25

CS 25.391 Control surface loads: general
The control surfaces must be designed for the limit loads resulting from the flight conditions in CS 25.331, CS 25.341(a) and (b), CS 25.349 and CS 25.351, considering the requirements for:
(a) Loads parallel to hinge line, in CS 25.393;
(b) Pilot effort effects, in CS 25.397;
(c) Trim tab effects, in CS 25.407;
(d) Unsymmetrical loads, in CS 25.427; and
(e) Auxiliary aerodynamic surfaces, in CS 25.445.

CS 25.397 Control system loads
(a) *General.* The maximum and minimum pilot forces, specified in subparagraph (c) of this paragraph, are assumed to act at the appropriate control grips or pads (in a manner simulating flight conditions) and to be reacted at the attachment of the control system to the control surface horn.
(b) *Pilot effort effects.* In the control surface flight loading condition, the air loads on movable surfaces and the corresponding deflections need not exceed those that would result in flight from the application of any pilot force within the ranges specified in subparagraph (c) of this paragraph. Two thirds of the maximum values specified for the aileron and elevator may be used if control surface hinge moments are based on reliable data. In applying this criterion, the effects of servo mechanisms, tabs, and automatic pilot systems, must be considered.

What next in CS-25

Look at CS-23

CS 23.423 Manoeuvring loads
(See AMC 23.423)
Each horizontal surface and its supporting structure, and the main wing of a canard or tandem wing configuration, if that surface has pitch control, must be designed for manoeuvring loads imposed by the following conditions:
(a) A sudden movement of the pitching control, at the speed VA to the maximum aft movement, and the maximum forward movement, as limited by the control stops, or pilot effort, whichever is critical.
(b) A sudden aft movement of the pitching control at speeds above VA, followed by a forward movement of the pitching control resulting in the following combinations of normal and angular acceleration:

Look at CS-23

Condition	Normal acceleration (n)	Angular acceleration (radian/sec.^{2})
Nose-up pitching	1·0	$+\frac{39}{V}n_m(n_m - 1{\cdot}5)$
Nose-down pitching	n_m	$-\frac{39}{V}n_m(n_m - 1{\cdot}5)$

where -

(1) n_m = positive limit manoeuvring load factor used in the design of the aeroplane; and

(2) V = initial speed in knots.

(d) In the absence of a more rational analysis, the incremental load due to the gust must be computed as follows only on aeroplane configurations with aft-mounted, horizontal surfaces, unless its use elsewhere is shown to be conservative:

$$\Delta L_{ht} = \frac{\rho o K_g U_{de} V a_{ht} S_{ht}}{2}\left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

where –

ΔL_{ht} = Incremental horizontal tail load (N);

ρo = Density of air at sea-level (kg/m^3)

K_g = Gust alleviation factor defined in CS 23.341;

U_{de} = Derived gust velocity (m/s);

V = Aeroplane equivalent speed (m/s);

a_{ht} = Slope of aft horizontal tail lift curve (per radian);

S_{ht} = Area of aft horizontal tail (m^2); and

$\left(1 - \frac{d\varepsilon}{d\alpha}\right)$ = Downwash factor

Loads due to gusts

CS 23.427 Unsymmetrical loads

(a) Horizontal surfaces other than main wing and their supporting structure must be designed for unsymmetrical loads arising from yawing and slipstream effects, in combination with the loads prescribed for the flight conditions set forth in CS 23.421 to 23.425.

(b) In the absence of more rational data for aeroplanes that are conventional in regard to location of engines, wings, horizontal surfaces other than main wing, and fuselage shape –

(1) 100% of the maximum loading from the symmetrical flight conditions may be assumed on the surface on one side of the plane of symmetry; and

(2) The following percentage of that loading must be applied to the opposite side:

% = 100-10 (n-1), where n is the specified positive manoeuvring load factor, but this value may not be more than 80%.

Unsymmetrical loads

... and what next

- we compute:
  - angle of attack on the tailplane (α_H)
  - elevator deflection (δ_H),
  - lift coefficient ($a_1\alpha_H$) on the tailplane due to angle of attack,
  - lift force increment (coefficient) ($a_2\delta_H$) due to elevator deflection,
- chordwise distribution
- spanwise distribution
- and next as in case of main wing ...