Chapter 3

Lecture 14

Longitudinal stick–free static stability and control – 3

Topics

3.4.4 Requirement for proper stick force variation

The stick force variation is called proper, when (i) a pull force is needed to reduce the flight speed below the trim speed and (ii) a push force is needed to increase the speed above the trim speed. This requirement is due to the following reasons.

When the pilot wishes to reduce the speed below the trim speed, he knows that the lift coefficient and hence the angle of attack should increase or the nose should go up. For proper feel he should pull the stick or apply a pull force. When he wishes to increase the flight speed above the trim speed, a lower angle of attack is needed.Then, he should push the stick forward. Thus, for proper variation of stick force, the gradient (dF/dV) should be negative. In Eq.(3.31) it is observed that $C_{m\delta e}$ is negative and $(dC_m/dC_L)_{stick\text{-}free}$ is also negative for a stable airplane. Hence, for (dF/dV) to have a small but negative value, $C_{h\delta e}$ should have a small negative value.

3.4.5 Feel of the stability level by the pilot

The pilot feels the stability of the airplane through (dF/dV). If (dF/dV) is high, he feels that the airplane is stiff and hence very stable. However, if (dF/dV) is very low then artificial means are employed for proper feel. Friction in the control deflection linkage masks the feel and hence, it needs to be kept low.

Example 3.3

From the following additional data for the airplane in example 3.2, calculate and plot the stick-force required versus equivalent airspeed for tab settings of 0^0, 5^0, 10^0 and 15^0, Assume $(dC_m/dC_L)_{\text{stick-free}} = -0.15$. Cross plot these curves to give tab setting for zero stick force versus equivalent airspeed (100 to 300 kmph). $S_e = 1.8\ m^2$, $\bar{c}_e = 0.6m$, $G = 1.6$ per meter, $\alpha_{0Lw} = -2^0$, $\delta_{e0CL} = +4^0$.

Solution:

The data given are:

$C_{L\alpha w} = 0.085\ deg^{-1}$, $C_{L\alpha t} = 0.058\ deg^{-1}$, $dC_{Lt}/d\delta = 0.032\ deg^{-1}$,

$C_{h\alpha t} = -0.003\ deg^{-1}$, $C_{h\delta e} = -0.0055\ deg^{-1}$, $C_{h\delta t} = -0.003\ deg^{-1}$, $i_w = 0$, $i_t = -1^0$,

$\alpha_{0Lw} = -2^0$, $S_t = 0.25\ S$, $l_t/c = 3$, a.c. at 0.25 c, $\eta = 1.0$, $(C_{m\alpha})_{f,n,p} = 0.37/\text{rad}$.

$S_e = 1.8\ m^2$, $\bar{c}_e = 0.6m$, $G = 1.6/m$. $\delta_{e0CL} = 4^0$, $(dC_m/dC_L)_{\text{stick-free}} = -0.15$,

$W/S = 1500\ N/m^2$

From Eq.(3.24) :

$$F = K\frac{1}{2}\rho V^2\{A + C_{h\delta t}\delta_t\} - K\frac{W}{S}\frac{C_{h\delta e}}{C_{m\delta}}(dC_m/dC_L)_{\text{stick-free}}$$

$$K = G\ S_e\bar{c}_e\eta;\quad A = C_{h\alpha t}\ \{\alpha_{0Lw} - i_w + i_t\} + C_{h\delta e}\ \delta_{e0CL}$$

$$K = 1.6 \times 1.8 \times 0.6 \times 1 = 1.728$$

$$A = -0.003\{-2 - 0 - 1\} + (-0.0055)(+4^0)$$
$$= 0.009 - 0.022 = -0.013$$

$$C_{m\delta} = -V_H\ \eta\ C_{L\alpha t}\ \tau = -0.25 \times 3 \times 1.0 \times 0.032 \times 57.3 = -1.3752\text{rad}^{-1};\text{note } C_{L\alpha t}\ \tau = \frac{dC_{Lt}}{d\delta_e}$$

$$K\frac{W}{S}\frac{C_{h\delta e}}{C_{m\delta}}\left(\frac{dC_m}{dC_L}\right)_{\text{stick-free}} = 1.728 \times 1500\left(\frac{-0.0055 \times 57.3}{-1.3752}\right)(-0.15) = -89.1$$

$$\frac{1}{2}\rho V^2 = \frac{1}{2}\rho_0 V_e^2;\quad \rho_0 = 1.225\ kg/m^3$$

$$F = 1.728 \times \frac{1}{2}\rho_0 V_e^2\ \{-0.013 + (-0.003)\delta_t\} + 89.1 \qquad \text{(E 3.3.1)}$$

$$= 1.059 V_e^2\{-0.013 - 0.03\delta_t\} + 89.1;$$

For $\delta_t = 0$: $F = 89.1 - 0.01377\ V_e^2$

The values of F for different values of V_e with δ_t equal to 0^0, 2.5^0, 5^0, 7.5^0 and 10^0 are tabulated in Table E3.3a.The values are plotted in Fig. E3.3a.

V_e (kmph)	V_e (m/s)	F(N) From Eq. (E 3.3.1)				
		$\delta_t = 0$	2.5^0	5^0	7.5^0	10^0
0	0	89.1	89.1	89.1	89.1	89.1
100	27.78	78.47	72.35	66.22	60.01	54.0
150	41.07	65.19	51.4	37.52	23.81	10.0
200	55.56	46.59	22.08	-2.43	-26.97	-51.5
250	69.44	22.7	-15.58	-53.87	-92.2	
300	83.33	-6.52	-61.65			

Table E3.3a F vs V_e with δ_t as parameter

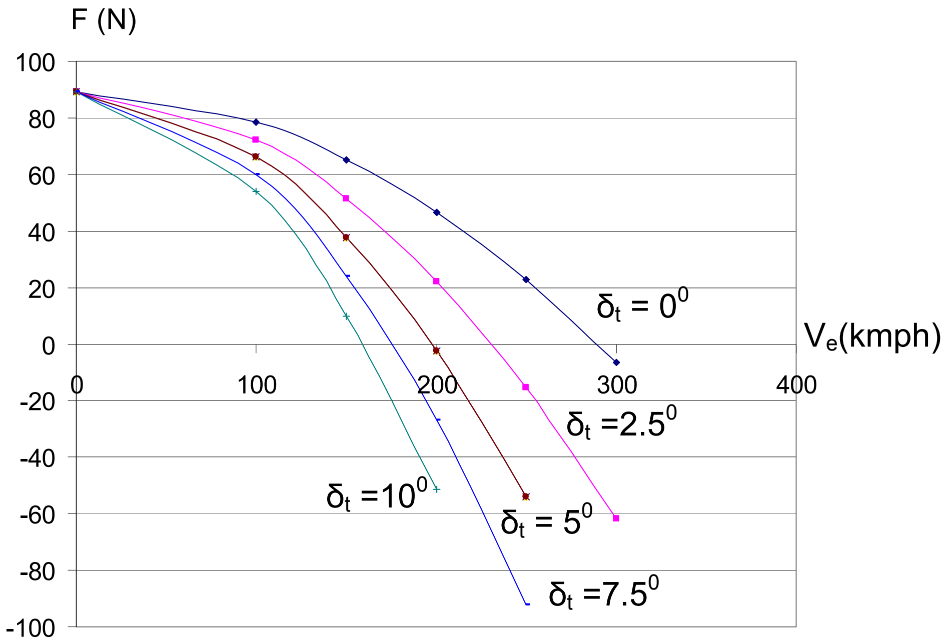

Fig. E3.3a Variations of stick force vs equivalent airspeed with tab deflection as parameter

Cross plotting the data in Fig.E3.3a gives the values of $(\delta_t)_{trim}$ for different values of equivalent airspeed. Alternatively, from Eq.(E3.3.1), $(\delta_t)_{trim}$ can be evaluated as:

$$0 = 1.059\,V_e^2\,\{-\,0.013 - 0.03(\delta_t)_{trim}\} + 89.1$$

$$\text{Or}\,(\delta_t)_{trim} = -\,4.33 + \frac{28045}{V_e^2} \text{ with } V_e \text{ in m/s}$$

$$= -\,4.33 + \frac{363463}{V_e^2} \text{ with } V_e \text{ in kmph}$$

The values of $(\delta_t)_{trim}$ at different equivalent airspeeds are tabulated in Table E3.3b and plotted in Fig.E3.3b. Since, the wing loading is given as 1500 N/m^2 we can calculate the lift coefficient in level flight (C_L) can be calculated as:

$$C_L = \frac{2W}{\rho_0 S V_e^2} = \frac{2449}{V_e^2} \text{ for } \frac{W}{S} = 1500\,N/m^2 \text{ and } \rho_0 = 1.225\,kg/m^3$$

The values of C_L are also shown in Table E3.3b. The plot of $(\delta_t)_{trim}$ vs C_L is shown in Fig. E 3.3 c.

V_e (kmph)	V_e (m/s)	C_L	$(\delta_t)_{trim}$ (degrees)
150	41.67	1.41	11.82
200	55.56	0.793	4.76
250	69.44	0.508	1.49
289.7	80.47	0.378	0
300	83.33	0.352	-0.29

Table E3.3b Tab deflection for trim at different equivalent airspeeds and lift coefficients

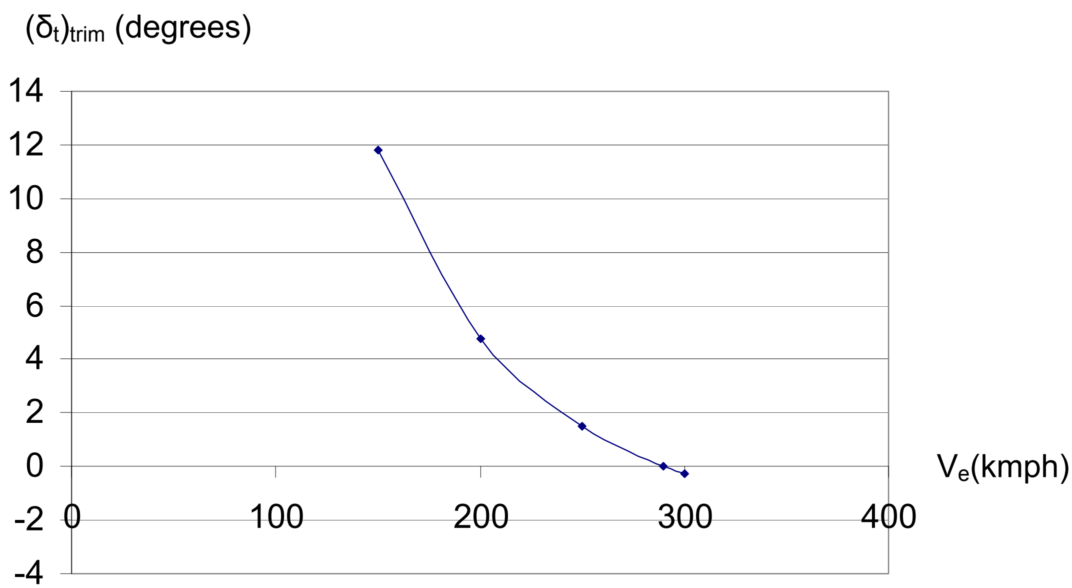

Fig. E3.3b Tab deflection for trim at different equivalent airspeeds

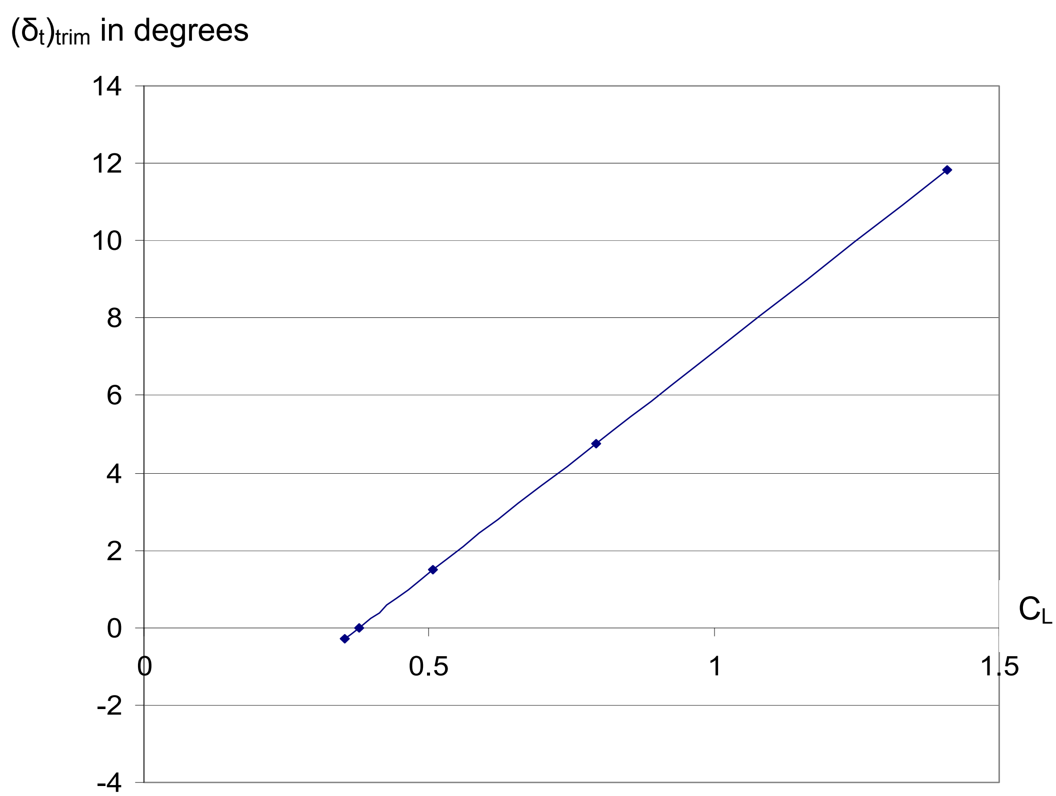

Fig. E3.3c Variation of $(\delta_t)_{trim}$ with C_L

Remark:

The $(\delta_t)_{trim}$ vs C_L curve in Fig. E3.3c is linear as the non-linear terms in the expression for $C_{m\alpha}$ have been ignored. For actual airplanes the curves from flight tests will be slightly non-linear. See Ref.2.5 chapter 3 and Ref.1.7, chapter 6.

3.5 Determination of stick-free neutral point from flight tests

In section 2.13, a procedure was explained to obtain the stick-fixed neutral point (x_{NP}) from flight tests. It was based on the fact that when c.g. is at x_{NP} then $d\delta_e / dC_L$ is zero. Similarly to obtain stick-free neutral point from flight tests, two ways are suggested by Eqs. (3.27) and (3.29). Equation (3.27) suggests that $d(F/q) / dC_L$ is zero when $(dC_m/dC_L)_{stick\text{-}free}$ is zero and Eq.(3.29) suggests that $(d\delta_t/dC_L)$ is zero when $(dC_m/dC_L)_{stick\text{-}free}$ is zero. Thus, by measuring either F or δ_t during the flight tests at different flight velocities and at different c.g. locations, $d(F/q) /dC_L$ or $(d\delta_t/dC_L)$ can be obtained for these c.g. locations. Extrapolating these curves gives the neutral point stick-free. For details see Ref.1.7 chapter 6.

Remark:

It may be recalled that (a) the exact contribution of wing is slightly non-linear and (b) the contribution of power changes with C_L. Hence, the δ_t vs C_L and (F/q) vs C_L curves from flight tests show slight non- linearity. Consequently, the stick free neutral point location also shows slight dependence on the lift coefficient similar to that shown in Fig.2.37.