2. Work-Out Problems (50 Points)

One version of the Lockheed Martin F-16 Fighting Falcon has the following geometric and aerodynamic properties:

$\bar{c}_w = 10$ ft

$\bar{c}_h = 5.4913$

$$S_w = 300\text{ ft}^2,\quad b_w = 30.0\text{ ft},\quad R_{T_w} = 0.2275,\quad \Lambda_{c/4_w} = 32\text{ deg},$$
$$S_h = 63.7\text{ ft}^2,\quad b_h = 11.6\text{ ft},\quad R_{T_h} = 0.39,\quad \Lambda_{c/4_h} = 32\text{ deg},$$
$$C_{L_w,\alpha} = 3.73,\quad \alpha_{0_w} = 1.9°,\quad \alpha_{L0_w} = -1.62°,\quad C_{m_w} = -0.041,$$
$$C_{L_h,\alpha} = 3.20,\quad \alpha_{0_h} = 0.0°,\quad \alpha_{L0_h} = 0.0°,\quad \varepsilon_e = 1.0,\quad C_{m_h,\delta_e} = 0.0$$

The longitudinal components all lie directly on the fuselage reference line, and their locations are known relative to the nose of the aircraft as follows:

Component	Distance Aft of Nose [ft]
CG	26.94
Main Wing Aerodynamic Center	26.42
Horizontal Tail Aerodynamic Center	43.55

$l_w = 26.42 - 26.94 = -0.52'$

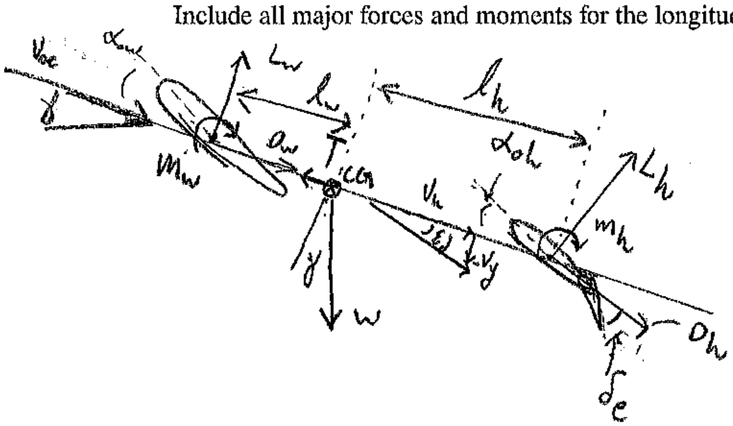
$l_h = 43.55 - 26.94 = 16.61'$

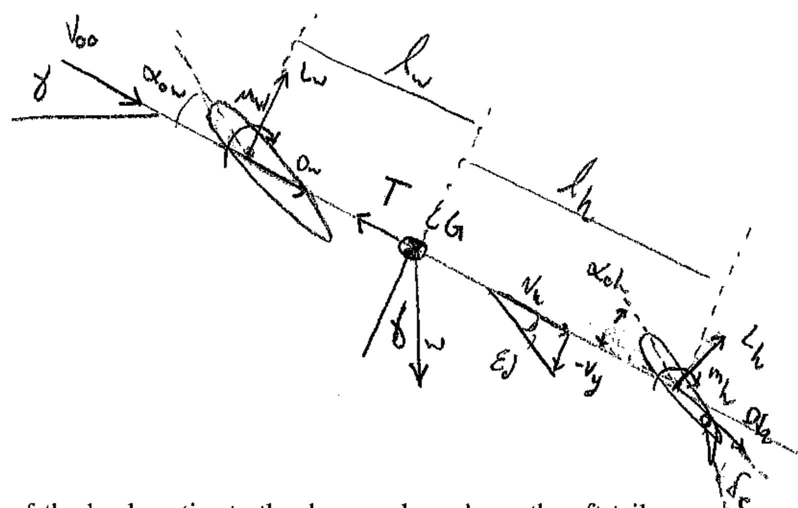
$l_{hw} = l_h - l_w = 17.13'$

Notice that this aircraft has an all-flying tail, i.e. $\varepsilon_e = 1.0$. For the following analysis, neglect the influence of the fuselage and engine, assume the tail efficiency factor, η_h, is unity, and neglect the upwash on the main wing due to the horizontal tail.

$\eta_h = 1$ ε_u = Neglected

2.1 Draw a free-body diagram of this aircraft using the simplified model discussed in Section 4.3 of the book. Include all major forces and moments for the longitudinal components.





2.2 Using the simplified analysis given in Section 4.5 of the book, estimate the downwash angle on the aft tail as a function of angle of attack, $\varepsilon_d = \varepsilon_{d0} + \varepsilon_{d,\alpha}\alpha$. Compute values for

$$\varepsilon_d = \frac{k_v k_p k_s}{K_b} \cdot \frac{C_{L_w}}{R_{A_w}}$$

$k_p =$

$$\varepsilon_{d0} = \frac{k_v k_p k_s}{K_b R_{A_w}} \cdot C_{L_{w_0}} = 0.2147(0.22915) = 0.0492$$

$$\varepsilon_{d,\alpha} = \frac{k_v k_p k_s}{k_b R_{A_w}} C_{L_{w,\alpha}} = 0.8008$$

$$\boxed{\varepsilon_d = 0.0492 + 0.8008\alpha}$$

$\varepsilon_{d,0}$ $\varepsilon_{d,\alpha}$ 2

2.5 Compute the angle of attack and elevator deflection **in degrees** required to trim the aircraft at this operating condition.

$$\begin{bmatrix} C_{L,\alpha} & C_{L,\delta_e} \\ C_{m,\alpha} & C_{m,\delta_e} \end{bmatrix} \begin{bmatrix} \alpha \\ \delta_e \end{bmatrix} = \begin{bmatrix} C_L - C_{L0} \\ -C_{m0} \end{bmatrix}$$

$$\boxed{\begin{aligned} \alpha &= 13.766^\circ \\ \delta_e &= 0.965^\circ \end{aligned}}$$

$C_{L,\alpha} = 3.865$ [Prob 2.3]

$C_{m,\alpha} = -0.030856$ [Prob 2.3]

$C_L = 1.13576$ [Prob 2.4]

Need C_{L,δ_e} ✓, C_{m,δ_e} ✓, C_{L0} ✓, C_{m0} ✓

$$C_{L,\delta_e} = \frac{S_h}{S_w} \eta_h C_{Lh,\alpha} \varepsilon_e = \frac{63.7}{300}(1)(3.2)(1) = \underline{0.67946}$$

$$C_{m,\delta_e} = \frac{S_h \bar{c}_h}{S_w \bar{c}_w} \eta_h C_{mh,\delta_e} - \frac{S_h l_h}{S_w \bar{c}_w} \eta_h C_{Lh,\alpha} \varepsilon_e = \frac{63.7 \cdot 5.4913}{300 \cdot 10}(1)(0.0) - \frac{63.7 \cdot 16.61}{300 \cdot 10}(1)(3.20)(1) = \underline{-1.1286}$$

$$C_{L0} = C_{Lw,\alpha}(\alpha_{0w} - \alpha_{L0w}) + \frac{S_h}{S_w} \eta_h C_{Lh,\alpha}(\alpha_{0h} - \varepsilon_0) =$$

$$\underbrace{3.73\left(3.52 \cdot \frac{\pi}{180}\right)}_{0.229155} + \underbrace{\frac{63.7}{300}(1)(3.2)(0 - 0.0492)}_{-0.03342} = \underline{0.1957}$$

$$C_{m0} = C_{mw} - \underbrace{\frac{l_w}{\bar{c}_w} C_{Lw,\alpha}(\alpha_{0w} - \alpha_{L0w})}_{} - \underbrace{\frac{S_h l_h}{S_w \bar{c}_w} \eta_h C_{Lh,\alpha}(\alpha_{0h} - \varepsilon_0)}_{}$$

$$-0.041 - (-0.011916) - (-0.0555) = \underline{0.02644}$$

$$\begin{bmatrix} 3.865 & 0.67946 \\ -0.030856 & -1.1286 \end{bmatrix} \begin{bmatrix} \alpha \\ \delta_e \end{bmatrix} = \begin{bmatrix} 0.94006 \\ -0.02644 \end{bmatrix}$$ "Calc RREF"

$$\boxed{\begin{aligned} \alpha &= 0.24026 \text{ Rad} = 13.766 \text{ degrees} \\ \delta_e &= 0.0168 \text{ Rad} = 0.965 \text{ degrees} \end{aligned}}$$