Atmosfera

Camada com temperatura constante

$$\frac{p}{p_1} = \frac{\rho}{\rho_1} = \exp\left(-\frac{g(z-z_1)}{RT}\right) \tag{1}$$

Camada com gradiente de temperatura

$$T = T_0 + \lambda h \quad (\lambda = -6.5 \cdot 10^{-3}\ K/m) \tag{2}$$

$$\frac{p}{p_1} = \left(\frac{T}{T_1}\right)^{-g/(\lambda R)} \tag{3}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-g/(\lambda R)-1} \tag{4}$$

R = 287.053 J/(kg K)

$$p = \rho R T \tag{5}$$

Altimetria

$$TA = IA\,\frac{T}{T_{ISA}} \tag{6}$$

Aerodinâmica

$$C_D = C_{D0} + kC_L^2 \tag{7}$$

$$C_L = C_{L\alpha}(\alpha - \alpha_{L=0}) \tag{8}$$

$$\left(\frac{C_L}{C_D}\right)_{max} \rightarrow C_L = \left(\frac{C_{D0}}{k}\right)^{1/2};\quad C_D = 2C_{D0} \tag{9}$$

$$\left(\frac{C_L^{0.5}}{C_D}\right)_{max} \rightarrow C_L = \left(\frac{C_{D0}}{3k}\right)^{1/2};\quad C_D = \frac{4C_{D0}}{3} \tag{10}$$

$$\left(\frac{C_L^{1.5}}{C_D}\right)_{max} \rightarrow C_L = \left(\frac{3C_{D0}}{k}\right)^{1/2};\quad C_D = 4C_{D0} \tag{11}$$

$$\left(\frac{C_L^{3}}{C_D^{2}}\right)_{max} \rightarrow C_L = \left(\frac{3C_{D0}}{k}\right)^{1/2};\quad C_D = 4C_{D0} \tag{12}$$

Voo planado

Equações básicas

$$D - W\sin\gamma = 0 \tag{13}$$

$$L - W\cos\gamma = 0 \tag{14}$$

Ângulo de planeio

$$\tan\gamma = \frac{1}{E} \tag{15}$$

Velocidade de planeio

$$V = \sqrt{\frac{2W\cos\gamma}{\rho S C_L}} \tag{16}$$

Razão de descida

$$\dot{h} = V\sin\gamma \tag{17}$$

Velocidade de mínimo ângulo de planeio

$$V = \sqrt{\frac{2W\cos\gamma}{\rho S}\left(\frac{k}{C_{D0}}\right)^{1/2}} \tag{18}$$

Voo cruzeiro

Principais equações

$$L - W = 0 \tag{19}$$

$$T - D = 0 \tag{20}$$

$$\frac{dx}{dt} = V \tag{21}$$

$$\frac{dW}{dt} = -cT \quad \text{(à jato)} \tag{22}$$

$$\frac{dW}{dt} = -\hat{c}\,P_e \quad \text{(à hélice)} \tag{23}$$

Aeronave a jato

Velocidade

$$V = \left\{\frac{T}{S}\frac{1}{\rho C_{D0}}\left\{1 \pm \left[1 - 1\Big/\left(E_m\frac{T}{W}\right)^2\right]^{1/2}\right\}\right\}^{1/2} \tag{24}$$

Arrasto

$$D = \frac{1}{2}\rho V^2 S C_{D0} + 2kS\left(\frac{W}{S}\right)^2\frac{1}{\rho V^2} \tag{25}$$

Alcance

Equação básica

$$x = -\frac{1}{c}\int_{W_1}^{W_2}\frac{V}{D}\,dW \tag{26}$$

$$x = -\frac{1}{c}\int_{W_1}^{W_2}\frac{V}{E}\frac{1}{W}\,dW \tag{27}$$

Casos específicos

$$x_{h-C_L} = \frac{2EV_1}{c}\left(1 - \sqrt{1-\xi}\right) \tag{28}$$

$$x_{V-C_L} = \frac{EV_1}{c}\ln\left(\frac{1}{1-\xi}\right) \tag{29}$$

$$x_{V-h} = \frac{2E_mV_1}{c}\tan^{-1}\left[\frac{E_1\xi}{2E_m(1-kE_1C_{L,1}\xi)}\right] \tag{30}$$

Autonomia

Equação básica

$$t = -\frac{1}{c}\int_{W_1}^{W_2}\frac{E}{W}\,dW \tag{31}$$

Casos específicos

$$t_{h-C_L} = t_{V-C_L} = -\frac{E}{c}\ln\left(\frac{1}{1-\xi}\right) \tag{32}$$

$$t_{V-h} = \frac{2E_m}{c}\tan^{-1}\left[\frac{E_1\xi}{2E_m(1-kE_1C_{L,1}\xi)}\right] \tag{33}$$

Aeronave a hélice

Velocidade

$$V^4 - 2\hat{k}\eta_p\frac{P_e}{W}\frac{W}{S}\frac{V}{\rho C_{D0}} + \frac{4k(W/S)^2}{\rho^2 C_{D0}} = 0 \tag{34}$$

Potência requerida

$$P_r = (1/2)\rho C_{D0} S V^3 + \frac{2kS(W/S)^2}{\rho V} \tag{35}$$

Alcance

Equação básica

$$x = -\frac{\hat{k}\eta_P}{\hat{c}}\int_{W_1}^{W_2}\frac{E}{W}\,dW \tag{36}$$

Casos específicos

$$x_{h-C_L} = x_{V-C_L} = \frac{\hat{k}\eta_P E}{\hat{c}} \ln\left(\frac{1}{1-\xi}\right) \tag{37}$$

$$x_{V-h} = \frac{2\hat{k}\eta_P E}{\hat{c}} \tan^{-1}\left[\frac{E_1\xi}{2E_m(1-kE_1C_{L,1}\xi)}\right] \tag{38}$$

Autonomia

Equação básica

$$t = -\frac{\hat{k}\eta_P}{\hat{c}} \int_{W_1}^{W_2} \frac{E}{V\,W}\, dW \tag{39}$$

Casos específicos

$$t_{h-C_L} = \frac{2\hat{k}\eta_P E}{V_1\,\hat{c}} \left(\frac{1}{\sqrt{1-\xi}} - 1\right) \tag{40}$$

$$t_{V-C_L} = \frac{\hat{k}\eta_P E}{V_1\,\hat{c}} \ln\left(\frac{1}{1-\xi}\right) \tag{41}$$

$$t_{V-h} = \frac{2\hat{k}\eta_P E}{V\,\hat{c}} \tan^{-1}\left[\frac{E_1\xi}{2E_m(1-kE_1C_{L,1}\xi)}\right] \tag{42}$$

Voo ascendente

Principais equações

$$T - D - W\sin\gamma = 0 \tag{43}$$

$$L - W\cos\gamma = 0 \tag{44}$$

$$\frac{dx}{dt} = V\cos\gamma \tag{45}$$

$$\frac{dh}{dt} = V\sin\gamma \tag{46}$$

$$\frac{dW}{dt} = -c\,T \quad \text{(à jato)} \tag{47}$$

$$\frac{dW}{dt} = -\hat{c}\,P_e \quad \text{(à hélice)} \tag{48}$$

Aeronave a jato

Ângulo de subida

$$\sin\gamma = \frac{T-D}{W} \tag{49}$$

$$\gamma = \frac{T}{W} - \left[\rho V^2 C_{D0} \Big/ (2\frac{W}{S}) + 2k\frac{W}{S}\frac{1}{\rho V^2}\right] \tag{50}$$

Razão de subida

$$\dot{h} = V\sin\gamma \tag{51}$$

$$\dot{h} = \frac{T}{W}V - \left[\rho V^3 C_{D0} \Big/ (2\frac{W}{S}) + 2k\frac{W}{S}\frac{1}{\rho V}\right] \tag{52}$$

Tempo de subida

$$t = \int_{h_1}^{h_2} \frac{1}{\dot{h}}\, dh \tag{53}$$

Distância horizontal

$$x = \int_{h_1}^{h_2} \frac{1}{\gamma}\, dh \tag{54}$$

Consumo de combustível

$$\xi = 1 - \exp\left(-c\int_{h_1}^{h_2} \frac{T}{W}\frac{1}{\dot{h}}\, dh\right) \tag{55}$$

Máximo ângulo de subida

Velocidade

$$V_{SC} = V_{E_m} = \left[\frac{2}{\rho}\frac{W}{S}\right]^{1/2} \left(\frac{k}{c_{D0}}\right)^{1/4} \tag{56}$$

Máxima razão de subida

$$V_{FC} = \left[\frac{(T/W)(W/S)}{3\rho C_{D0}} \left\{1 + \sqrt{1 + \frac{3}{E_m^2(T/W)^2}}\right\}\right]^{1/2} \tag{57}$$

Aeronave a hélice

Ângulo de subida

$$\sin\gamma = \frac{P}{VW} - \frac{D}{W} \tag{58}$$

$$\gamma = \frac{\hat{k}\eta_P}{V}\frac{P_e}{W} - \left[\rho V^2 C_{D0} \Big/ (2\frac{W}{S}) + 2k\frac{W}{S}\frac{1}{\rho V^2}\right] \tag{59}$$

Razão de subida

$$\dot{h} = V\sin\gamma \tag{60}$$

$$\dot{h} = \hat{k}\eta_P\frac{P_e}{W} - \left[\rho V^3 C_{D0} \Big/ (2\frac{W}{S}) + 2k\frac{W}{S}\frac{1}{\rho V}\right] \tag{61}$$

Tempo de subida

$$t = \int_{h_1}^{h_2} \frac{1}{\dot{h}}\, dh \tag{62}$$

Distância horizontal

$$x = \int_{h_1}^{h_2} \frac{1}{\gamma}\, dh \tag{63}$$

Consumo de combustível

$$\xi = 1 - \exp\left(-\hat{c}\int_{h_1}^{h_2} \frac{P_e}{W}\frac{1}{\dot{h}}\, dh\right) \tag{64}$$

Máximo ângulo de subida

Velocidade

$$V^4 + \frac{\hat{k}\eta_P(P_e/W)(W/S)}{\rho C_{D0}}V - \frac{4k(W/S)^2}{\rho^2 C_{D0}} = 0 \tag{65}$$

Máxima razão de subida

$$V_{FC} = \left[\frac{2}{\rho}\frac{W}{S}\right]^{1/2} \left(\frac{k}{3C_{D0}}\right)^{1/4} \tag{66}$$

Manobras

$$L\cos\phi = W \tag{67}$$

$$L\sin\phi = \frac{W\,V^2}{g\,R} \tag{68}$$

$$n = \frac{L}{W} = \frac{1}{\cos\phi} \tag{69}$$

$$V^2 = \frac{(T/W)(W/S)}{\rho C_{D0}} \left[1 + \left(1 - \frac{n^2}{E_m^2(T/W)^2}\right)^{1/2}\right] \tag{70}$$

$$\omega = \frac{g}{V}\sqrt{n^2-1} \tag{71}$$

$$V = \omega\,R \tag{72}$$