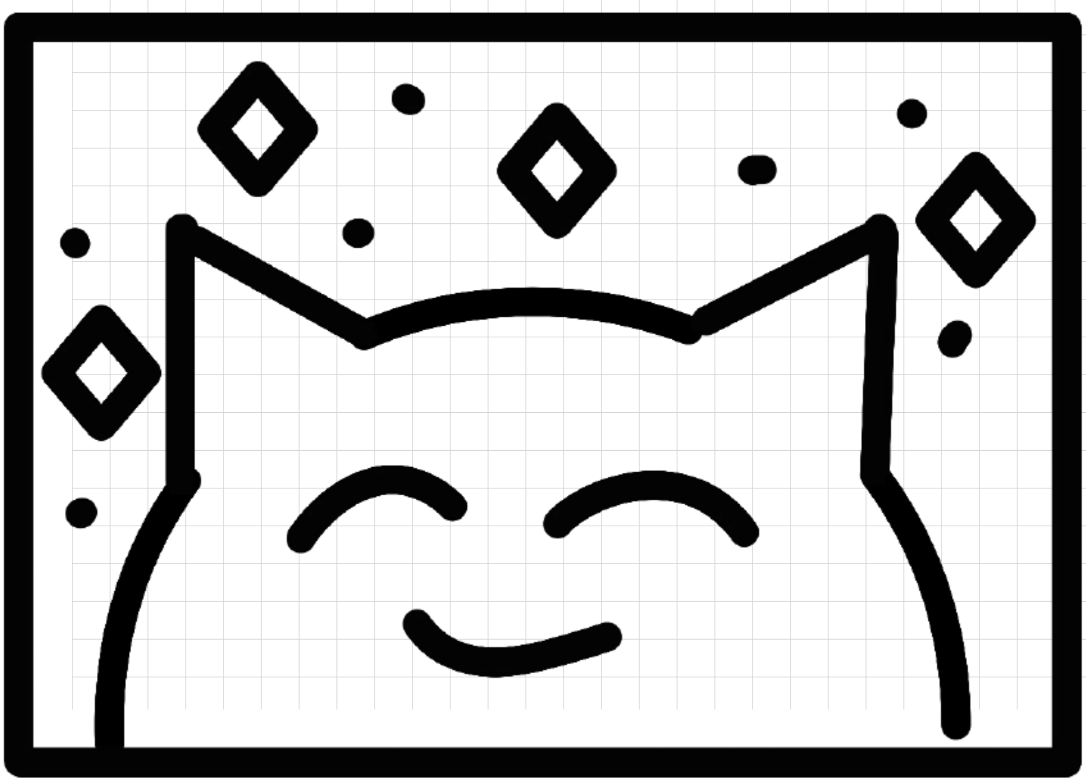
MAE 159

ALL HAND CALCULATIONS

TRIET



C_L LOOP

① $M = 0.8$ at $35\,000$ [ft]

Select conventional airfoil $\quad \Lambda = 35°$, $AR = 8$

② Assume $C_L = 0.5$

From Figure 2

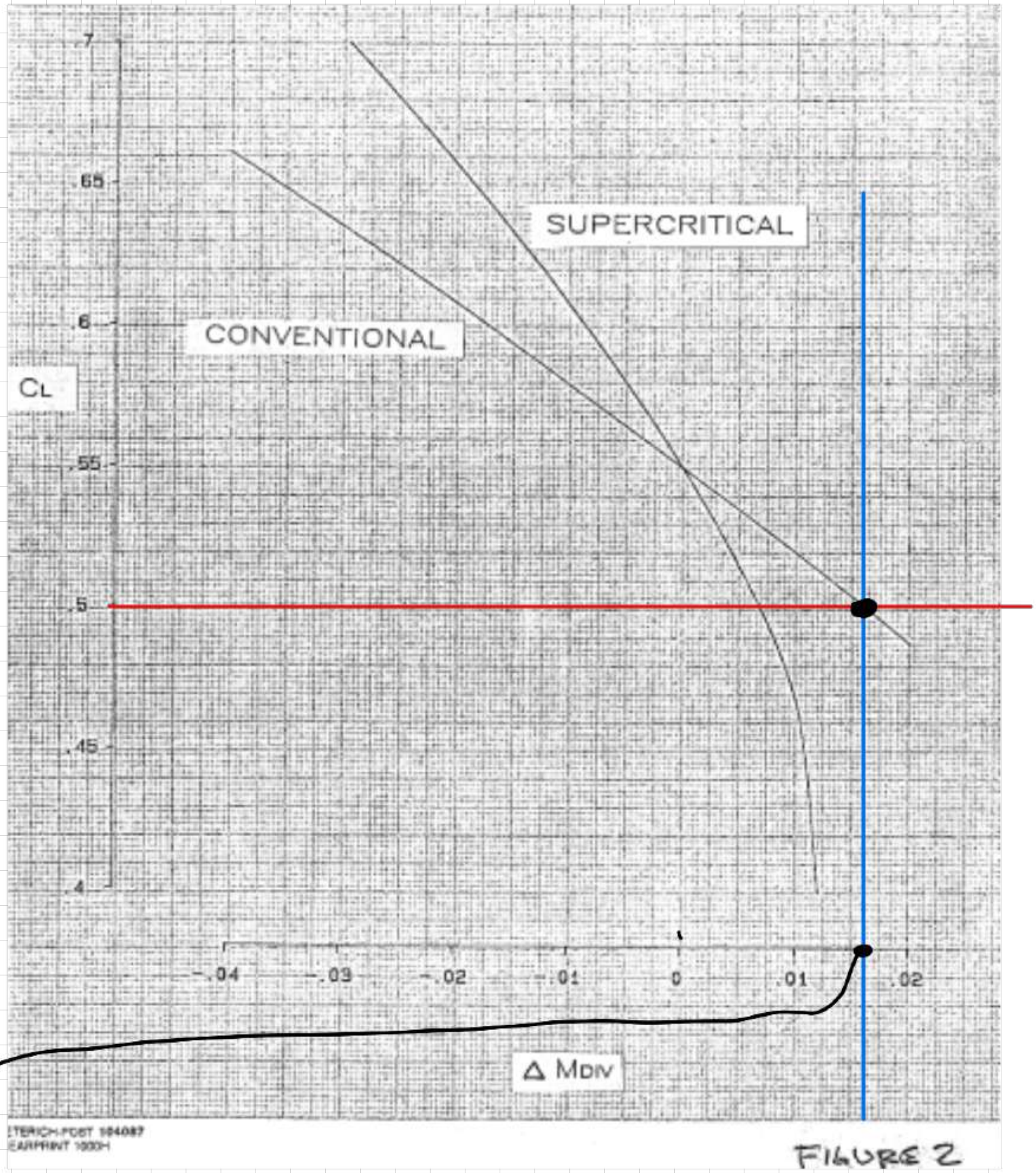


FIGURE 2

$\Delta M_{Div} = 0.016$

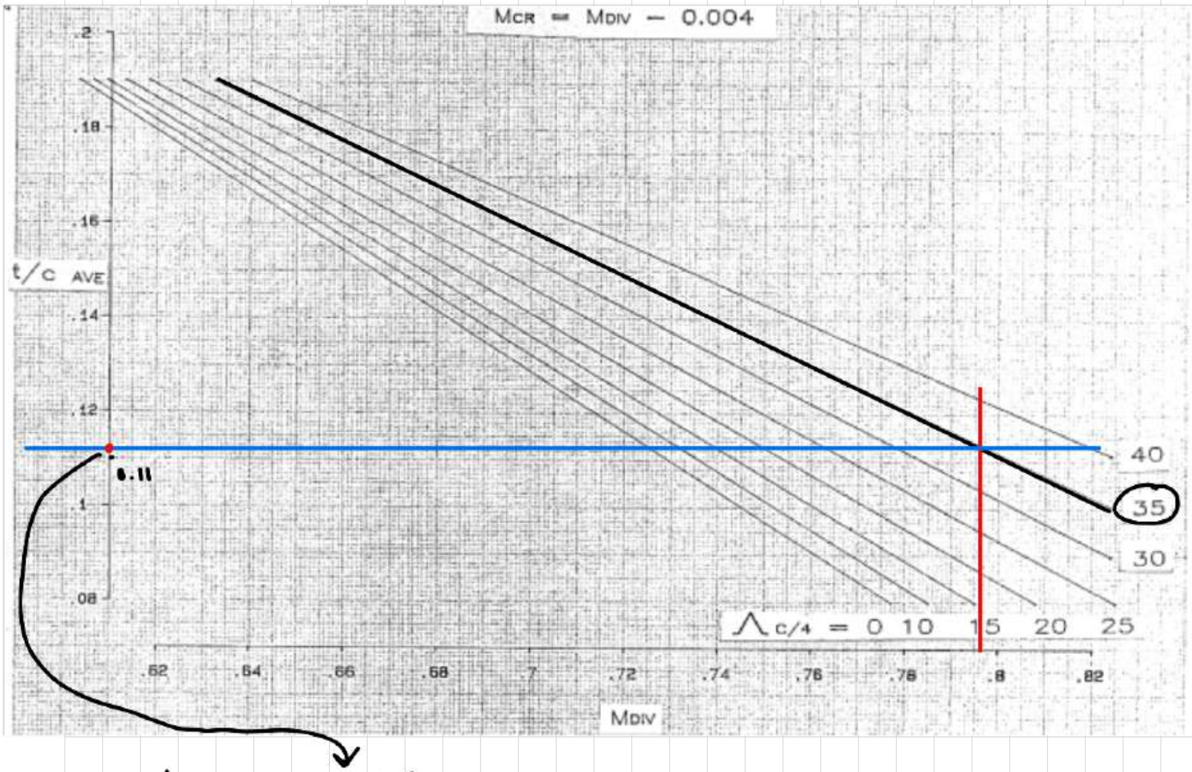
③ $M_{Div} = (M_{Cruise} + 0.004) - \Delta M_{Div}$

$= (0.8 + 0.004) - 0.016$

$M_{Div} = 0.788$

④ $\Lambda = 35°$ $\qquad M_{Div} = 0.788$

From Figure 1a



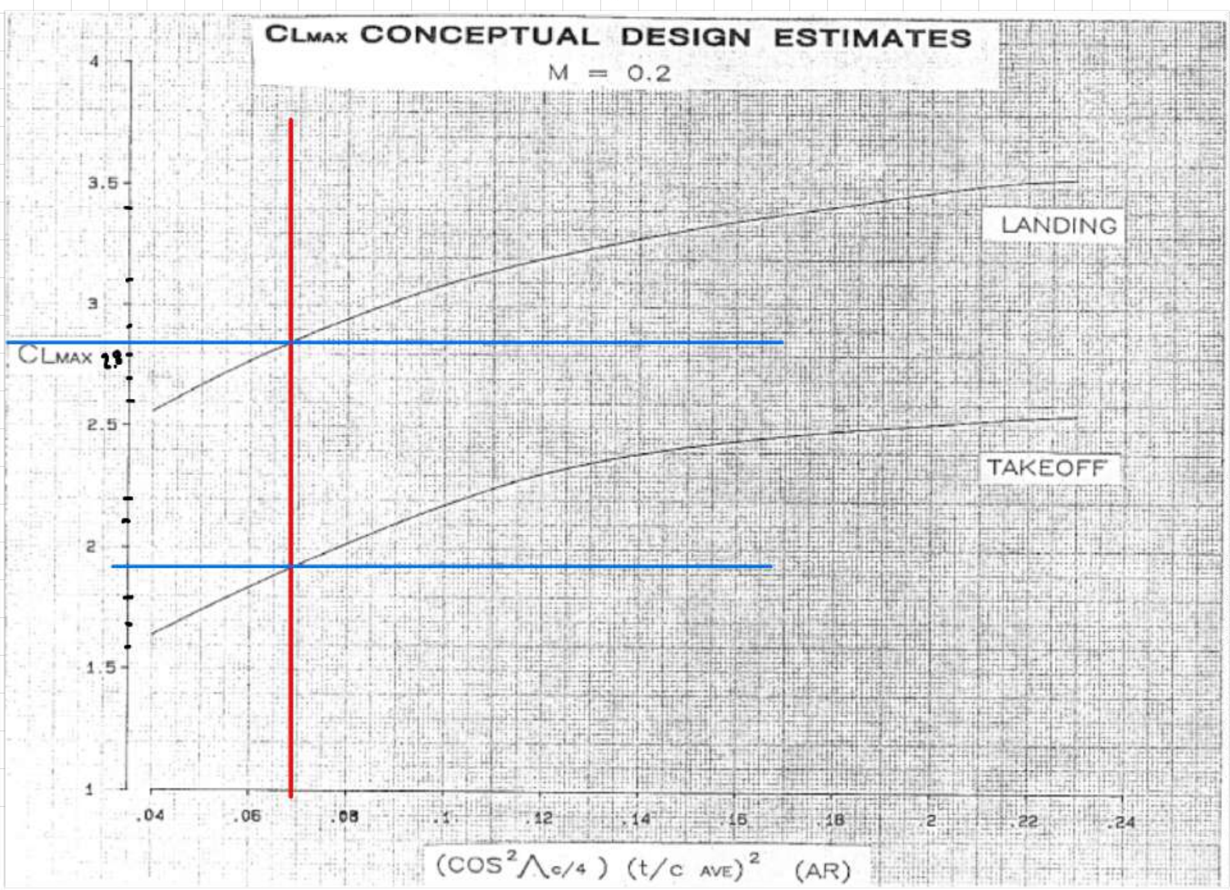
$t/c = 0.113$

⑤ $\cos^2\Lambda \, (t/c)^2 \, AR = \cos^2(35) \, (0.113)^2 \, 8 = 0.0685$

Figure 3

$C_{L_{max}})_{LDG} = 2.85$

$C_{L_{max}})_{T/O} = 1.9$



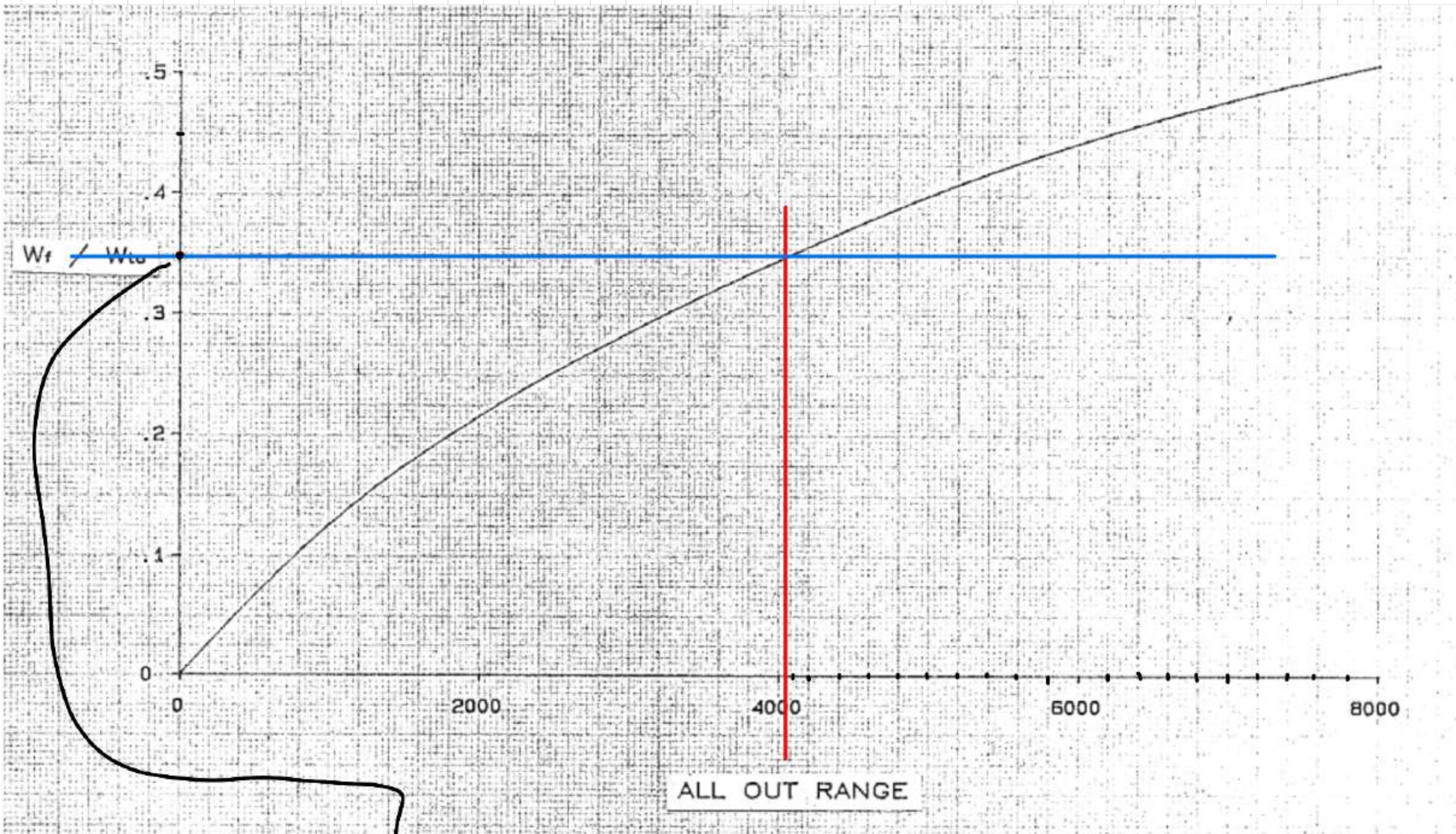
⑥ $$\left.\frac{W}{S}\right)_{LDG} = \left(\frac{V_{approach}}{1.3}\right)^2 \frac{\sigma\ C_{Lmax})_{LDG}}{296} = \left(\frac{135}{1.3}\right)^2 \frac{0.953 \times 2.85}{296} = 98.9525\ [\#/ft^2]$$

⑦ $$V_{cruise} = M\sqrt{\gamma R T} = 0.80 \times 576.4 = 461.12\ [KTS]$$

$$R_{All\text{-}out} = R_{schedule} + R_{reserved} = R_{schedule} + 200 + 0.75\,V_{cruise}$$

$$= 3500 + 200 + 0.75 \times 461.12 = 4045.84\ [Nmi]$$

⑧ From Figure 4



$$\frac{W_f}{W_{T/o}} = 0.35$$

⑨ Engine tye JT9D

$$\left.\frac{W_f}{W_{T/o}}\right)_{JT9D} = \left.\frac{W_f}{W_{T/o}}\right)_{JT8D} \times \frac{SFC)_{JT9D}}{SFC)_{JT8D}} = 0.35 \times \frac{0.61}{0.78} = 0.2737 \xrightarrow{+0.0257} 0.299$$

⑩ $$\left.\frac{W}{S}\right)_{T/O} = \frac{W/S)_{LDG}}{1 - X \cdot \frac{W_f}{W_{T/o}}} = \frac{98.9525}{1 - 75\% \times 0.299} = 127.5572\ [\#/ft^2]$$

(11) $\left.\frac{W}{S}\right)_{IC} = 0.965 \left.\frac{W}{S}\right)_{T/O} = 0.965 \times 127.5572 = 123.0927 \quad [\#/ft^2]$

(12) $\left.C_L\right)_{IC} = \dfrac{W/S)_{IC}}{1481\ \delta\ M^2} = \dfrac{123.0927}{1481 \times 0.236 \times 0.80^2} = 0.5503 \neq C_L = 0.5$

Try $C_L = 0.55$

② $C_L = 0.55$

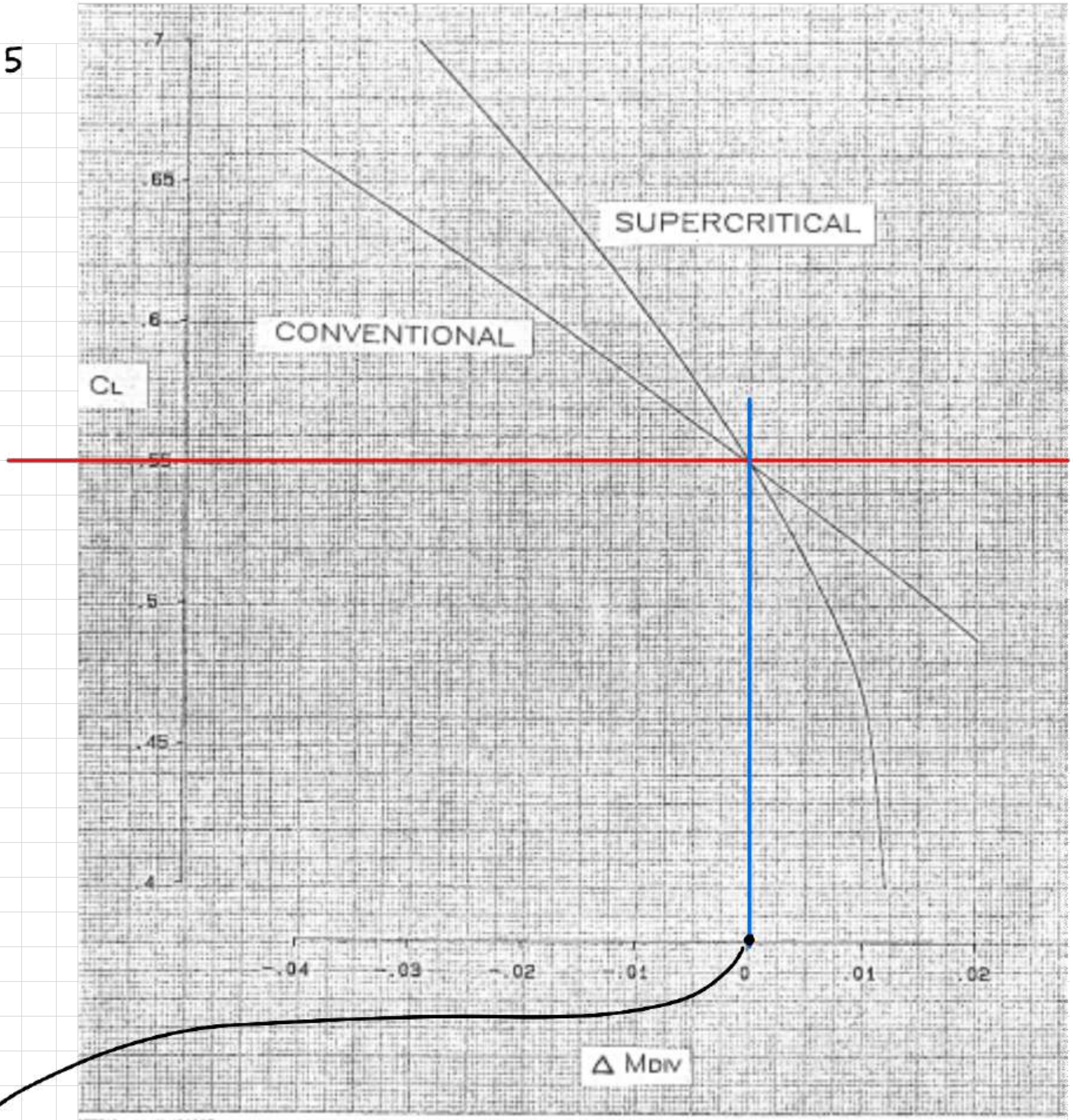


FIGURE 2

$\Delta M_{Div} = 0$

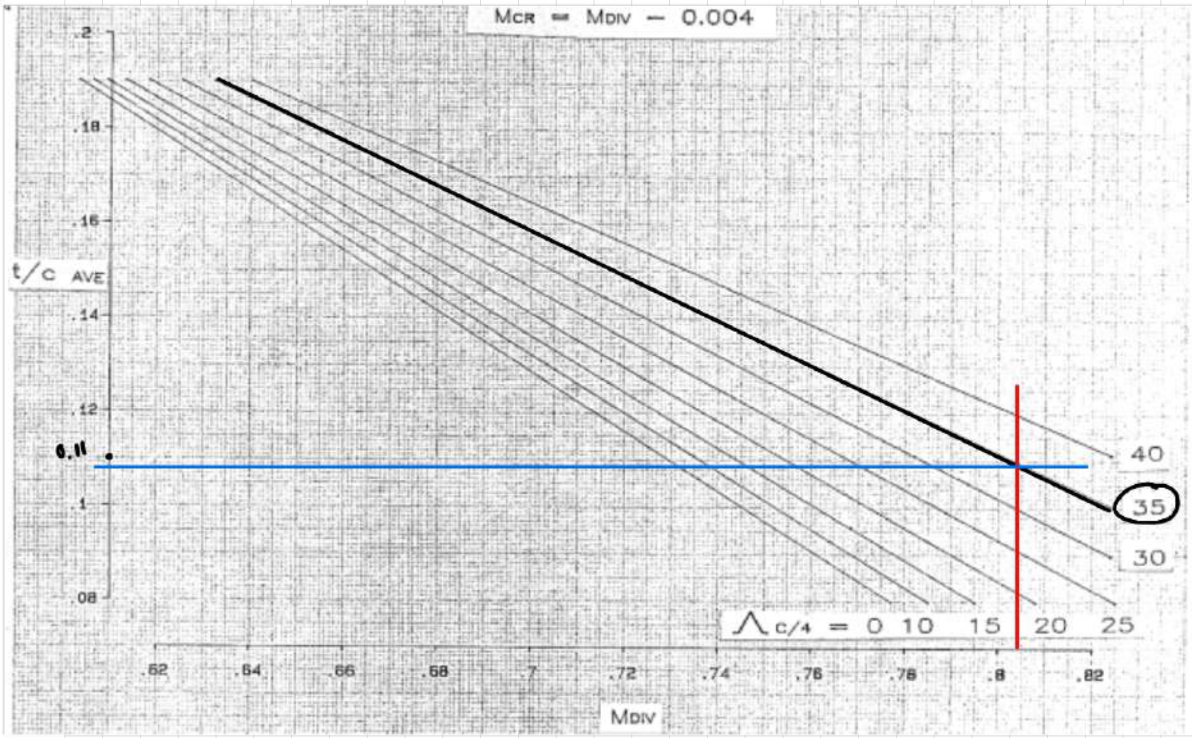
③ $M_{Div} = (M_{cruise} + 0.004) - \Delta M_{Div}$

$= (0.8 + 0.004) - 0$

$M_{Div} = 0.804$

④ $\Lambda = 35°$ $M_{Div} = 0.804$

From Figure 1a



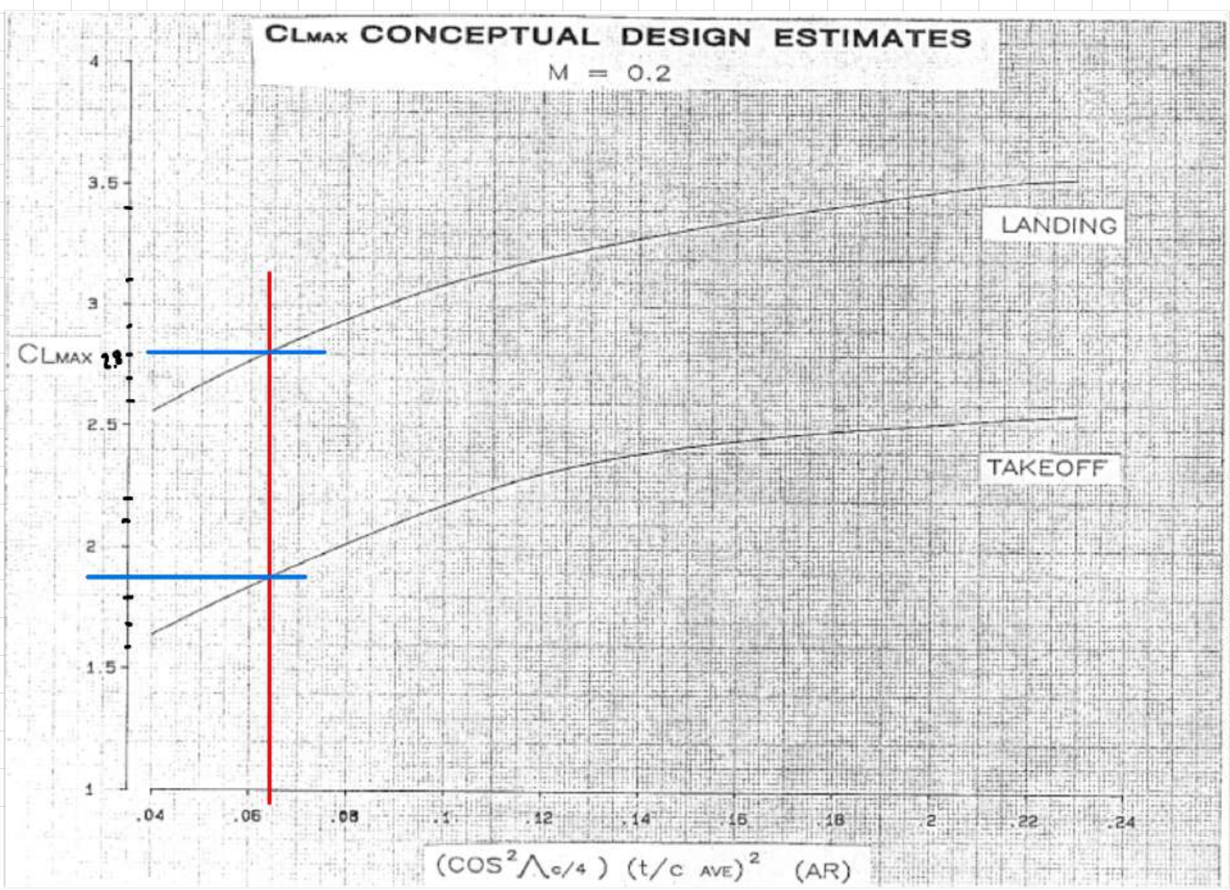
$t/c = 0.109$

⑤ $\cos^2\Lambda \, (t/c)^2 \, AR = \cos^2(35) \, (0.109)^2 \, 8 = 0.064$

Figure 3

$C_{L\,max})_{LDG} = 2.8$

$C_{L\,max})_{T/O} = 1.88$



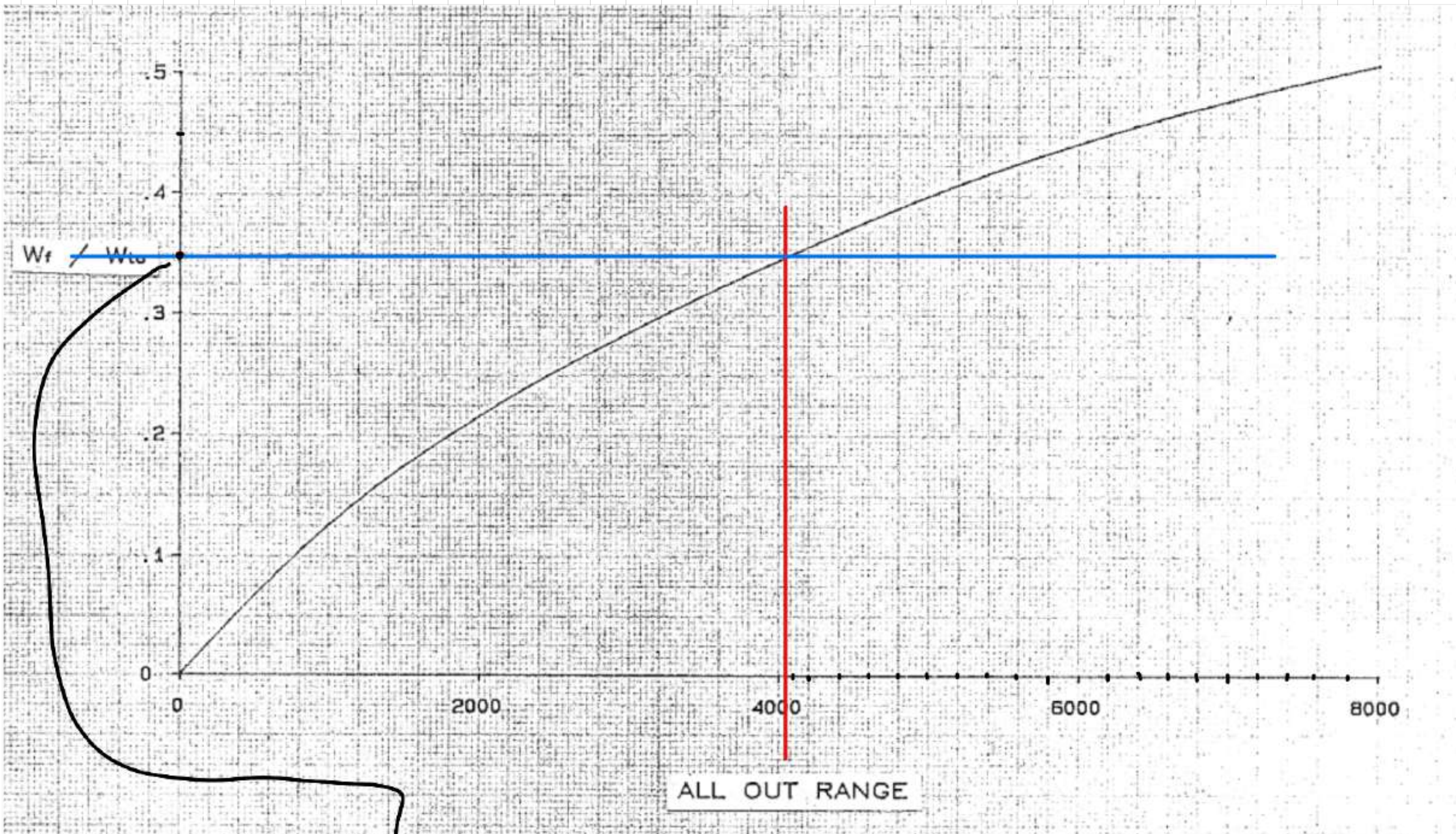
⑥ $\left.\frac{W}{S}\right)_{LDG} = \left(\frac{V_{approach}}{1.3}\right)^2 \frac{\sigma \; C_{Lmax})_{LDG}}{296} = \left(\frac{135}{1.3}\right)^2 \frac{0.953 \times 2.8}{296} = 97.22 \; [\#/ft^2]$

⑦ $V_{cruise} = M\sqrt{\gamma R T} = 0.80 \times 576.4 = 461.12 \; [KTS]$

$R_{All\text{-}out} = R_{schedule} + R_{reserved} = R_{schedule} + 200 + 0.75\, V_{cruise}$

$= 3500 + 200 + 0.75 \times 461.12 = 4045.84 \; [Nmi]$

⑧ From Figure 4



$\frac{W_f}{W_{T/o}} = 0.35$

⑨ Engine tye JT9D

$\left.\frac{W_f}{W_{T/o}}\right)_{JT9D} = \left.\frac{W_f}{W_{T/o}}\right)_{JT8D} \times \frac{SFC)_{JT9D}}{SFC)_{JT8D}} = 0.35 \times \frac{0.61}{0.78} = 0.2737 \xrightarrow{+0.0257} 0.299$

⑩ $\left.\frac{W}{S}\right)_{T/O} = \frac{W/S)_{LDG}}{1 - x \cdot \frac{W_f}{W_{T/o}}} = \frac{97.22}{1 - 75\% \times 0.299} = 125.324 \; [\#/ft^2]$

(11) $\left.\frac{W}{S}\right)_{IC} = 0.965 \left.\frac{W}{S}\right)_{T/O} = 0.965 \times 127.5572 = 120.94 \quad [\#/ft^2]$

(12) $\left.C_L\right)_{IC} = \frac{W/S)_{IC}}{1481\ \delta\ M^2} = \frac{120.94}{1481 \times 0.236 \times 0.80^2} = 0.54 \approx C_L = 0.55$

$\Downarrow$

$\boxed{C_L = 0.545}$

TAKE OFF

FIELD

LENGTH

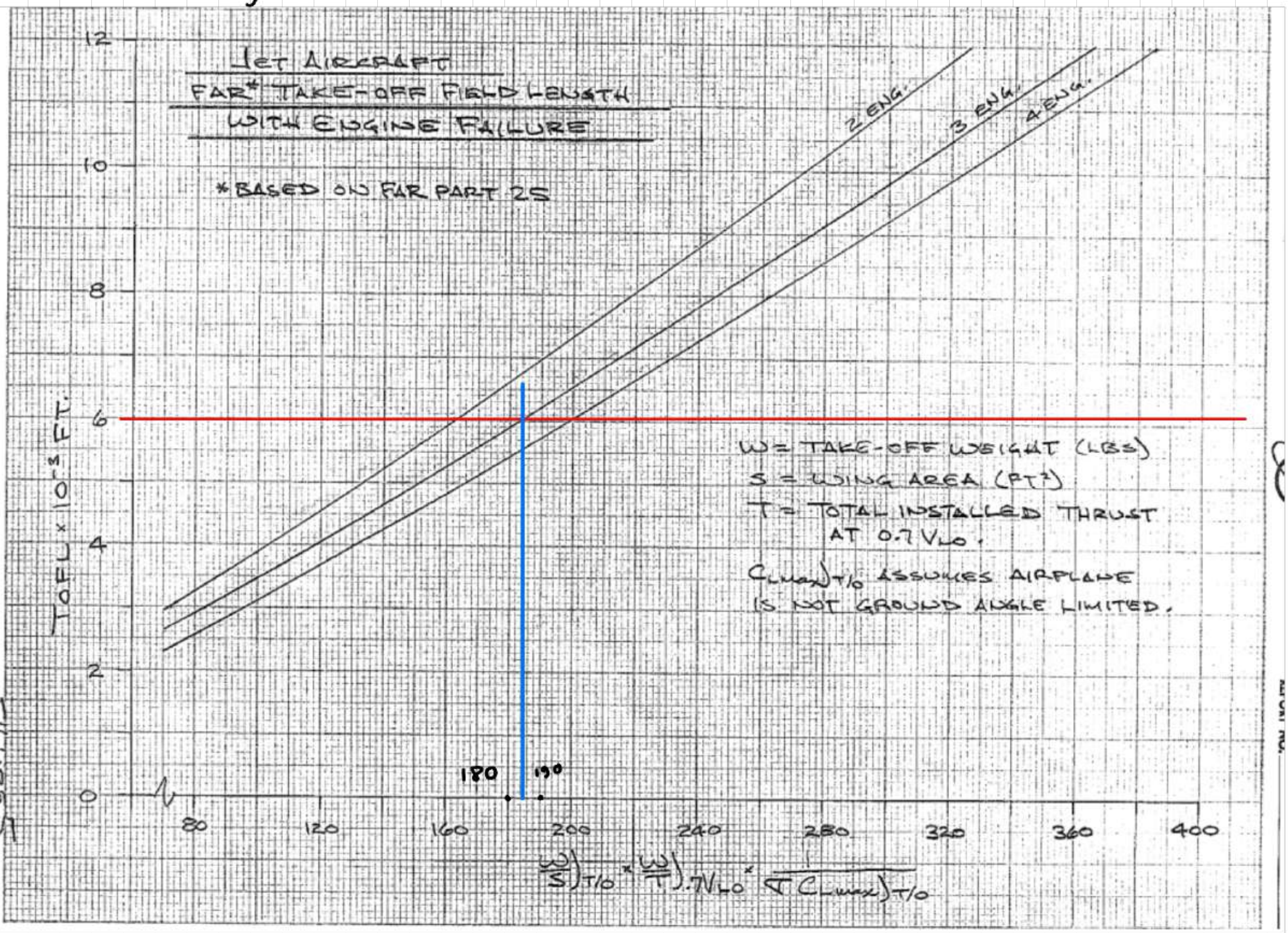
Design Specification:

Number of passengers (2-class, domestic rules)	210
Weight of cargo (10 pounds/ft^3)	8000 pounds
Range (still air)	3500 nautical miles
Takeoff field length (sea-level, hot day 84° f)	6000 feet
Landing approach speed	135 knots
Cruise Mach number	0.80
Initial cruise altitude	35,000 feet
Maximum wingspan	118 feet

TOFL

3 Engines TOFL = 6000 [ft]

From Figure 5



$$\frac{W}{S}\Big)_{T/O} \times \frac{W}{T}\Big)_{0.7V_{LO}} \times \frac{1}{\sigma\, C_{L_{max}}\big)_{T/O}} = 184$$

$$\Rightarrow \quad \frac{W}{T}\Big)_{0.7V_{LO}} = 184\,\frac{\sigma\, C_{L_{max}}\big)_{T/O}}{\frac{W}{S}\Big)_{T/O}}$$

$$= 184\,\frac{0.953 \times 1.88}{125.324}$$

$$= 2.63$$

$$V_{L/O} = 1.2\left[\frac{296 \;\; W/S)_{T/O}}{\sigma \;\; C_{L\max T/O}}\right]^{0.5} = 1.2\left[\frac{296 \times 125.324}{0.953 \times 1.88}\right]^{0.5} = 172.67\,[\text{KTS}]$$

$$M_{L/O} = \frac{V_{L/O}}{661 \times \sqrt{\sigma}} = \frac{172.67}{661 \times \sqrt{0.953}} = 0.2676$$

$$0.7\, M_{L/O} = 0.7 \times 0.2676 = 0.1873$$

From JT9D Chart at sea level:

TAKE-OFF RATING WITHOUT WATER INJECTION
Ambient Temperature 80° F

Static	T_{SLST} = 45500	1482
0.15	39120	1509
0.1873		
0.30	34820	1585
0.45	31750	1700

$$T_{M=0.2676} = 38050.7 \;\#$$

$$\frac{W}{T} = \frac{W}{T}\Big)_{0.7 V_{L/O}} \times \frac{T_{M=0.2676}}{T_{SLST}} = 2.63 \times \frac{38050.7}{45500} = \boxed{2.2}$$

WEIGHT

LOOP

$$W_{wing} = \frac{0.00945\,(W_{T/O})^{1.195}\,(\mathcal{R})^{0.8}\,(1+\lambda)^{0.25}}{(\bar{t}/c)^{0.4}\,(\cos\Lambda_{c/4})\left[(W/S)_{T/O}\right]^{0.695}}\,k_w\,\eta^{0.5}$$

constant ↓ design, wing engine, constant

$$= \frac{0.00945\,(W_{T/O})^{1.195}\,(8)^{0.8}\,(1+0.35)^{0.25}}{(0.109+0.03)^{0.4}\,\cos(35^\circ)\,(125.324)^{0.695}}\,1.01\times 3.75^{0.5}$$

$$= 0.0098\,(W_{T/O})^{1.195}$$

$$W_{fuselage} = 0.6727\,k_f\,(W_{T/O})^{0.235}\,\ell^{0.6}\,d^{0.72}\,\eta^{0.3} \leftarrow \text{Constant}$$

$$\ell = \left(3.76 \times \frac{\#s \text{ of PAX}}{\#s \text{ of Seat Abreast}} + 33.2\right)1.1$$

↑ design

$$= \left(3.76 \times \frac{210}{8} + 33.2\right)1.1$$

$$= 145.09\ [ft]$$

design ↓

$$d = (1.75 \times \#s \text{ of Seat Abreast} + 1.58 \times \#s \text{ of Aisles} + 1)\,1.1$$

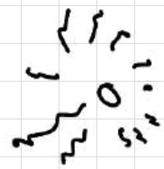
$$= (1.75 \times 8 + 1.58 \times 2 + 1)\,1.1 = 19.976\ [ft]$$

Constant PAX > 135 ↓

- $$W_{fuselage} = 0.6727\,k_f\,(W_{T/O})^{0.235}\,\ell^{0.6}\,d^{0.72}\,\eta^{0.3}$$

$$= 0.6727 \times 11.5 \times (W_{T/O})^{0.235}\,145.09^{0.6}\,19.976^{0.72}\,3.75^{0.3}$$

$$= 1968.2365\,(W_{T/O})^{0.235}$$



- $$W_{Landing\ Gear} = 0.040 \times W_{T/O}$$

- $$W_{Nacelle + Pylon} = 0.0555\,T = \frac{0.0555 \times W_{T/O}}{(W/T)} = \frac{0.0555}{2.2}\,W_{T/O} = 0.02523\,W_{T/O}$$

$$W_{Tail\ Surface} = K_{TS}\,W_{wing} = \left(0.17 + \frac{0.08}{3}\right)W_{wing} = 0.1967\,W_{wing}$$

0.17 wing engine

0.25 fuselage engine

- $$W_{TS+wing} = W_{Tail\ Surface} + W_{wing} = 0.1967\,W_{wing} + W_{wing} = 1.1967\,W_{wing}$$

$$= 1.1967 \times 0.0098\,(W_{T/O})^{1.195} = 0.0117\,(W_{T/O})^{1.195}$$

- $W_{Power\ Plant} = \dfrac{W_{T/O}}{3.58\ W/T} = \dfrac{1}{3.58 \times 2.2} W_{T/O} = 0.12697\ W_{T/O}$

- $W_{fuel} = 1.0275 \times \dfrac{W_{fuel}}{W_{T/O}} \times W_{T/O} = 1.0275 \times 0.35 \times W_{T/O}$

$= 0.359625\ W_{T/O}$

- $W_{Payload} = 215\ PAX + W_{cargo} = 215 \times 210 + 8000 = 53150\ \#$

- $W_{fixed\ equipment} = 132\ PAX + 300\ \#s$ of engine $+ 0.035\ W_{T/O}$

$+ 260\ N_{Flight\ Crew} + 170\ N_{Cabin\ attendants}$

$= 132 \times 210 + 300 \times 3 + 0.035 \times W_{T/O}$

$+ 260 \times 2 + 170 \times 6 = 30160 + 0.035\ W_{T/O}$

$$W_{TS+wing} + W_{fuselage} + W_{Landing\ Gear} + W_{Nacelle+Pylon} + W_{Power\ Plant} + W_{fuel} + W_{Payload} + W_{fixed\ equipment} = W_{T/O}$$

$$0.0098(W_{T/O})^{1.195} + 1968.2365\,(W_{T/O})^{0.235} + 0.040 \times W_{T/O} + 0.02523\ W_{T/O} + 0.12697\ W_{T/O} + 0.359625\ W_{T/O} + 53150 + 30160 + 0.035\ W_{T/O} - W_{T/O} = 0$$

$$0.0117(W_{T/O})^{1.195} + 1968.2365\,(W_{T/O})^{0.235} - 0.413175\ W_{T/O} + 83310 = 0$$

$\Rightarrow W_{T/O} = 477897\ \#$

$$S_{REF} = \frac{W_{T/O}}{WL_{T/O}} = \frac{477897}{125} = 3873\ [ft^2]$$

$$AR = \frac{b^2}{S_{REF}} \Rightarrow b = \sqrt{AR\ S_{REF}} = \sqrt{8 \times 3873} = 176\ [ft]$$

$$M.A.C. = \frac{S_{REF}}{b} = \frac{3873}{176} = 22 \ [ft]$$

$$\text{Thrust} = \frac{W_{T/O}}{W/T} = \frac{477897}{2.2} = 217226 \ \#$$

$$\text{Thrust per engine} = \frac{\text{Thrust}}{\#\text{s of engine}} = \frac{217226}{3} = 72408.6 \ \#$$

DRAG

This section works with assumption $M = 0.5$ & $h = 20{,}000$ [ft]

Reynolds number over characteristic length:

$$\frac{Re}{\ell} = \frac{\rho V_{M=0.5}}{\mu} = 1.426 \times 10^6 \left[\frac{1}{ft}\right]$$

Parasite drag

WING:

$b = 176$ [ft]
$S_{REF} = 3873$ [ft²]
$t/c = 0.1$ [1]
$\Lambda = 35°$
$\lambda = 0.35$
$MAC = 22$ [ft]

Reynolds number:

$$Re = 1.426 \times 10^6 \; MAC = 1.426 \times 10^6 \times 22 = 31372000 \; [1] \quad [1]$$

Friction coefficient:

Figure 11.2 $\Rightarrow$ $c_f = 0.002765$

Form factor:

Figure 11.3 $\Rightarrow$ $k = 1.19$

Wetted area:

$$S_{wet} = 2\,(S_{ref} - 20 \times 30)\,1.02 = 2(3873 - 20 \times 30)\,1.02 = 6677 \; [ft^2]$$

Drag area:

$$f = k\, c_f\, S_{wet} = 21.05 \; [ft^2]$$

FUSELAGE

$$L = 179 \text{ [ft]}$$
$$D = 20 \text{ [ft]}$$
$$S_{wet} = 10122 \text{ [ft}^2\text{]}$$

Reynolds number:

$$Re = 1.426 \times 10^6 L = 255254000 \text{ [1]}$$

Friction coefficient:

Figure 11.2 $\Rightarrow$ $C_f = 0.00183$

Form factor:

$L/D = 8.36$ & Figure 11.4 $\Rightarrow$ $K = 1.1135$

Drag area

$$f = K \, C_f \, S_{wet} = 20.635 \text{ [ft}^2\text{]}$$

OTHER

Tail Surface:

$$f = 0.38 \, f_{wing} = 8 \text{ [ft}^2\text{]}$$

Nacelle:

$$f = 1.25 \times C_{f\,wing} \times S_{wet\ nacelle} = 5.87 \text{ [ft}^2\text{]}$$

Pylon:

$$f = 0.2 \times f_{nacelle} = 1.174 \text{ [ft}^2\text{]}$$

TOTAL

$$f_{total} = \Sigma f = 60.133 \ [ft^2]$$

$$C_{D_p} = \frac{f}{S_{ref}} = 0.0161$$

$$e = \frac{1}{1.035 + 0.38 C_{D_p} \pi AR} = 0.84$$

CLIMB

$$W_{climb} = \frac{1+0.965}{2} W_{T/O} = 464722.5 \,[lb]$$

$$V_{(L/D)max} = \frac{12.9}{(f e)^{1/4}} \left(\frac{W}{\sigma b}\right)^{1/2} = 332.11$$

$$V_{climb} = 1.3\, V_{(L/D)max} = 431.744 \text{ KTS} \Rightarrow M = 0.749$$

$$T_r = Drag = \frac{\sigma f v^2}{296} + \frac{94.1}{\sigma e}\left(W/L\right)^2 \frac{1}{v^2}$$
$$= 29196.7 \,[lb]$$

$$T_a)_{JT9D} = 15400 \text{ lb}, \; M = 0.65 \text{ at } 20\,000 \,[ft]$$

$$T_a = \frac{\text{Thrust per engine}}{\text{Thrust sea level static}} \times T_a)_{JT9D} = 24604.23 \,[lb]$$

$$R/C = 101 \frac{T_a - T_r}{W} V = 4186.44$$

$$Time_{climb} = \text{Initial cruise altitude} / R/C = 8.36 \,[hr]$$

$$Range_{climb} = V_{climb} \times Time = 60.1586 \,[nmi]$$

$$W_{fuel\ climb} = N_{engine} \times T_a \times M \times Time / 60$$
$$= 6685.73 \,[lb]$$

RANGE

LOOP

These sections are in range loop:

C_L LOOP

TAKE OFF FIELD LENGTH

WEIGHT LOOP

DRAG

CLIMB

Next section in Range loop

RANGE

$$W_0 = W_{t/o} - W_f)_{CL} = 327000 - 5717 = 321283 \ lb$$

$$W_1 = (1 - W_f / W_{to}) \ W_{t/o} = (1 - 0.3) \ 342000 = 239206$$

$$C_L)_{Average} = \frac{(W_0 + W_1)/2 \ S_{REF}}{1481 \times 0.236 \times M^2} = 0.474$$

$$C_{Di} = \frac{C_L)_{AVG}^2}{pi \ AR \ e} = 0.010815$$

0.001

$$C_{D \, total} = C_{DP} + C_{Di} + \Delta C_{DC} = 0.030152$$

$$\frac{L}{D} = \frac{C_L)_{Average}}{C_{D \, total}} = 0.030152$$

$$T_r = \frac{W_0 + W_1}{2} \div \frac{L}{D} = 18321.4$$

$$T_r)_{JT9D} = T_r \times \frac{T_{JT9D \ sea \ level \ static}}{T_{per \ engine}} = 5267 \ lb$$

At 35K $\quad M = 0.8$

Specific fuel Consumption, SFC, $c = 0.6145$

$$R_{Cruise} = \frac{V}{c} \frac{L}{D} \ln\left(\frac{W_0}{W_1}\right) = 3885.37 \ (nmi)$$

$$R = R_{cruise} + R_{climb} = 3885 + 84.6 = 3970 \ (nmi)$$

Finished Range loop! Vary Weight fuel takeoff step 8 in C_L loop to get Correct Range

CLIMB
PERFORM
-ANCE

TOP CLIMB

$$C_{L_{IC}} = \frac{W_0/S_{REF}}{1481 \times 0.7362 \times M^2} = 0.5578$$

$$C_{D_i} = \frac{{}^2}{\pi AR e} = 0.01525$$

$$C_D = C_{D_i} + C_{D_p} + \Delta C_{D_c} = 0.03689$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 15.1$$

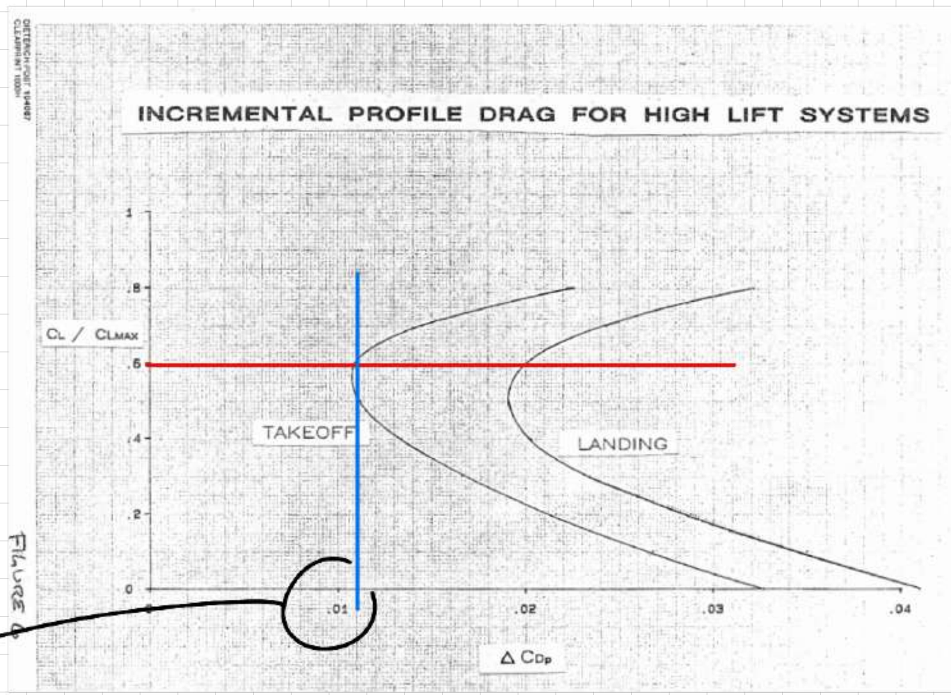
$$T_r = \frac{W_0}{L/D} \div \#\text{ of engines} = 5668.66 \text{ lb}$$

$$T_r)_{JT9D} = T_r \times \frac{T_{\text{sea level static}}}{T_{\text{per engine}}} = 7232.1 < 10\,000 \checkmark$$

Segment 1

$$C_{L\,takeoff} = \frac{C_{L\,max\,take\,off}}{1.2^2} = 1.296$$

$$\frac{C_{L\,take\,off}}{C_{L\,max\,take\,off}} = 0.592$$



$$\Delta C_{Dp} = 0.014$$

$$C_{Di} = \frac{C_L^2}{\pi AR e} = 0.08233$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \Delta C_{D\,gear} + C_{Di}$$

$$C_D = 0.131466$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 9.857$$

$$T_r = \frac{W_{Take\ off}}{L/D} = 26580 \text{ lb}$$

$$\frac{T_a}{N_{engine}} = \frac{T_{per\ engine}}{T_{sea\ level\ static}} \times T_{Max\ limit\ operating\ dry\ take\ off}$$

$$= 27641.186 \text{ lb}$$

$$\text{Gradient} = \frac{(\#s\ of\ engine - 1) \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 10.955\ \%$$

Segment 2

$$C_D = C_{Dp} + \Delta C_{Dp} + C_{Di} = 0.117$$

$$\frac{L}{D} = \frac{C_L^{\leftarrow seg\ 1}}{C_D} = 11.07$$

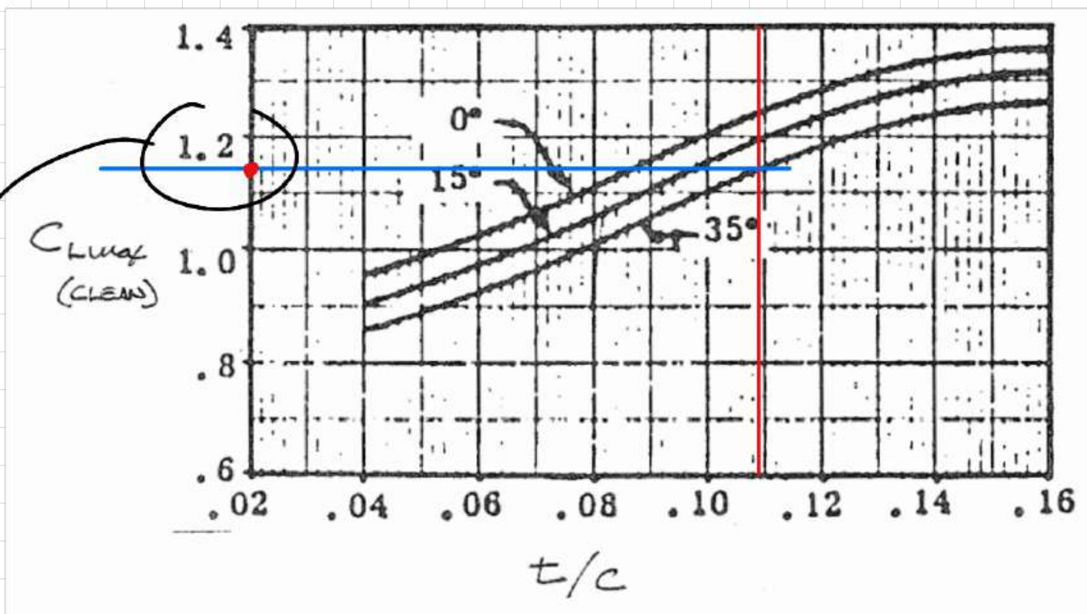
$$T_r = W_{Take\ off} / (L/D) = 23648 \text{ lb}$$

$$\text{Gradient} = \frac{(\#\text{s of engine} - 1) \times \overset{\text{seg 1}}{\left(\frac{T_a}{N_{engine}}\right)} - \overset{\text{seg 2}}{T_r}}{W_{take\ off}} \times 100\%$$

$$= 12.674\%$$

Segment 3

$t/c = 0.108 \quad \Lambda = 35°$



$C_{L_{max}})_{clean} = 1.14467$

$$V = 1.2 \sqrt{\frac{296 \times \frac{W}{S})_{take\ off}}{6.9204 \times C_L}} = 226.8 \text{ KTS}$$

$$M = \frac{V}{c} = \frac{226.8}{659} = 0.344$$

$$C_L = \frac{C_{L\,max})_{clean}}{(1.2)^{\wedge}2} = 0.795$$

$$C_D = C_{Dp} + \frac{C_L^2}{\pi AR\, e} = 0.0516$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 15.4$$

$$T_r = \frac{W_{TO}}{L/D} = 17011.6 \text{ lb}$$

$$T_{JT9D\ Mx\ climb\ condition} = 27318 \text{ lb}$$

$$\frac{T_a}{\#s\ of\ engine} = \frac{T_{per\ engine}}{T_{sea\ level\ stic}} \times 27318 = 21412.4 \text{ lb}$$

Segment 3

$$\text{Gradient} = \frac{(\#\text{s of engine} - 1) \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 9.85\%$$

APPROACH

$$C_L)_{approach} = \frac{C_{L\,max\ take\ off}}{1.3^2} = 1.1$$

$$\frac{C_{L\,approach}}{C_{L\,max\ T/O}} = 0.5917 \Rightarrow \Delta C_p = 0.01083$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \frac{C_L^2}{\pi A\!\!R e} = 0.189$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 12.1$$

$$W_{Landing} = \frac{W}{S}\Big)_{landing} \times S_{REF} = 199865\ lb$$

$$T_r = \frac{W_{landing}}{L/D} = 16514.5 \text{ lb}$$

$$V = \sqrt{\frac{296 \left.\frac{W}{S}\right)_{landing}}{0.953 \times \left.C_L\right)_{approach}}} = 165.2 \text{ kTS}$$

$$M = \frac{V}{\text{sound velocity}} = \frac{V}{667} = 0.2476$$

$$T_{JT9D \text{ Max clim condition}} = 29492.3 \text{ lb}$$

$$\frac{T_a}{\#\text{s of engine}} = \frac{T_{per\ engine}}{T_{sea\ level}} \times \checkmark = 23116.67 \text{ lb}$$

$$\text{Gradient} = \frac{\left(\#\text{s of engine} - 1\right) \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 14.87\ \%$$

LANDING

$$C_L = \frac{C_{L\,max\ landing}}{(1.3)^2} = 1.653$$

$$\frac{C_{L\,landing}}{C_{L\,max\ landing}} = 0.592 \Rightarrow \Delta C_{Dp} = 0.02$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \Delta C_{D\,gear} + \frac{C_L^2}{\pi A\!\!R\, e}$$

$$= 0.189$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 8.74$$

Same value in approach section

$$T_r = \frac{W_{Landing}}{\frac{L}{D}} = 22856.77 \text{ lb}$$

given in specs

$$M = \frac{V}{C} = \frac{V}{667} = 0.2024$$

$$T_{JT9D\ M_{landing}\ Dry} = 37310.85 \text{ lb}$$

$$\frac{T_a}{\#s\ \text{of engine}} = \frac{T_{\text{per engine}}}{T_{\text{sea level static}}} \times \checkmark = 29245\ \text{lb}$$

$$\text{Gradient} = \frac{\#s\ \text{of engine} \times \frac{T_a}{N_{\text{engine}}} - T_r}{W_{\text{take off}}} \times 100\%$$

$$= 32.46\ \%$$

DIRECT

OPERATING

COST

Block velocity

$D = 1.15 \times R = 4025$ nmi

$T_{gm} = 0.25$ hr $\quad T_{CL} = 0.1D \quad T_D = 0 \quad T_{am} = 0.1$

$$T_{cruise} = \frac{D + k_a + 20 - D_{CL}}{V_{cr}} = 7.6 \text{ hr}$$

$$V_b = \frac{D}{\Sigma \text{Time}} = 493.6 \text{ mph}$$

Block time

$T_B = 13.33$ hr

Block fuel

$F_{CL} = W_{fuel\ climb} = 4855$ lb

$F_{cr} + F_{AM} = T_r)_{range} \times C_{at\ 35k} \times T_{cruise} = 72010$

$$F_B = (F_{cr} + F_{AM}) + F_{CL} = 76865 \text{ lb}$$

Fly operating cost

(a) Flight Crew

$$\text{Payload} = \frac{W_{payload}}{2000} = 26.575$$

$$\frac{Cost}{block\text{-}hour} = 17.849 \times \left(V \times \frac{W_{takeoff}}{10^5}\right)^{0.3} + 40.83 = 1973$$

$$\frac{Cost_{flight\text{-}crew}}{ton\text{-}mile} = \frac{}{V_{Block} \times Payload} = 0.015$$

(b) Fuel & oil

$$\frac{Cost_{fuel+oil}}{ton\text{-}mile} = \frac{1.02\, F_B C_F + N_e C_{OT} + T_B \times 0.135}{D \times P}$$

$$= 0.0458$$

(c) Hull Insurance

$$W_a = W_{T/O} - W_{fuel} - W_{PL} - W_{PP}$$

$$= 93839.2 \text{ lb}$$

$$C_a = 2.4 \times 10^6 + 87.5\, W_a = \$10610928.7$$

$$C_e = 590\,000 + 16\, T_e = \$1160621.868$$

$$C_T = C_a + N_e C_e = \$14092754$$

$$U = 630 + \frac{4000}{1 + \frac{1}{T_B + 0.5}} = 4215.68$$

$$C_{T\ \text{insurance}} = \frac{IRA \times C_T}{U\ V_B\ P} = \$0.0025485 / \text{ton-mile}$$

(d) Direc maintenance

a. Air-frame — Labor

$$K_{FHa} = 4.9169\ \log_{10}\left(\frac{W_a}{10^3}\right) - 6.425 = 3.273$$

$$K_{FCa} = 0.21256\left[\log_{10}\left(\frac{W_a}{10^3}\right)\right]^{3.7375} = 2.6$$

$$T_F = T_B - T_{gm} = 7.9\ hr$$

$$R_L = \$8.6$$

$$C_{Tm} = \frac{K_{FHa} \times T_F + K_{FCa}}{V_B\ T_B\ P} \times R_L = \$0.002 / \text{ton-mile}$$

b. Airframe — Material

$$K_{FHa} = 1.5994 \times \frac{C_a}{10^6} + 3.4263 = 20.4$$

$$K_{FCa} = 1.922 \times \frac{C_a}{10^6} + 2.2504 = 22.6$$

$$C_{Tm} = \frac{K_{FHa} \times T_F + K_{FCa}}{V_B\ T_B\ P} = \frac{\$0.00172}{\text{ton-mile}}$$

c. Engine - labor

$$k_{FH_e} = \frac{N_e (T_e/10^3)}{0.82715 \frac{T_e}{10^3} + 13.639} = 2.48$$

$$k_{FC_e} = 0.2 \times N_e = 0.6$$

$$T_F = T_B - T_{gm} = 7.9\ hr$$

$$R_L = \$8.6$$

$$C_{TM} = \frac{k_{FH_e} \times T_F + k_{FC_e}}{V_B \ T_B \ P} \times R_L = \frac{\$0.002}{\text{ton-mile}}$$

$$= \$0.00162 / \text{ton-mile}$$

d. Engine - Material

$$k_{FH} = \left(28.23 \times \frac{C_e}{10^6} - 6.57\right) N_e = 78.75$$

$$k_{FC_e} = \left(3.66 \times \frac{C_e}{10^6} - 1.36\right) N_e = 16.88$$

$$C_{TM} = \frac{k_{FH_e} \times T_F + k_{FC_e}}{V_B \ T_B \ P} = \frac{\$0.00597}{\text{ton-mile}}$$

e. Total

$$C_{TM} = \Sigma(a+b+c+d) \times 2 = \frac{\$0.02323}{\text{ton mile}}$$

(e) Depreciation

$$C_{Tm} = \frac{1}{V_B \times P}\left(\frac{C_T + 0.6(C_T - N_e C_e) + 0.3 N_e C_e}{D_a V}\right)$$

$$= \frac{\$\,0.026375}{\text{ton - mile}}$$

Total DOC

$$DOC = \sum(a + b + c + d + e)$$

$$= \frac{\$0.107078}{\text{ton - mile}}$$

$$\times \frac{\text{Payload}}{PAX} = \frac{\$0.01355}{PAX \times \text{mile}}$$