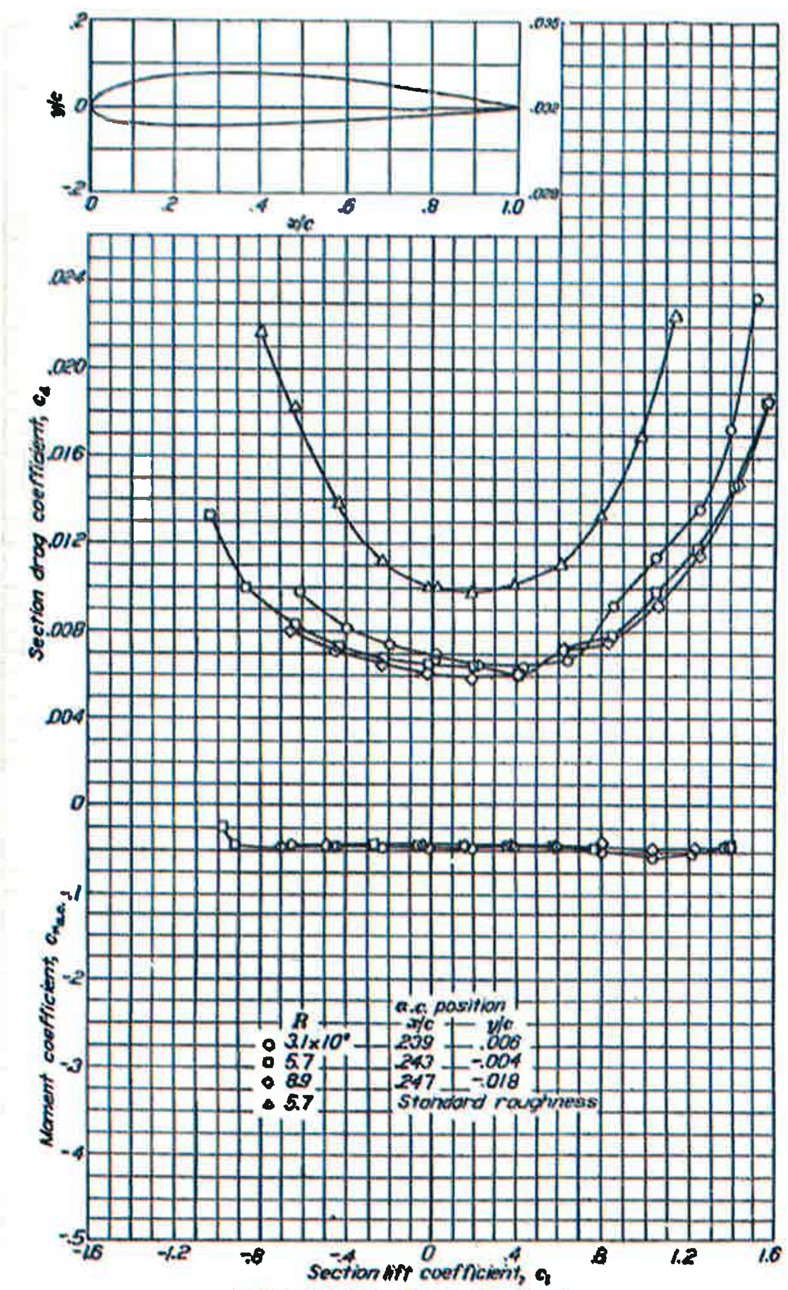
AEM 313 Problem Set #8

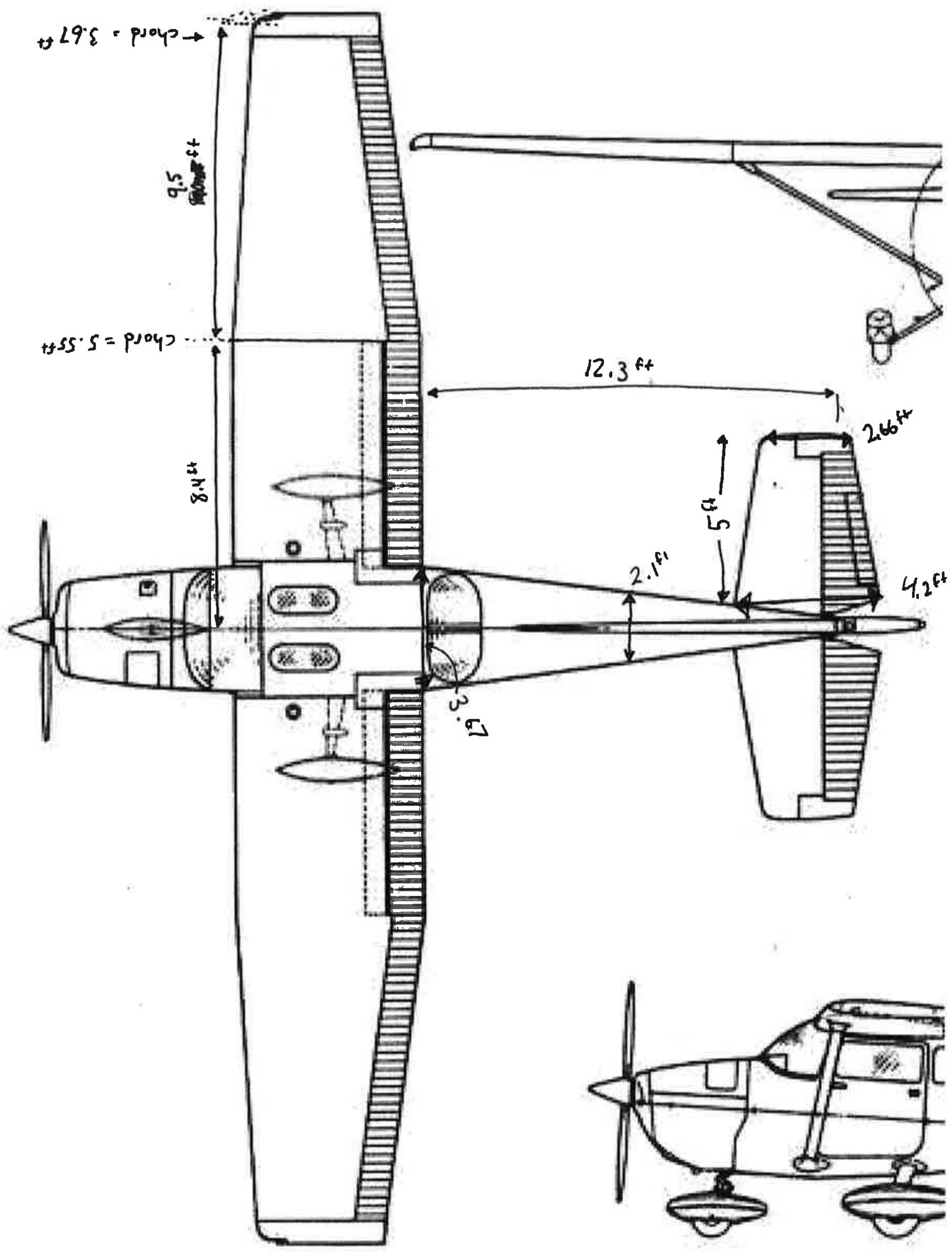
Due: 20th November 2017

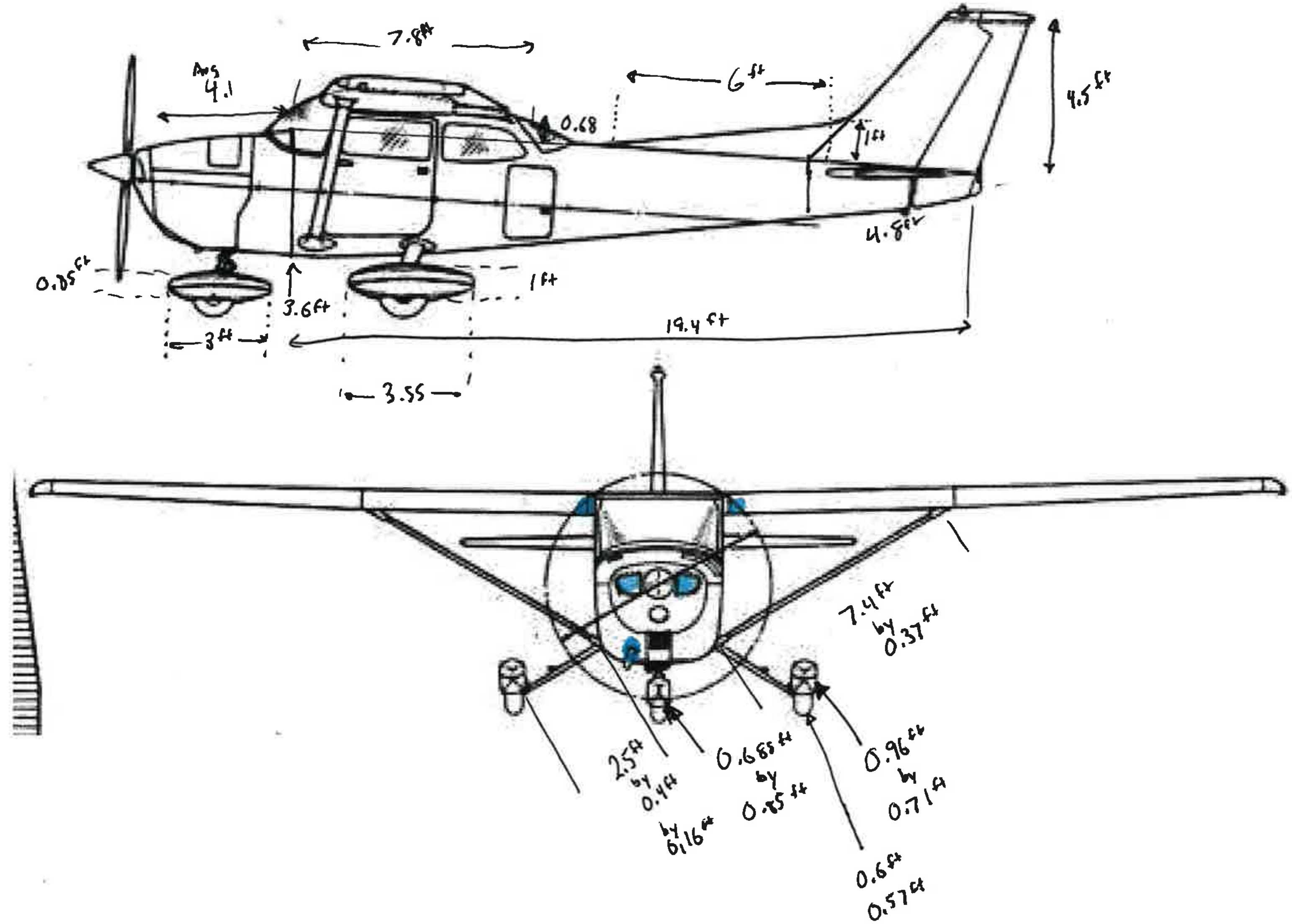
1. Estimate the total wetted area of the Cessna 172 (b=36 ft, S=174 sq-ft) below
2. Estimate the drag of the landing gear (reference area S=174 sq-ft)
3. Estimate C_{D0} given the NACA 2412 airfoil and a flat plate approximation elsewhere.

Cessna 172 3-view drawing on following page



NACA 2412 Wing Section (*Continued*)


chord = 3.67 ft
9.5 ft
chord = 5.55 ft
8.4 ft
12.3 ft
2.66 ft
5 ft
2.1 ft
4.2 ft
3.67

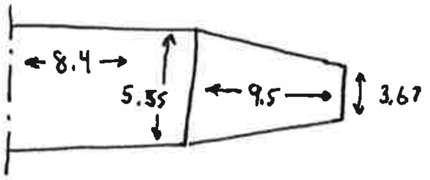

7.8ft
Avg 4.1
6ft
0.68
1ft
4.5ft
4.8ft
0.85ft
1ft
3.6ft
3ft
19.4ft
3.55
7.4ft by 0.37ft
2.5ft by 0.4ft by 0.16ft
0.68ft by 0.85ft
0.96ft by 0.71ft
0.6ft 0.57ft

Scale

$36'$ span $= 3.925^{unit} \cdot 2 = 7.850^{unit} \Rightarrow 4.59\ ^{ft}/_{unit}$

where my measuring unit is inches with calipers

Verify Wing Area

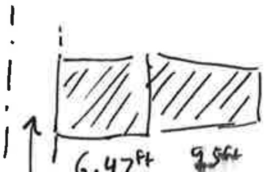


$$A = (8.4)(5.55) + \frac{(5.55 + 3.67)}{2} \cdot (9.5) = 90.4$$

$$S = 2A \approx 180^{ft^2} \approx \text{off by } \frac{6}{180} \approx 3\%$$

Wetted Area

Wing (Don't count fuselage!)



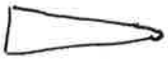
$A \approx 10.7^{ft^2}$

$\Rightarrow A_{wp} = 80^{ft^2}$

$S_{wet_{wing}} = 4 \cdot A_{wp} =$ [illegible] 320^{ft^2}

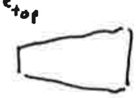
fuselage

Aft_{top}



Average width $\approx 2.1^{ft}$
Length $12.3\ ft$ $\Rightarrow 25.8^{ft^2}$

$Fore_{top}$

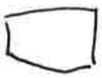


width $\approx 3.6^{ft}$
Length ≈ 10.7 $\Rightarrow 38.5^{ft^2}$

Aft_{side}

$\approx 69.8^{ft^2}$

$Fore_{side}$

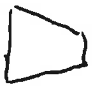


$\approx 16^{ft^2}$

Cockpit

$\approx 5^{ft^2}$

Horizontal



$$\left(\frac{4.2 + 2.66}{2}\right)(5) = 17.1^{ft^2}$$

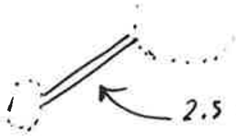
Vert

$$\frac{(6)}{2}(1) + (4.8)(4.5) = 24.6$$

Strut

$7.4^{ft} \times 0.37^{ft} = 2.7^{ft^2}$

Main Gear



$2.5 \times 0.4 = 1^{ft^2}$

Pants

$3 \times 0.85 = 2.55^{ft^2}$

$3.55 \times 1 = 3.55$

Total Wetted Area

$$S_{wet} = \overset{\text{wing}}{320} + \overbrace{\overset{\text{fuse Aft} ~~\text{top}~~}{(25.8)(2)} + \overset{\text{fuse fore}}{(38.5)(2)} + \overset{\text{fuse side aft}}{(69.8)(2)} + \overset{\text{fuse side fore}}{(16)(2)} + \overset{\text{cockpit}}{(5)(2)}}^{\approx 310^{ft^2}}$$

$$+ \overset{\text{horizontal}}{(17.1)(2)} + \overset{\text{vertical}}{(24.6)(2)} + \overset{\text{strut}}{(2.7)(4)} + \overset{\text{main strut}}{(1)(2)} + \overset{\text{nose}}{(2.55)(2)} + \overset{\text{main}}{(3.55)(2)}$$

$$\approx 739^{ft^2} \approx \boxed{740^{ft^2} = S_{wet}}$$

$$\frac{S}{S_{wet}} = 0.235$$

Landing Gear Drag

Nose

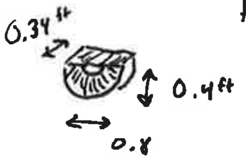
$\varnothing \approx 2.5^{in} \approx 0.21^{ft}$

Image is when the a/c is on the ground. In flight, the strut is fully extended
Estimated at 1.1 ft in length from image (I think it is more in reality....)

$C_D \approx 0.6$ Frontal Area $\approx 0.21 \cdot 1.1 = 0.23\ ft^2$ $f = 0.14\ ft^2$

$\not\Rightarrow C_{D_{\text{frontal area}}} \approx 0.06$ if similar to a fuselage shape

Frontal Area $\approx 0.58 ft^2$ $\Rightarrow f \approx 0.035 ft^2$



$C_D \approx 0.3$ Frontal Area $\approx 0.4 \times 0.34 \Rightarrow f = 0.04\ ft^2$

Main (1x)

part

$0.06 \cdot 0.96 \cdot 0.71$ $f = 0.04\ ft^2$

wheel

$0.3 \cdot 0.6 \cdot 0.57$ $f = 0.10\ ft^2$

~~wheel~~ Strut

$2.5^{ft} \times 0.16^{ft}$ with $C_D \approx 0.3 \Rightarrow f = 0.12\ ft^2$

Total

$$f = \underbrace{0.14 + 0.035 + 0.04}_{\text{front } 0.215} + \underbrace{2(0.04 + 0.10 + 0.12)}_{0.52} = 0.735\ ft^2$$

$$C_D = \frac{f}{S} = \frac{0.735}{174} \approx 42 \text{ counts}$$

C_{D_0}

Wing

$C_d \approx 0.006$ $\quad C_d = \frac{D'}{\frac{1}{2}\rho V^2 c}$ $\quad C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$

$f = (0.006)(90.4)(2) = 1.085\,ft^2$ $\quad C_D \approx 62$ counts

Horizontal

Assume $V_\infty \approx$ ~~100~~ $110^{kts} \approx 185\,ft/s$

$$C_f = \frac{0.074}{Re^{1/5}}$$

$\bar{c} \approx 3.5^{ft} \Rightarrow Re \approx 6350 \cdot 185\,ft/s \cdot 3.5^{ft} = 4\times10^6$

$C_f = 0.00353$ per side

$C_D = C_f \cdot \frac{2S_h}{S} = 0.00353 \cdot \frac{(17.1\,ft^2)2\cdot2}{174\,ft^2} \approx$ ~~0.0007~~ 0.0014

Vertical

$\bar{c} \approx 4.5^{ft} \Rightarrow R_e \approx 5.3\times10^6$

$C_f = 0.003347$ per side per area

$C_D = C_f \cdot \frac{2S_v}{S} = 0.003347 \cdot 2 \cdot \frac{24.6}{174} = 0.00095$

Fuselage

- $l_{fuse} \approx 23$ ft
  $d_{max} \approx 4.5$ ft
  $l/d \approx 5.1 \Rightarrow C_{d_\square} \approx 0.06$ from fig ~~in~~ lesson 23 page 15

  frontal area

  $C_D = 0.06 \cdot \frac{3.67^{ft} \cdot 4.5^{ft}}{174\,ft^2} \approx 0.0057$

- Flat plate
  $l \approx 23$ ft $\Rightarrow Re \approx 27\times10^6 \Rightarrow C_f \approx 0.0024$

  $C_D \approx 0.0024 \cdot \frac{310\,ft^2}{174\,ft^2} = 0.0043$ ← lower than above because the actual fuselage has depth and width.

Strut

$C_d \approx 0.02$ lookup $\quad$ Frontal Area $\approx 2.5\,ft^2$

$C_D = 0.02 \cdot \frac{2.5}{174} \approx 3$ counts $\quad$ I don't believe this calculation seems too low.

Cooling

Estimate as 1 ft^2 $C_D = \frac{1}{174} = 57$ counts

Rivets

#1000 of 3/16 in rivets

$\frac{\pi D^2}{4} = 0.000192\ ft^2$

$C_d \approx 0.04$

$C_D = \frac{1000 \cdot 0.04 \cdot 0.000192}{174} = 0.000044$ ≈ ½ a count.

Total

$$C_{D_0} \approx \overset{\text{wing}}{62} + \overset{\text{horiz}}{14} + \overset{\text{vert}}{9.5} + \overset{\text{fuse}}{57} + \overset{\text{gear}}{42} + \overset{\text{cooling}}{57} + \overset{\text{strut}}{3}$$

$$\approx \boxed{244.5 \text{ counts}}$$

too low!