MAE 158: Aricraft Performance
Recommended Homework #8

Jordi Ventura Siches

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Recall, from last week's homework:
The Bede BD-5J is a very small single-seat home-built jet airplane which became available in the early 1970s. The data for the BD-5J are as follows

- Wing span: 17 ft
- Wing planform area: 37.8 ft^2
- Gross weight at takeoff: 960 lb
- Fuel capacity: 55 gal
- Power plant: one French-built Microturbo TRS 18 turbojet engine with maximum thrust at sea level of 202 lb and a specific fuel consumption of 1.3 lb/(lb · h)

We will approximate the drag polar for this airplane by

$$C_D = 0.02 + 0.062C_L^2$$

Also, assume:
Free roll time of 3 seconds
$\Delta C_{D,0,\text{configuration}} = 0.0124$
No reverse thrust
C_L on the runway of 0.1
$C_{L,\text{ max, landing}} = 2.7$
You may neglect ground effect
$V_{\text{REF}} = 1.3\,V_{\text{stall}}$, $V_{TD} = 1.15\,V_{\text{stall}}$, $V_{\text{flare}} = 1.23\,V_{\text{stall}}$

- **6.8** For the BD-5J (see Problem 5.1), calculate the total landing distance, starting with the clearance of a 50-ft obstacle, assuming the landing weight is the same as the takeoff gross weight. the runway is firm dirt with a brakes-on coefficient of rolling friction of 0.3. the approach angle is 4º.
  The total landing distance will be the sum of the flare distance s_f, the approach distance s_a and the total ground distance s_g.
  - For the flare distance, to compute the radius of flare, we need the flare velocity V_f

    $$V_f = 1.23\,V_{\text{stall}} = 1.23\sqrt{\frac{2W}{\rho S C_{L,\max}}} = 1.23\sqrt{\frac{2 \cdot 960\,\text{lb}}{0.002377\,\text{slug }/\text{ft}^3 \cdot 37.8\,\text{ft}^2 \cdot 2.7}} = 109.3\,\text{ft/s}$$

    where we have used that the landing weight equals the gross weight. The radius is

    $$R = \frac{V_f^2}{g(n-1)} = \frac{(109.3\,\text{ft/s})^2}{32.2\,\text{ft/s}^2 \cdot (1.2-1)} = 1855\,\text{ft}$$

    where $n = 1.2$ is the typical value of the load factor in the landing. The flare height is

    $$h_f = R(1 - \cos\theta_a) = 1855\,\text{ft}\,(1 - \cos 4^{\text{o}}) = 4.52\,\text{ft}$$

where we have used the fact that the approach trajectory is tangent to the flaring path and so $\theta = \theta_f$. The flaring distance is thus

$$s_f = R\sin\theta_a = 1855\,\text{ft}\cdot\sin(4^{\text{o}}) = 129.4\,\text{ft}$$

– The approach distance can now be computed

$$s_a = \frac{h_c - h_f}{\tan\theta_a} = \frac{50\,\text{ft} - 4.52\,\text{ft}}{\tan 4^{\text{o}}} = 650.39\,\text{ft}$$

– The ground distance is the sum of the free roll distance and the ground roll distance. The free roll distance is the product of the free roll time t_{fr} times the touchdown velocity V_{TD}

$$s_{fr} = t_{fr}\cdot V_{TD} = 3\,\text{s}\cdot 1.15\cdot V_{\text{stall}} = 3\,\text{s}\cdot 102.2\,\text{ft/s} = 306.6\,\text{ft}$$

The ground roll distance is

$$s_{gr} = \left(\frac{j^2}{g\rho C_{L,\max}}\right)\frac{W/S}{\left[\frac{T_{\text{rev}}}{W} + \frac{D}{W} + \mu_r\left(1-\frac{L}{W}\right)\right]_{0.7V_{TD}}} =$$
$$= \left(\frac{1.15^2}{32.2\,\text{ft/s}^2\cdot 0.002377\,\text{slug}\;/\text{ft}^3 2.7}\right)\frac{960\,\text{lb}/37.8\,\text{ft}^2}{\left[0+\frac{7.6\,\text{lb}}{960\,\text{lb}} + 0.3\left(1-\frac{23\,\text{lb}}{960\,\text{lb}}\right)\right]} = 543.1\,\text{ft}$$

where t_{rev} is zero since we don't have reverse thrust and the drag and lift forces are

$$L = \frac{1}{2}\rho V^2 S C_L = \frac{1}{2}0.002377\,\text{slug}\;/\text{ft}^3\cdot(0.7\cdot 102.2\,\text{ft/s})^2\cdot 37.8\,\text{ft}^2\cdot 0.1 = 23\,\text{lb}$$
$$D = \frac{1}{2}\rho V^2 S C_D = \frac{1}{2}0.002377\,\text{slug}\;/\text{ft}^3\cdot(0.7\cdot 102.2\,\text{ft/s})^2\cdot 37.8\,\text{ft}^2\cdot 0.03303 = 7.6\,\text{lb}$$

with

$$C_D = 0.02 + 0.062\,C_L^2 + \Delta C_{D,0} = 0.02 + 0.063\cdot 0.1^2 + 0.0124 = 0.03303$$

The total ground distance is

$$s_g = s_{fr} + s_{gr} = 306.6\,\text{ft} + 543.1\,\text{ft} = 849.7\,\text{ft}$$

All in all, we sum and get

$$s = s_f + s_a + s_g = 129.4\,\text{ft} + 650.39\,\text{ft} + 849.7\,\text{ft} = 1629\,\text{ft}$$

- **15.11** If a DC-9-30, landing at a pressure altitude of 4000 ft at a weight of 85,000 lb, requires a FAR landing-field length of 4900 ft, what is the stalling speed, the approach speed over the 50-ft height, and the ambient air temperature? see Figure 14.15 for the DC-9 $C_{L\max}$ at the landing flap angle of 50 degrees, slats extended. Wing area is 1000 ft^2.
From figure 15.13, we can find the square of the stall velocity from a DC-9 aircraft with a flapping deflection angle of 50º (see figure 1. We get a value of $V_{\text{stall}}^2 = 10.500$ knots, and so, we have $V_{\text{stall}} = 173.8$ ft/s. The approach speed, V_{50}, is the speed at a height of 50ft and is 1.3 times the stall speed, so $V_{50} = 1.3\cdot 173.8\,\text{ft/s} = 225.9\,\text{ft/s}$.

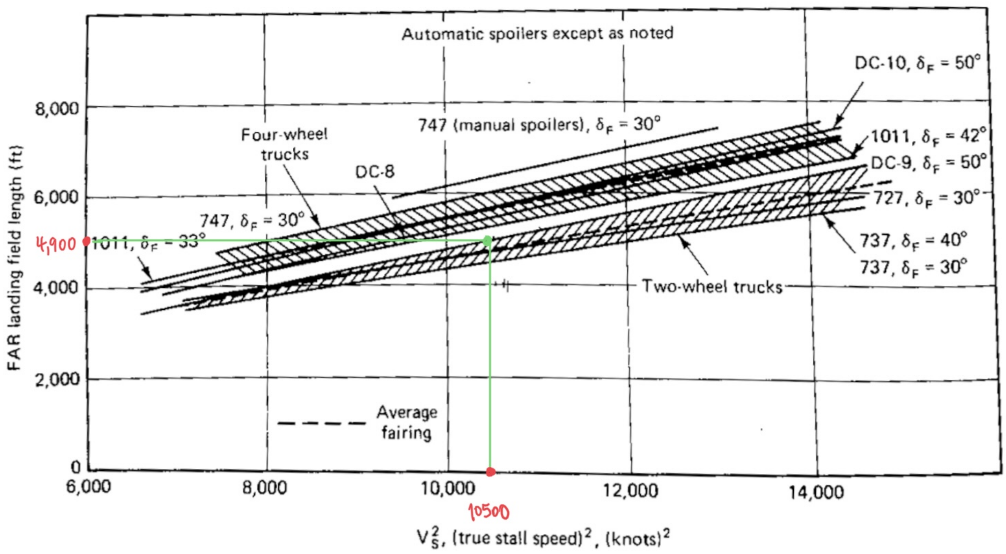

Figure 1: Use of table 15.13

To determine the density we will further need the maximum lift coefficient. We will take it from figure 14.15 with $\delta_F = 50$ degrees (see figure 2). Its value is $C_{L,\,\text{max}} = 3.0$. From the stall velocity we can compute the density:

$$V_{\text{stall}}^2 = \frac{2W}{\rho\, S\, C_{L,\text{max}}}, \qquad \rightarrow \qquad \rho = \frac{2W}{V_{\text{stall}}^2 C_{L,\text{max}}} = \frac{2 \cdot 85000\,\text{lb}}{(173.8\,\text{ft/s})^2\, 1000\,\text{ft}^2\, 3} = 0.001876\,\text{slug/ft}^3$$

From the altitude, we find the pressure to be $p = 1827.7\,\text{lb/ft}^2$ and so, by the equation of state we have

$$T = \frac{p}{\rho R} = \frac{1827.7\,\text{lb/ft}^2}{0.001876\,\text{slug/ft}^3 \cdot 1718\,\text{ft lb/slug}\,^{\text{o}}\text{R}} = 567.1\,^{\text{o}}R = 107.4\,^{\text{o}}F$$

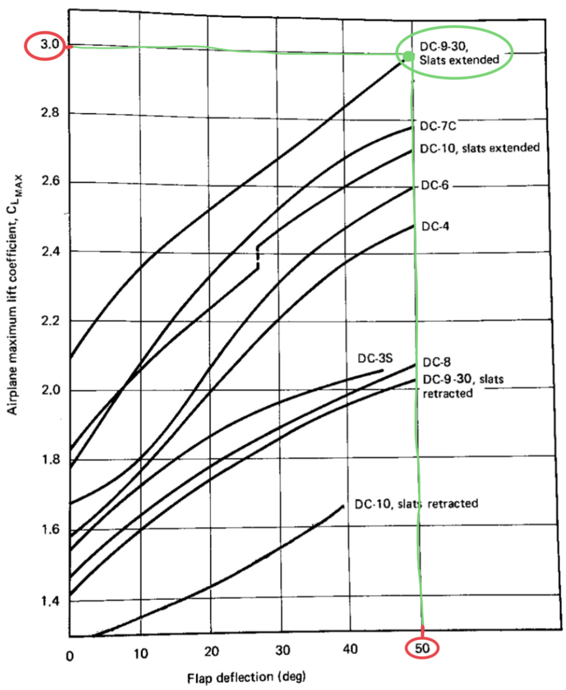

Figure 2: Use of figure 14.15

- **16.2** A fighter airplane is pursuing a target at 22,000 ft on a standard day at $M = 0.87$. The pilot has a pressure suit so that he can withstand a maximum load factor of 6g. What is the fighter's turn radius? What distance must be covered to complete a 180 degree turn? If the fighter has a wing loading of 58 lb/ft^2, what is the lift coefficient?
  Pressure at this altitude is $894.6\,\mathrm{lb/ft^2}$, density is $\rho = 0.011836\,\mathrm{slug/ft^2}$ and temperature is $T = 440.5\,^{\mathrm{o}}\mathrm{R}$. Also, $q = 473.98\,\mathrm{lb/ft^2}$. The true airspeed is $V = M\sqrt{\gamma RT} = 0.87\sqrt{1.4 \cdot 1718\,\mathrm{lb\ ft/slug\ ^oR} \cdot 440.5\,^{\mathrm{o}}\mathrm{R}} = 895.3\,\mathrm{ft/s}$. The turn radius is

  $$R = \frac{V^2}{g\sqrt{n^2-1}} = \frac{(895.3\,\mathrm{ft/s})^2}{32.2\,\mathrm{ft/s^2} \cdot \sqrt{6^2-1}} = 4207.88\,\mathrm{ft}$$

  The distance of half a turn is $d = \pi R = \pi \cdot 4207.88\,\mathrm{ft} = 13219\,\mathrm{ft}$. Finally, the lift coefficient will be

  $$C_L = \frac{L}{qS} = \frac{6W}{qS} = \frac{6(W/S)}{q} = \frac{6 \cdot 58\,\mathrm{lb/ft^2}}{473.98\,\mathrm{lb/ft^2}} = 0.734.$$

- **16.3** A transport flying at 39,000-ft altitude at $M = 0.83$ makes a 180 degree turn. temperature is standard. The pilot limits the bank angle to 25 degrees to avoid alarming the passengers. What is the turn radius and the time to complete the turn?
  At this altitude we have $p = 412.41\,\mathrm{lb/ft^2}$, $T = 390\,^{\mathrm{o}}\mathrm{R}$, $a = \sqrt{1.4 \cdot 1718\,\mathrm{lb\ ft/slug\ ^oR} \cdot 390\,^{\mathrm{o}}\mathrm{R}} = 968.1\,\mathrm{ft/s}$. The true airspeed is then $V = Ma = 0.83 \cdot 968.1\,\mathrm{ft/s} = 803.5\,\mathrm{ft/s}$. The radius is then

  $$R = \frac{V^2}{g\tan\phi} = \frac{(803.5\,\mathrm{ft/s})^2}{32.3\,\mathrm{ft/s^2} \cdot \tan(25\,^{\mathrm{o}})} = 43000\,\mathrm{ft}$$

  The distance covered in a 180 degree turn is $d = \pi R = \pi 43000\,\mathrm{ft} = 135085\,\mathrm{ft}$ and so the time needed is

  $$t = \frac{d}{V} = \frac{135085\,\mathrm{ft}}{803.5\,\mathrm{ft/s}} = 168.12\,\mathrm{s}$$