Problem 2.23

The two major forces opposing the motion of a vehicle are the rolling resistance of the tires, F_r, and the aerodynamic drag force of the air flowing around the vehicle, F_d, given respectively by

$$F_r = f\mathcal{W}, \qquad F_d = C_d A(1/2)\rho V^2$$

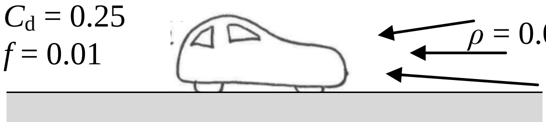
where f and C_d are constants known as rolling resistance and drag coefficient, respectively, $\mathcal{W}$ and A are the vehicle weight and projected frontal area, respectively, V is the vehicle velocity, , and ρ is the air density. For a popular gasoline hybrid car with $\mathcal{W}$= 3040 lbf, A = 6.24 ft^2 and C_d = 0.25, when f = 0.02 and ρ= 0/08 lb/ft^3.
(a) determine the power required, in hp, to overcome rolling resistance and aerodynamic drag when V is 55 mph.
(b) plot versus vehicle velocity ranging from 0 to 90 mi/h (i) the power to overcome rolling resistance, (ii) the power to overcome aerodynamic drag, and (iii) the total power, all in hp. What implications for vehicle fuel economy can be deduced from the results of part (b)?

KNOWN: The drag force and the force associated with rolling resistance are known as functions of variables associated with a vehicle in motion.

FIND: (a) Determine the power required to overcome drag and rolling resistance when the vehicle is moving at 55 mi/h. (b) Plot the quantities of part (a) and their sum versus vehicle velocity ranging from 0 to 90 mi/h. Discuss implications for fuel economy.

SCHMATIC AND GIVEN DATA:

$\mathcal{W}$ = 3040 lbf
A = 6.24 ft^2
C_d = 0.25
f = 0.01



ρ = 0.08 lb/ft^3

ENGINEERING MODEL: The vehicle is the closed system.

ANALYSIS: Applying Eq. 2.13, the power, in hp, required to overcome aerodynamic drag is

$$\dot{W}_d = \mathbf{F}_d \cdot \mathbf{V} = \left(\frac{1}{2}C_d A\rho V^2\right)V = \frac{1}{2}C_d A\rho V^3$$

$$= \frac{1}{2}(0.25)(6.24\text{ft}^2)\left(0.08\ \frac{\text{lb}}{\text{ft}^3}\right)\left[V\frac{\text{mi}}{\text{h}}\left|\frac{5280\text{ ft}}{1\text{ mi}}\right|\left|\frac{1\text{ h}}{3600\text{ s}}\right|\right]^3\left|\frac{1\text{ lbf}}{32.2\text{ lb}\cdot\text{ft/s}^2}\right|\left|\frac{1\text{ hp}}{550\text{ ft}\cdot\text{lbf/s}}\right| \qquad (*)$$

= 1.11 x 10^{-5} [V^3] (where V is in mi/h)

The power, in hp, required to overcome rolling resistance is

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$$\dot{W}_r = \mathbf{F_r} \cdot \mathbf{V} = (f\,\mathcal{W})\mathrm{V}$$

$$= (0.01)(3040\ \mathrm{lbf})\left[\mathrm{V}\,\frac{\mathrm{mi}}{\mathrm{h}}\left|\frac{5280\ \mathrm{ft}}{1\ \mathrm{mi}}\right|\left|\frac{1\ \mathrm{h}}{3600\ \mathrm{s}}\right|\right]\left|\frac{1\ \mathrm{hp}}{550\ \mathrm{ft{\cdot}lbf/s}}\right| = 0.0811\ \mathrm{V}\ \left(\frac{\mathrm{mi}}{\mathrm{h}}\right) \qquad (^{**})$$

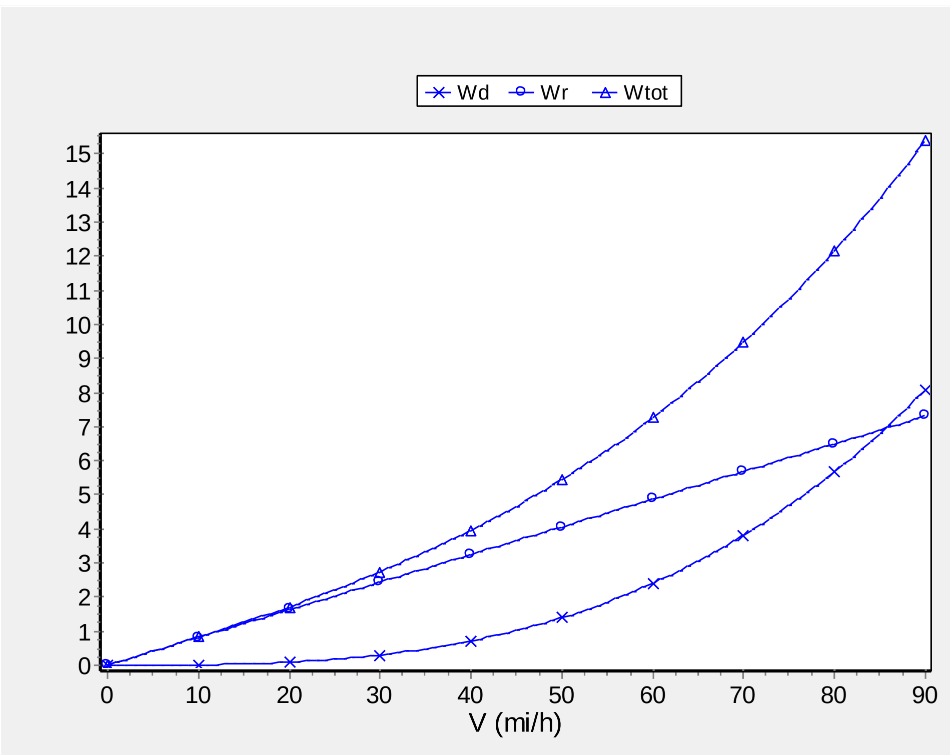
(a) When V = 55 mi/h, we get

$\dot{W}_d$= 1.847 hp

$\dot{W}_r$ = 4.461 hp

$\dot{W}_{\mathrm{total}}$ = 6.308 hp

(b) The plots are developed by letting V vary from 0 to 90 mi/h:



We see from the plots that up to about 87 mi/h, the power required to overcome rolling resistance exceeds the power to overcome aerodynamic drag. However, the total power required increases dramatically with velocity. The aerodynamic drag varies as the cube of velocity, so it increases rapidly and contributes much more significantly as speed increases. The total power required by the engine increases about 5-fold from 30 mi/h to 90mi/h. Since the power is developed by the engine from fuel stored on board the vehicle, high-speed driving has a significant negative effect on fuel consumption.