Consider a NASA Moonbuggy (light, four-wheeled, human-powered, crew of two, open frame, similar to that pictured below) with the following characteristics:

- Operating sprung mass (i.e., with crew) – 400 lbm.
- Unsprung mass per corner (i.e., four of these) – 8 lbm.
- Track width (front and rear) – 48 in.
- Wheelbase – 66 in.
- Longitudinal weight split (front/rear) – 50/50
- Vertical center of mass at ride height – 30 in.
- Effective wheel rate (stiffness) at each corner – 33 lb/in.
- Wheel rolling radius – 12 in.
- Projected frontal area – 10.8 ft²
- Drag coefficient – 0.77

For the case of flat, hard pavement (rolling resistance coefficient 0.02), size a single-cylinder 4-stroke internal combustion engine (with associated final drive reduction) that will propel the GV at a speed of 13.9 mph (must add weight for engine – must retain a crew of two). Assume a combustion efficiency of 1.0, a volumetric efficiency of 0.85, a mechanical efficiency of 0.93, a thermal efficiency of 0.52, a fuel/air ratio of 0.068, a fuel heating value of 43.2 MJ/kg, and natural aspiration on the Earth’s surface (air density 1.2 kg/m³). A reasonable bmep is 8 atmospheres. The mean piston speed must be 10 m/s.

Report:
- Bore, in. and mm
- Stroke, in. and mm
- Displacement, in³ and cc
- Rpm at 13.9 mph
- Engine weight in lbm and kg
- Air flow rate in cfm and l/s
- Fuel flow rate in gpm and l/s
- Bmep in atm, psi, and kPa
- Bsfc in lbm/hp·h and g/kW·h
- Overall drivetrain reduction ratio
Solution

\[ F_{\text{drag}} = \frac{1}{2} \rho_{\text{air}} V^2 C_D A + C_R mg \]

\[ F_{\text{drag}} = \frac{1}{2} \left( \frac{1.2 \text{ kg}}{\text{m}^3} \right) \left( 6.214 \frac{\text{m}}{s} \right)^2 \left( 0.77 \left( 1.005 \text{ m}^2 \right) \right) + \left( 0.02 \right) \left( 196 \text{ kg} \right) \left( 9.81 \frac{\text{m}}{s^2} \right) = 56.4 \text{ N} \]

\[ \dot{W} = F_{\text{drag}} V = 350 \text{ W} \]

\[ \dot{W} = \text{bmepr} \frac{V_d}{2} = \text{bmepr} \frac{\pi}{4} B^2 S \frac{n}{2} = \text{bmepr} \frac{\pi}{16} B^2 \bar{U}_p \]

\[ B = \left( \frac{16 \dot{W}}{\pi \text{bmepr} \bar{U}_p} \right)^\frac{1}{2} = \left[ \frac{16 (350 \text{ W})}{\pi (8 \text{ atm}) (101325 \frac{\text{N}}{\text{m}^2 \text{atm}}) (10 \frac{\text{m}}{s})} \right]^\frac{1}{2} = 14.8 \text{ mm} = 0.583 \text{ in.} \]

\[ S = B = 14.8 \text{ mm} = 0.583 \text{ in.} \]

\[ n = \frac{\bar{U}_p}{2S} = \frac{10 \frac{\text{m}}{s}}{2 (0.0148 \text{ m})} = 337 \frac{\text{rev}}{s} = 20,220 \text{ rpm} \]

\[ V_d = \frac{\pi}{4} B^2 S = 2.55 \text{ cc} = 0.156 \text{ in.}^3 \]

\[ \text{weight} \approx (0.350 \text{ kW}) \left( 5.5 \frac{\text{kg}}{\text{kW}} \right) = 1.92 \text{ kg} \]

Adjust for addition of engine weight

\[ \dot{W} = 353 \text{ W} \]

\[ B = 15 \text{ mm} = 0.59 \text{ in.} \]

\[ S = 15 \text{ mm} = 0.59 \text{ in.} \]

\[ V_d = 2.65 \text{ cc} = 0.162 \text{ in.}^3 \]

\[ n = 20,000 \text{ rpm} \]

\[ \text{weight} \approx 2 \text{ kg} \]
Further figures:

\[ \dot{V}_{air} = \frac{n}{2} V_{d} \eta_{v} = 0.375 \frac{l}{s} = 0.796 \text{ cfm} \]

\[ \dot{m}_{air} = \rho_{air} \dot{V}_{air} = \left( 1.2 \frac{\text{kg}}{\text{m}^3} \right) \left( 0.000375 \frac{\text{m}^3}{\text{s}} \right) = 0.00045 \frac{\text{kg}}{\text{s}} \]

\[ \dot{m}_{fuel} = \frac{\dot{m}_{air}}{AF} = \frac{0.00045 \frac{\text{kg}}{\text{s}}}{14.2} = 0.0000317 \frac{\text{kg}}{\text{s}} \]

\[ \dot{V}_{fuel} = \frac{\dot{m}_{fuel}}{\rho_{fuel}} = \frac{0.0000317 \frac{\text{kg}}{\text{s}}}{720 \frac{\text{kg}}{\text{m}^3}} = 4.4 \times 10^{-5} \frac{l}{s} = 0.0007 \text{ gpm} \]

\[ b_{mep} = 8 \text{ atm} = 810.6 \text{ kPa} = 120 \text{ psi} \]

\[ bsfc = \frac{\dot{m}_{fuel}}{W} = \frac{0.0317 \frac{\text{g}}{\text{s}}}{0.353 \text{ kW}} = 323 \frac{\text{g}}{\text{kW} \cdot \text{h}} = 0.532 \frac{\text{lb}}{\text{hp} \cdot \text{h}} \]

\[ n_{axle} = \frac{V}{2 \pi w} = \frac{6.214 \frac{\text{m}}{\text{s}}}{2 \pi (0.305 \text{ m})} = 194.6 \text{ rpm} \]

\[ R = \frac{20,000 \text{ rpm}}{194.6 \text{ rpm}} = 102.8 \]

which is a very significant gearbox. Better ground vehicle system design would be to treat the gearbox and engine together, for the best combined outcome.