Problem E, Solution

a) As the throttle voltage↑, duty cycle↑, % of time transistor is on and current flows↑, speed↑.

b) Since the motor is inductive, it clamps the voltage at the top (drain) of the transistors to 1 diode drop above the supply rail (24V) when the transistor shuts off (dI/dt is large, so there is a large voltage across the inductor (i.e., motor)).

c) The voltage across the resistor is \( V_C = V_{dd} - V_R \). Power dissipated in the resistor is current times voltage.

\[
P_r(t) = (i) \cdot V_R = \left( C \frac{dV_C}{dt} \right) \cdot V_R
\]

\[
= C \frac{d(V_{dd} - V_R)}{dt} \cdot V_R \quad \{V_{dd} \text{ is constant}\}
\]

\[
= -C \frac{dV_R}{dt} \cdot V_R
\]

Energy = \( W = \int_0^\infty P_r(t) \, dt = \int_0^\infty \left( -C \frac{dV_R}{dt} \cdot V_R \right) \, dt \)

\[
W = - \int_0^\infty C \frac{dV_R}{dt} \cdot V_R \, dt \quad \{\text{change variables}\}
\]

\[
= - \int_{V_{dd}}^{V_{dd}} CV_R \, dV_R = \int_0^{V_{dd}} CV_R \, dV_R
\]

\[
= \frac{1}{2} C \cdot V_{dd}^2
\]

Note that the above shows that the energy lost charging a capacitor is not only independent of the resistor, but is true for any device (the current voltage relationship for a resistor was never used), even a non-linear one.

d) Power dissipated is split between resistor (33 Ohms) and the drive circuitry (unity gain buffer). This makes it easier to design the buffer. It also reduces the max current.