Total area of 3 blades is:
\[ A = 3 \times W \times L = 3 \times (3.5 \times 10^{-3}) \times (60 \times 10^{-3}) = 6.3 \times 10^{-3} \text{ (m}^2) \]

Think this problem as a plate sliding over the rice.

The shear stress on upper plate is:
\[ \tau = \frac{\mu A \frac{dV}{dt}}{h} = \mu \frac{V}{h} \quad - - - (2) \]

The drag force
\[ F = -\tau A = -A \mu \frac{V}{h} \quad (-'' \text{indicates direction)} \]

---

Method

According to Newton's 2nd law:
\[ F = ma \]

\[ -A \mu \frac{V}{h} = m \frac{dV}{dt} \]

\[ \frac{dV}{V} = -\frac{A \mu}{m h} dt \]

Integrate
\[ \ln V = -\frac{A \mu}{m h} t + C \quad \text{constant} \]

\[ V = Be^{-\frac{A \mu}{m h} t} \quad \text{a constant} \quad - - - (2) \]

Apply initial condition:
\[ \text{at } t = 0, \quad V = V_0 \]

Then get
\[ B = V_0 \]

So,
\[ V = V_0 e^{-\frac{A \mu}{m h} t} \quad - - - (3) \]

Find distance of sliding
\[ X = \int_{0}^{\infty} V dt = \int_{0}^{\infty} V_0 e^{-\frac{A \mu}{m h} t} dt = \frac{V_0 m h}{A \mu} \quad - - - (2) \]
Apply Newton's 2nd Law

\[ F = ma \]

\[- AV \frac{m}{h} = m \frac{dv}{dt} \]

\[- AV \frac{m}{h} = m \frac{dv}{dx} \cdot \frac{dx}{dt} \rightarrow \frac{dv}{dt} \]

\[- AV \frac{m}{h} = mV \frac{dv}{dx} \]

Then

\[- AV \frac{m}{h} = m \frac{dv}{dx} \]

\[ dx = - \frac{mh}{AV} \, dv \]

\[ \int_0^{x_0} dx = \int_{v_0}^v - \frac{mh}{AV} \, dv \]

\[ x_0 = \frac{mhV_0}{AV} \]

same as the one in Method I.

For viscosity:

"It's not affected by moderate pressure, but large increases have been found at very high pressures, e.g., viscosity of water at 10,000 atm is twice that at 1 atm." — From Text Book (7th edition) P704.

Here, pressure \( P = \frac{mg}{A} = \frac{240 \times 9.8}{7.1 \times 10^{-8}} = 3.3 \times 10^5 \text{ (Pa)} \approx 3 \text{ atm} \)

NOT too high, so, can ignore pressure effect. —— \( 1 \)

at \( 0^\circ \text{C}, \ \mu \text{ of water} = 2.175 \times 10^{-3} \text{ (N.s/m²)} \)

So,

sliding distance

\[ x_0 = \frac{mhV_0}{AV} = \frac{240 \times 0.0012 \times 10^{-2} \times 7.2}{6.3 \times 10^{-3} \times 2.175 \times 10^{-3}} \approx 188.1 \text{ (m)} \] —— \( 1 \)
For a belt rotating around a fixed body, if the gap \( h \) is small comparing with radius (\( R \& R \)), then we can consider them as two flat plates at small region if we zoom in. (It's like we stand on the earth (round), but we feel it's a flat surface.) \( \text{gap } h = R - y \) \( - - - \) (1)

Then, velo. of top plate \( \Rightarrow \) \( V = WR \)

Shear stress \( \tau \) is \( \tau = \mu \frac{dV}{dy} = \mu \frac{V}{h} = \mu \frac{WR}{h} \) \( \text{drag force on belt } \Rightarrow F = \tau \cdot A = \frac{\mu R A}{h} W \) \( \text{contacting area} \) \( - - - \) (2)

Power applied on a rotating body:

\[
\text{Power} = \text{torque} \times \text{angular velocity} \\
= (F \times R) \times W \\
= \frac{\mu R A}{h} W^2
\] \( - - - \) (2)

Viscosity: for SAE 10W at \( 40^\circ \text{C} \) \( \mu_{10} \approx 4 \times 10^{-2} \text{ N.S/m}^2 \)

SAE 30W at \( 40^\circ \text{C} \) \( \mu_{30} \approx 1 \times 10^{-1} \text{ N.S/m}^2 \)

For two cases, \( R, h, A, \& \text{Power} \) are same.

\[
\text{Power}_{10} = \text{Power}_{30}
\]

\[
\Rightarrow \frac{R_{10}}{R_{30}} \frac{W_{10}}{W_{30}} = \frac{\mu_{30}}{\mu_{10}} \cdot \frac{W_{30}^2}{W_{10}^2}
\]

\[
W_{30} = \sqrt{\frac{\mu_{30}}{\mu_{10}}} \cdot W_{10}
\]

\[
\Rightarrow W_{30} \approx 0.63 \ W_{10}
\]

\[
\text{The belt is a rotating slower when using SAE 30W}\]

\[
\text{So, (rotation speed)} = 0.63 \times 80 \text{ (rpm)} = 50.4 \text{ rpm}
\] \( - - - \) (1)
**Problem 3**

\[ \text{H}_2\text{O} \ (\text{didn't specify temp, but } p \approx 1.94 \text{ slug/ft}^3 \text{ for typical outdoor temps}) \]

\[ \text{door area} = 4 \text{ ft}^2 \]

\[ \uparrow P(h)A \ (\text{pressure from water outside}) \]

\[ \downarrow \text{W} \ (\text{weight}) \]

\[ \downarrow P_{\text{atm}}A \ (\text{pressure from air inside}) \]

(All forces act @ door centroid, so torque arms measured from hinge are equal)

- Ordinarily: upward water pressure stronger than downward forces \( \Rightarrow \) door stays shut
- For door to open \( \Rightarrow \) forces must balance

\[ \Rightarrow W + P_{\text{atm}}A = P(h)A = \left( P_{\text{atm}} + \rho_{\text{H}_2\text{O}} gh' \right)A \]

\[ \text{cancels} \]

\[ \Rightarrow \frac{W}{A} = \rho_{\text{H}_2\text{O}} gh' \Rightarrow h' = \frac{W}{\rho_{\text{H}_2\text{O}} A} \]

So \[ h' = \frac{20 \text{ lb}}{1.94 \text{ slug/ft}^3 \cdot 32.2 \text{ ft/s}^2 \cdot 4 \text{ ft}^2} = 0.08 \text{ ft} \]

- Initial \( h_0' = 25' - 10' = 15' \); \( h' \) drops \( 2.5 \text{ in/hr} \cdot \frac{\text{in}}{12 \text{ in}} = 0.208 \text{ ft/hr} \)

\[ h_0' - \Delta t \cdot 0.208 \frac{\text{ft}}{\text{hr}} = 0.08 \text{ ft} \]

\[ \Delta t = \frac{(15 - 0.08) \text{ ft}}{0.208 \frac{\text{ft}}{\text{hr}}} = 71.2 \text{ hr} = 71 \text{ hr}, 44 \text{ min} \]

Water starts draining at midnight: door opens at 11:44 pm on the 3rd day.