1. An airplane is flying at an altitude of 12000 m. Determine the gage pressure at the stagnation point on the nose of the plane if the speed of the plane is 200 km/h. What would be the gage pressure at a point on the surface of plane where the relative wind speed is 250 km/h?

Solve:

At an altitude of 12000m,

\[ P_1 = P_{atm} = 19.4 \text{ kPa}, \quad P_i = 0.312 \text{ kg/m}^3 \]

Apply Bernoulli Equation between freestream (1) and the nose of the plane (2).

\[ p_1 + \frac{1}{2} \rho_1 V_1^2 + \rho_1 g z_1 = p_2 + \frac{1}{2} \rho_2 V_2^2 + \rho_2 g z_2 \]

Because, \( z_1 = z_2 \), \( P_1 = P_2 \), \( V_2 = 0 \), \( P_{gage} = 0 \), \( V_1 = 200 \text{ km/h} \)

\[ P_2 = \frac{1}{2} \rho_1 V_1^2 = \frac{1}{2} \times 0.312 \times \left( \frac{200 \times 10^3}{3600} \right)^2 = 481.5 \text{ Pa} \]

At the point (3) where the relative wind speed is 250 km/h

\[ p_1 + \frac{1}{2} \rho_1 V_1^2 + \rho_1 g z_1 = p_3 + \frac{1}{2} \rho_3 V_3^2 + \rho_3 g z_3 \]

Because, \( z_1 = z_3 \), \( P_{gage} = 0 \), \( V_3 = 250 \text{ km/h} \), \( V_1 = 200 \text{ km/h} \)

\[ P_3 = \frac{1}{2} \rho_1 V_1^2 - \frac{1}{2} \rho_3 V_3^2 \]

\[ = \frac{1}{2} \times 0.312 \times \left( \frac{200 \times 10^3}{3600} \right)^2 - \frac{1}{2} \times 0.312 \times \left( \frac{250 \times 10^3}{3600} \right)^2 \]

\[ = -271 \text{ Pa} \]
#2. Water flows through a horizontal pipe at a rate of 1 gal/s. The pipe consists of
two sections of diameters 4 in and 2 in with a smooth reducing section. The
pressure difference between the two pipe sections is measured by a mercury
manometer. Neglecting the frictional effects, determine the differential height of
mercury between the two pipe sections.

\[
\begin{align*}
\text{Solve: } 1 \text{ gal/s} &= 0.13368 \text{ ft}^3/\text{s} \\
\text{At point} \ D:\ V_1 &= \frac{Q}{A_1} = \frac{0.13368}{\pi \left( \frac{4}{2} \right)^2} = 1.532 \text{ ft/s} \\
\text{At point} \ E:\ V_2 &= \frac{Q}{A_2} = \frac{0.13368}{\pi \left( \frac{2}{2} \right)^2} = 6.1261 \text{ ft/s} \\
\text{Apply Bernoulli Equation between point} \ D \text{ and} \ E:\ 
\frac{p_1}{\rho_1} + \frac{1}{2} \rho_1 V_1^2 + \rho_1 g z_1 &= \frac{p_2}{\rho_2} + \frac{1}{2} \rho_2 V_2^2 + \rho_2 g z_2 \\
&= \frac{1}{2} \rho_{\text{water}} (V_2^2 - V_1^2) \\
\Rightarrow p_1 - p_2 &= \frac{1}{2} \rho_{\text{water}} (V_2^2 - V_1^2) \\
&= \frac{1}{2} \times 1.94 \times (6.126^2 - 1.532^2) \\
&= 34.1312 \text{ lbf/ft}^2 \\
\text{According to the manometer:} \\
\frac{p_1 - p_2}{\rho_{\text{water}}} g \left( \frac{24 + h + \frac{h}{2}}{12} \right) &= \frac{p_2}{\rho_{\text{water}}} g \left( \frac{24 + \frac{h}{2}}{12} \right) + \rho_{\text{hg}} g \left( \frac{h}{12} \right) \\
\Rightarrow p_1 - p_2 &= (\rho_{\text{hg}} - \rho_{\text{water}}) g \left( \frac{h}{12} \right) \\
\Rightarrow 34.1312 &= (846.54 - 62.4) \left( \frac{h}{12} \right) \\
\Rightarrow h &= 0.5223 \text{ in} \ (0.0435 \text{ ft})
\end{align*}
\]
#3 A wind tunnel draws atmospheric air at 20°C and 101.3 kPa by a large fan located near the exit of the tunnel. In the air velocity in the tunnel is 80 m/s, determine the pressure in the tunnel.

\[
\begin{align*}
\text{Solve:} & \quad p_1 = \rho_0 m = 101.3 \text{ kPa.} \\
& \quad V_1 = 0 \\
& \quad V_2 = 80 \text{ m/s}, \quad \rho = 1.204 \text{ kg/m}^3 \\
\text{Apply Bernoulli equation between 1 and 2} & \quad \frac{p_1}{\rho} + \frac{1}{2} \rho V_1^2 + \rho g z_1 = \frac{p_2}{\rho} + \frac{1}{2} \rho V_2^2 + \rho g z_2 \\
\text{So:} & \quad p_2 = \frac{p_1}{\rho} - \frac{1}{2} \rho V_2^2 \\
& \quad = 101.3 \times 10^3 - \frac{1}{2} \times 1.204 \times 80^2 \\
& \quad = 101300 - 3852.8 \\
& \quad = 97447.2 \text{ Pa (Abs. Pressure)} \\
& \quad = 97.447 \text{ kPa.}
\end{align*}
\]
#4 A sea level, low-speed wind tunnel of circular cross section with a diameter upstream of the contraction of 20 ft and a test section diameter of 10 ft

The test section is vented to the atmosphere (sea level pressure is 2116 lbf/ft²). If the working section velocity is 180 mph, calculate the following: a). Upstream section velocity. b). Upstream pressure.

**Solve:** According to continuity equation, the mass flow rate is same at 1 and 2

\[ A_1 V_1 = A_2 V_2 \]

\[ \Rightarrow \frac{\pi}{4} \times 20^2 \times V_1 = \frac{\pi}{4} \times 10^2 \times \left( \frac{180 \times 5280}{3600} \right)^2 \]

\[ \Rightarrow V_1 = \frac{\pi}{4} \times 264 = 66 \text{ ft/s} \]

Apply Bernoulli equation between 1 and 2

\[ p_1 + \frac{1}{2} \rho V_1^2 + \rho g z_1 = p_2 + \frac{1}{2} \rho V_2^2 + \rho g z_2 \]

\[ p_1 = p_2 + \frac{1}{2} \rho (V_2^2 - V_1^2) \]

\[ = 2116 + \frac{1}{2} (0.00238) (264^2 - 66^2) \]

\[ = 2193.75 \text{ lbf/ft}^2 \]
Air flows steadily past a porous flat plate. Constant suction is applied along the porous section. The velocity profile at the section $cd$ is

$$\frac{u}{U_\infty} = 3\left[\frac{y}{\delta}\right] - 2\left[\frac{y}{\delta}\right]^{1.5}$$

Evaluate the mass flow rate across section $bc$.

**Solve:** Apply RTT to CN.

$$\frac{D}{Dt}(\int_C \rho d\mathbf{v}) = \int_C \nabla \cdot \mathbf{v} \rho d\mathbf{v} + \oint_{cs} \rho \mathbf{v} \cdot \hat{n} ds$$

**(0), mass conservation**

**(0), steady flow**

So,

$$\int_{cs} \rho \mathbf{v} \cdot \hat{n} ds = \int_{ab} \rho \mathbf{v} \cdot \hat{n} ds + \int_{bc} \rho \mathbf{v} \cdot \hat{n} ds + \int_{cd} \rho \mathbf{v} \cdot \hat{n} ds + \int_{da} \rho \mathbf{v} \cdot \hat{n} ds = 0$$

$$\Rightarrow \rho \left[\int_{bc} \mathbf{v} \cdot \hat{n} ds + \int_{da} \mathbf{v} \cdot \hat{n} ds \right] = \int_{ab} \mathbf{v} \cdot \hat{n} ds + \int_{cd} \mathbf{v} \cdot \hat{n} ds$$

$$\Rightarrow \dot{m}_{bc} = -\rho \int_{ab} \left[3\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^{1.5}\right] \delta dy - \frac{0.2 \times 2 \times 1.5}{10^{0.5}} \rho + \frac{3 \times 1.5 \times 1.5}{10^{0.5}} \rho$$

$$\Rightarrow \dot{m}_{bc} = -4.5 \rho \left[\frac{y^2}{2 \delta} - \frac{2}{3 \delta} \right] \delta - 6 \times 10^{-4} \rho + 6.75 \times 10^{-3} \rho$$

$$= -4.25 \times 10^{-3} \rho \text{ kg/s}$$

Width: $w = 1.5 \text{ m}$
#6 Air enters a tank through an area of 0.2 ft$^2$ with a velocity of 15 ft/s and a density of 0.03 slug/ft$^3$. Air leaves with a velocity of 5 ft/s and a density equal to that in the tank. The initial density of the air in the tank is 0.02 slug/ft$^3$. The total tank volume is 20 ft$^3$ and the exit area is 0.4 ft$^2$. Find the initial rate of change of density in the tank.

\[ \frac{\partial}{\partial t} (\rho \cdot V) = \frac{\partial}{\partial t} (\rho_1 \cdot V_1 \cdot A_1) + \int_{S} \rho \cdot V \cdot n \cdot ds \]

\( (\rho, \text{ mass conservation}) \)

\[ 0 = \frac{\partial}{\partial t} (\rho \cdot V) - \rho_1 V_1 A_1 + \rho_2 V_2 A_2 \]

\[ (20) \frac{\partial \rho_1}{\partial t} = \rho_1 V_1 A_1 - \rho_2 V_2 A_2 = (0.03)(15)(0.2) - (0.02)(0.4)(15) \]

\[ = 0.09 - 0.02 \]

\[ \frac{\partial \rho_1}{\partial t} = \frac{0.09}{20} - 0.1 \rho \]

\[ \left. \frac{\partial \rho_1}{\partial t} \right|_{\text{initial}} = \frac{0.09}{20} - (0.1) \rho_{\text{initial}} \]

\[ = \frac{0.09}{20} - (0.1)(0.02) \]

\[ = 0.0025 \text{ slug}/(ft^3 \cdot s) \]
Water flows steadily through a pipe of length $L$ and radius $R = 3$ in. Calculate the uniform inlet velocity, $U$, if the velocity distribution across the outlet is given by

$$u = u_{\text{max}} \left(1 - \frac{r^2}{R^2}\right) \quad \text{and} \quad u_{\text{max}} = 10 \text{ ft/s}$$

\[\text{Solve: Apply RRT on CV}\]

$$\frac{\partial}{\partial t} \int_{\text{CV}} \rho d\mathbf{V} = \frac{\partial}{\partial t} \int_{\text{CV}} \rho d\mathbf{A} + \int_{\text{CV}} \rho \mathbf{V} \cdot \mathbf{n} ds$$

\[\text{(o, mass conservation)(o, steady flow)}\]

So:

$$0 = \int_{\text{CV}} \rho \mathbf{V} \cdot \mathbf{n} ds$$

$$\Rightarrow -\rho U \pi R^2 + \int_0^R \rho U_{\text{max}} \left(1 - \frac{r^2}{R^2}\right) 2\pi r dr = 0$$

$$2\pi U_{\text{max}} \rho \int_0^R \left(r - \frac{r^3}{R^2}\right) dr = \rho U \pi R^2$$

$$2\pi U_{\text{max}} \rho \left[\frac{r^2}{2} - \frac{r^4}{4R^2}\right]_0^R = \rho U \pi R^2$$

$$2\pi U_{\text{max}} \rho \frac{R^2}{4} = \rho U \pi R^2$$

$$u = \frac{U}{2} \quad U \text{max} = \frac{1}{2} \times 10 = 5 \text{ ft/s}$$
Air at standard conditions enters a compressor at 75 m/s and leaves at an absolute pressure and temperature of 200 kPa and 345 K, respectively, and speed \( V = 125 \) m/s. The flow rate is 1 kg/s. The cooling water circulating around the compressor casing removes 18 kJ/kg of air. Determine the power required by the compressor.

**Solution:** For air, \( C_v = 716 \) kJ/(kg·K)

\[
\rho_1 = \frac{P_1}{RT_1} = \frac{101325}{(287)(273+15)} = 1.225 \text{ kg/m}^3
\]

\[
(U_1 - U_2) + \left(\frac{\rho_1}{\rho_2} - \frac{P_1}{P_2}\right) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2) = \dot{W}_{sh} + \dot{Q}_{net-out}
\]

\[
C_v(T_1 - T_2) + R(T_1 - T_2) + \frac{1}{2}(V_1^2 - V_2^2) + g(z_1 - z_2) = \dot{W}_{sh} + \dot{Q}_{net-out}
\]

\[
(C_v + R)(T_1 - T_2) + \frac{1}{2}(V_1^2 - V_2^2) = \dot{W}_{sh} + \dot{Q}_{net-out}
\]

\[
(716 + 287)(287 - 345) + \frac{1}{2}(75^2 - 125^2) = \dot{W}_{sh} + 18000
\]

\[
\dot{W}_{sh} = -(40812 + 16359) - 5000 - 18000
\]

\[
= -80171 \text{ J/kg}
\]

\[
\text{Power} = \dot{m} \dot{W}_{sh} = (1)(-80171)
\]

\[
= -80171 \text{ J/s}
\]
#9 A two-dimensional reducing bend has a linear velocity profile at section 1. The flow is uniform at sections 2 and 3. The fluid is incompressible and the flow is steady. Find the magnitude and direction of the uniform velocity at section 3.

Solve: Apply RTT on CV.

\[
\frac{\partial}{\partial t} \int_{CV} \rho \, dV = \frac{\partial}{\partial t} \int_{CV} \rho \, dV + \int \rho \vec{v} \cdot \hat{n} \, ds
\]

(0, mass conservation) (0, steady)

So:
\[
\int \rho \vec{v} \cdot \hat{n} \, ds = 0
\]

\[
- \int_0^{10.5} \rho \left( \frac{x^2}{2} \right) y \, dy + \int_0^2 \rho v_2 \, ds + \int_3 \rho v_3 \, ds = 0
\]

\[
- \int_0^{10.5} \rho \left( \frac{x^2}{2} \right) y \, dy + \rho v_2 \, h_2 + \rho v_3 \, h_3 = 0
\]

\[- \rho \frac{5}{2} (2^2) + \rho (15)(1) + \rho v_3 (15) = 0\]

\[V_3 = \frac{(10 \rho - 15 \rho)}{15 \rho} = -3.33 \text{ ft/s}\]

The negative sign means the fluid flows into the CV.
#10 Find the force required to hold the plug in place at the exit of the water pipe. The flow rate is 1.5 m/s, and the upstream pressure is 3.5 MPa.

**Solve:**

\[ Q_1 = 1.5 \text{ m}^3/\text{s}, \quad A_1 = \frac{\pi}{4} (0.25)^2 = 0.0491 \text{ m}^2 \]

\[ V_1 = \frac{1.5}{(\frac{\pi}{4})(0.25)^2} = 30.56 \text{ m/s} \]

\[ p_1 = 3.5 \text{ MPa} \]

\[ A_2 = \frac{\pi}{4} (0.25^2 - 0.2^2) = 0.0177 \text{ m}^2 \]

\[ V_2 = \frac{Q_1}{A_2} = 84.9 \text{ m/s}, \quad p_2 = p_{atm} = 101.325 \text{ kPa} \]

Apply RTT (conservation of momentum) on CV.

\[ \Sigma F = \frac{\partial}{\partial t} \int (\rho V \hat{n}) dA + \int \rho V (V \cdot \hat{n}) dA \]

So:

\[ \int \rho V (V \cdot \hat{n}) dA = \Sigma F \]

\[ \Rightarrow F_1 V_1^2 A_1 + F_2 V_2^2 A_2 = p_1 A_1 - p_2 A_2 - F \]

\[ = (1000)(30.56)^2(0.0491) + (1000)(84.9)^2(0.0177) \]

\[ = (3.5 \times 10^6)(0.0491) - (101.325 \times 10^3)(0.0177) - F \]

\[ \Rightarrow F = 45855.15 - 12781.78 + 171850 - 1793.45 \]

\[ = 88329.92 \text{ N} \approx 88.33 \text{ kN} \]
#11 The small boat in the figure is driven at a steady speed $V_0$ by a jet of compressed air issuing from a 3-cm-diameter hole at $V_e = 343$ m/s. Jet exit conditions are $p_e = 1$ atm and $T = 30^\circ C$. Air drag is negligible, and the hull drag is $kV_e^2$, where $k \approx 19$ N s/m. Estimate the boat speed $V_0$ in m/s.

\[
\rho_e = \frac{P_e}{R T_e} = \frac{101325}{(287)(273+30)} = 1.165 \text{ kg/m}^3
\]

\[
\text{Solve relative velocity: } W = V_e - V_0 = -343 - V_0
\]

Apply RTT (momentum) on CV

\[
\sum F = \frac{d}{dt} \int_C \rho V \, dt + \int_S \rho \overrightarrow{V} (\overrightarrow{W} - \overrightarrow{n}) \, ds
\]

\[
\Rightarrow \quad kV_0^2 = \rho V_e W A = \rho V_e W \left( \frac{\pi}{4} \right) (0.03)^2
\]

\[
\Rightarrow (1.165)(343)(343+V_0)(\frac{\pi}{4})(0.03)^2 = (19) V_0^2
\]

\[
19V_0^2 - 0.2823 V_0 - 96.8 = 0
\]

\[
V_0 = \frac{0.2823 \pm \sqrt{(0.2823)^2 + (4)(19)(96.8)}}{2(19)}
\]

\[
= 2.21 \text{ m/s}
\]
The jet engine on a test stand in figure admits at 20°C and 1 atm at section 1, where \( A_1 = 0.5 \, m^2 \) and \( V_1 = 250 \, m/s \). The fuel to air ratio is 1:30. The air leaves section 2 at atmospheric pressure and higher temperature, where \( V_2 = 900 \, m/s \) and \( A_2 = 0.4 \, m^2 \). Compute the horizontal test stand reaction \( R_x \) needed to hold this engine fixed.

\[ \begin{align*}
\Sigma F_x &= \frac{\partial}{\partial t} \int \rho \mathbf{V} \, dA + \int_{cs} \rho \mathbf{V} \cdot (\mathbf{V} \cdot \mathbf{n}) \, ds \quad (V_f \approx 0) \\
\Rightarrow R_x &= \int_{cs} \rho \mathbf{V} \cdot (\mathbf{V} \cdot \mathbf{n}) \, ds = -\rho_1 V_1^2 A_1 + \rho_2 V_2^2 A_2 - \rho_3 V_3^2 A_3
\end{align*} \]

According to mass continuity:

\[ \rho_2 A_2 V_2 = \rho_1 A_1 V_1 + \rho_3 A_3 V_f = \rho_1 A_1 V_1 + \frac{1}{30} \rho_1 A_1 V_1 \]

\[ \Rightarrow \rho_2 (0.4) (900) = \frac{31}{30} (1.204) (0.5) (250) \]

\[ \Rightarrow \rho_2 = 0.432 \, kg/m^3 \]

So,

\[ R_x = \rho_2 A_2 V_2^2 - \rho_1 A_1 V_1^2 \]

\[ = (0.432)(0.4)(900)^2 - (1.204)(0.5)(250)^2 \]

\[ = 102.31 \, kN \]
#13 Suppose that a deflector is deployed at the exit of the jet engine of problem #12 as shown in the figure. What will the reaction $R_x$ on the test stand be now? Is this reaction sufficient to serve as a braking force during airplane landing?

![Diagram of deflector](image)

**Solve:** Due to symmetry, consider half of the deflector as CV.

Apply RTT (momentum) on CV.

$$\sum F = \frac{d}{dt} \int_{CV} \rho V \, dV + \int_{CS} \rho V \cdot (\mathbf{V} \cdot \hat{n}) \, ds$$

$$\Rightarrow \frac{1}{2} R_x = \frac{1}{2} \rho_1 A_1 V_1^2 - \frac{1}{2} \rho_3 A_3 V_3 (-V_3 \sin 45^\circ)$$

According to mass conservation

$$\frac{1}{2} R_x = \frac{1}{2} (1.204)(0.5)(250)^2 + \frac{1}{2} (0.432)(0.4)(900)(900) \sin 45^\circ$$

$$\Rightarrow R_x = -137.03 \text{ kN}$$

So, this reaction is sufficient as a braking force during airplane landing. It's called "Thrust reversal".
Air at standard conditions flows along a flat plate. The undisturbed freestream speed is $U_0 = 10 \text{ m/s}$. At $L = 145 \text{ mm}$ downstream from the leading edge of the plate, the boundary-layer thickness is $\delta = 2.3 \text{ mm}$. The velocity profile at this location is

$$\frac{u}{U_0} = \frac{3y}{2\delta} - \frac{1}{2} \left[ \frac{y}{\delta} \right]^3$$

Calculate the horizontal component of force per unit width required to hold the plate stationary. Assume width = $W$.

**Solution:** Continuity equation.

$$\int_{\infty}^{s} \rho \left( \nabla \cdot \hat{n} \right) \, ds = 0$$

$$-m + \int_{0}^{\delta} \rho U_0 \left[ \frac{3y}{2\delta} - \frac{y^3}{2\delta^3} \right] \, dy = 0$$

$$\Rightarrow m = \rho \rho U_0 \left[ \frac{3y^2}{4\delta^2} - \frac{y^4}{8\delta^3} \right] \bigg|_{0}^{\delta} = \frac{5}{8} \rho U_0 \delta w$$

Apply momentum equation on $x$-direction.

$$F_x = \int_{\infty}^{s} \rho \nabla \cdot \left( \nabla \cdot \hat{n} \right) \, ds$$

$$= -mU_0 + \rho \int_{0}^{\delta} w U_0^2 \left[ \frac{3y}{2\delta} - \frac{y^3}{2\delta^3} \right]^2 \, dy$$

$$= -\frac{5}{8} \rho U_0^2 \delta w + \frac{17}{35} \rho \delta w U_0^2$$

$$\Rightarrow \frac{F_x}{W} = 0.0392 \text{ N/m}$$
#15 Air is drawn from the atmosphere into a turbomachine. At the exit, conditions are 500kPa (gage) and 130°C. The exit speed is 100 m/s and the mass flow rate is 0.8 kg/s. The flow is steady and there is no heat transfer. Compute the shaft power.

Solve:

\[ T_1 = 15^\circ C = 288 \text{ K}, \quad P_1 = 1013.25 \text{ Pa} \]
\[ T_2 = 130^\circ C = 403 \text{ K}, \quad P_2 = 500 \text{ kPa} \]
\[ C_v = 716 \text{ J/kg K} \quad \bar{u} = C_v T \quad \rho = 287 \text{ kJ/kg K} \]

Apply Energy equation:

\[ (\bar{u}_1 - \bar{u}_2) + (\frac{P_1}{\rho} - \frac{P_2}{\rho}) + (\frac{V_1^2}{2} - \frac{V_2^2}{2}) + g(z_1 - z_2) = W_{sh} + \frac{\bar{Q}}{\rho} \]

\[ C_v (T_1 - T_2) + \rho (T_1 - T_2) + \frac{1}{2} (V_1^2 - V_2^2) = W_{sh} \]

\[ (716 + 287) (288 - 403) + \frac{1}{2} (0 - 100^2) = W_{sh} \]

\[ \Rightarrow W_{sh} = -120460 \text{ J/kg} \]

Power = \[ W_{sh} \cdot \dot{m} = (-120460) (0.8) \]

\[ = -96368 \text{ W} \]
#16 A 0.85-hp motor is required by a ducted fan to produce a 24-in stream of air having a velocity of 40 ft/s. Estimate the efficiency of the fan.

\[
\rho_{\text{air}} = 0.00237 \text{ slug/ft}^2
\]

\[
\zeta = \frac{(14.7 \text{ psi})(146 \frac{\text{in}^3}{\text{ft}^2})}{(1716)(3.30)}
\]

**Solve:**

\[
\text{Power} = 0.85 \text{ hp} = (0.85)(150) = 467.5 \text{ ft lb/s}
\]

\[
W_{sh} = \frac{\text{Power}}{PQ} = \frac{467.5}{(0.00237)(\frac{34}{12})^2(40)} = 1570.52 \frac{\text{ft lb}}{\text{slug}}
\]

Apply energy equation

\[
\frac{P_i}{P_0} - \frac{P_e}{P_0} + \frac{1}{2}(V_i^2 - V_e^2) + g(z_i - z_e) = W_{shaft} + E_{loss}
\]

\[
\Rightarrow E_{loss} = -\frac{1}{2}V_e^2 + W_{sh in} = 1570.52 - \frac{40^2}{2} = 770.52 \frac{\text{ft lb}}{\text{slug}}
\]

So: efficiency = \[
\frac{W_{shaft} - E_{loss}}{W_{shaft}} = \frac{1570.52 - 770.52}{1570.52}
\]

\[
= 50.93\%
\]