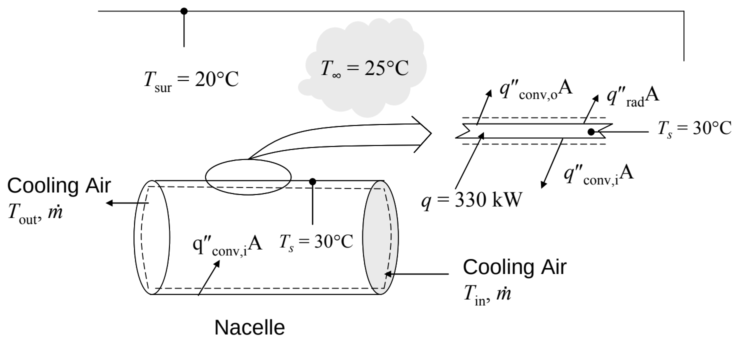
# PROBLEM 1.59

**KNOWN:** Total rate of heat transfer leaving nacelle (from Example 1.3). Dimensions and emissivity of the nacelle, ambient and surrounding temperatures, convection heat transfer coefficient exterior to nacelle. Temperature of exiting forced air flow.

**FIND:** Required mass flow rate of forced air flow.

**SCHEMATIC:**




**ASSUMPTIONS:** (1) Steady-state conditions, (2) Large surroundings, (3) Surface of the nacelle that is adjacent to the hub is adiabatic, (4) Forced air exits nacelle at the nacelle surface temperature.

**ANALYSIS:** The total rate of heat transfer leaving the nacelle is known from Example 1.3 to be $q = 0.33 \times 10^6$ W = 330 kW. Heat is removed from the nacelle by radiation and convection from the exterior surface of the nacelle ($q_{rad}$ and $q_{conv,o}$, respectively), and by convection from the interior surface to the forced flow of air through the nacelle ($q_{conv,i}$). An energy balance on the nacelle based upon the upper-right part of the schematic yields

$$q = q_{rad} + q_{conv,o} + q_{conv,i} = A\left[q''_{rad} + q''_{conv,o}\right] + q_{conv,i}$$

Thus the required rate of heat removal by the forced air is given by

$$q_{conv,i} = q - A\left[q''_{rad} + q''_{conv,o}\right] = q - \left[\pi DL + \frac{\pi D^2}{4}\right]\left[\varepsilon\sigma\left(T_s^4 - T_{sur}^4\right) + h\left(T_s - T_\infty\right)\right]$$

In order to maintain a nacelle surface temperature of $T_s$ = 30°C, the required $q_{conv,i}$ is

$$q_{conv,i} = 330\text{ kW} - \left[\pi \times 3\text{ m} \times 6\text{ m} + \frac{\pi \times (3\text{ m})^2}{4}\right] \times$$

$$\left[0.83 \times 5.67 \times 10^{-8}\text{ W/m}^2 \cdot \text{K}^4\left((273+30)^4 - (273+20)^4\right)\text{K}^4 + 35\text{ W/m}^2 \cdot \text{K}(30-25)\text{K}\right]$$

$$= 330\text{ kW} - (3\text{ kW} + 11\text{ kW}) = 316\text{ kW}$$

The required mass flow rate of air can be found by applying an energy balance to the air flowing through the nacelle, as shown by the control volume on the lower left of the schematic. From Equation 1.12e:

$$\dot{m} = \frac{q_{conv,i}}{c_p(T_{out} - T_{in})} = \frac{q_{conv,i}}{c_p(T_s - T_\infty)} = \frac{316\text{ kW}}{1007\text{ J/kg}\cdot\text{K}(30-25)\text{K}} = 63\text{ kg/s}$$ <

Continued...

## PROBLEM 1.59 (Cont.)

**COMMENTS:** (1) With the surface temperature lowered to 30°C, the heat lost by radiation and convection from the exterior surface of the nacelle is small, and most of the heat must be removed by convection to the interior forced air flow. (2) The air mass flow rate corresponds to a velocity of around $V = \dot{m} / \rho A_c = \dot{m} / (\rho \pi D^2 / 4) = 7$ m/s, using an air density of 1.1 kg/m$^3$ and assuming that the air flows through the entire nacelle cross-sectional area. This would lead to uncomfortable working conditions unless the forced air flow were segregated from the working space. (3) The required heat transfer coefficient on the interior surface can be estimated as $h_i = q_{\mathrm{conv,i}}/(\pi DL(T_s - T_\infty)) =$ 1100 W/m$^2$·K. In Chapter 8, you will learn whether this heat transfer coefficient can be achieved under the given conditions.