Applied Thermal Systems

Introduction

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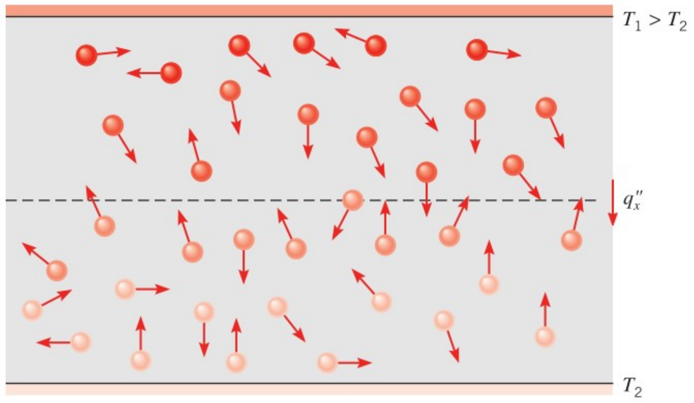
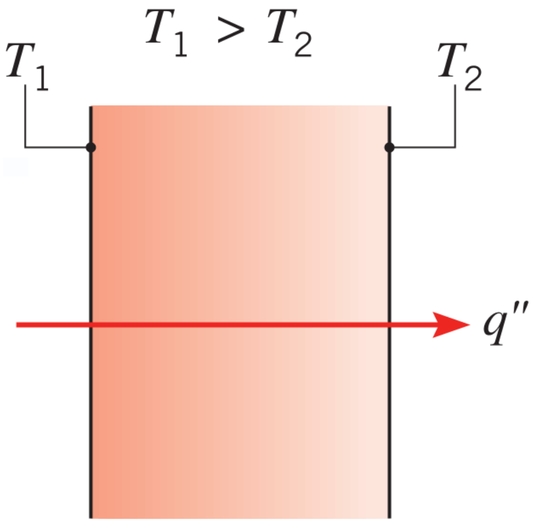
- Applied Thermal Systems consists of an applied approach to understanding the basics of various modes of heat transfer.
- The 3 modes of heat transfer are:
  - Conduction
  - Convection
  - Radiation
- The 3 modes will be analyzed from a 1^{st} Law of Thermodynamics perspective.

Conduction

- The process by which heat is directly transmitted through a substance
- Occurs whenever there is a finite temperature difference across a substance
- A result of the transfer of molecular energy across the substance
- Occurs in solids, liquids, and vapors. However, is most commonly associated with solids

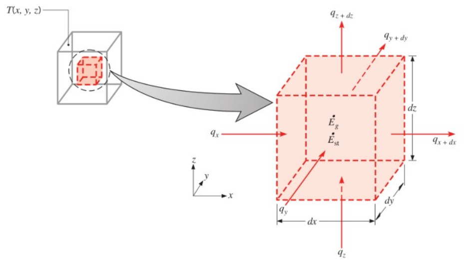


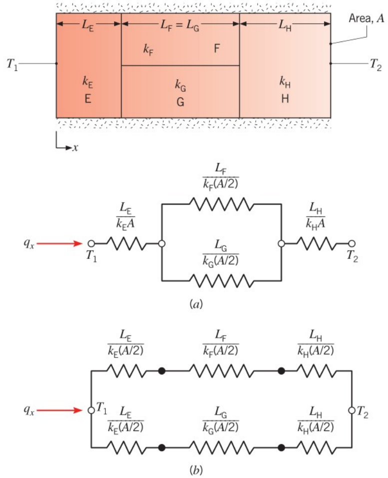


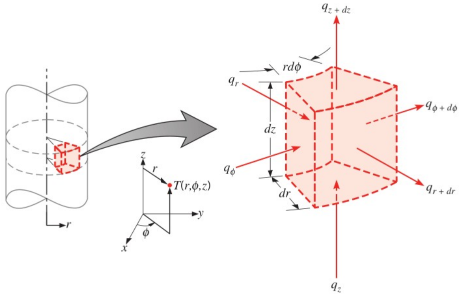
$$\dot{Q} = -kA\frac{dT}{dx}$$

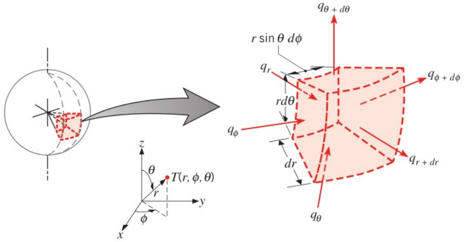
Conduction Topics

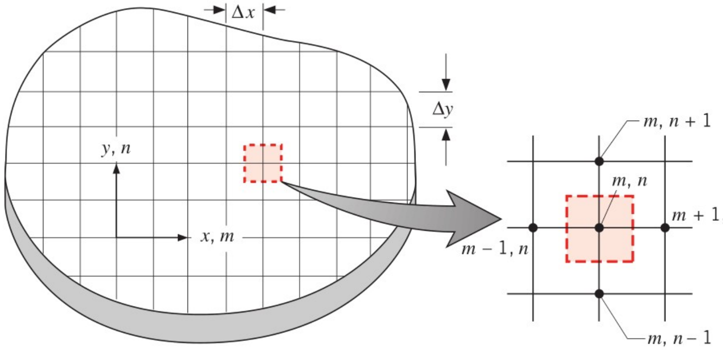
- Material properties involved (thermal conductivity, etc.)
- 1D analysis of planar, cylindrical, and spherical systems
- Thermal circuits
- Fins and their effectiveness
- Overall surface efficiency
- Finite difference methods

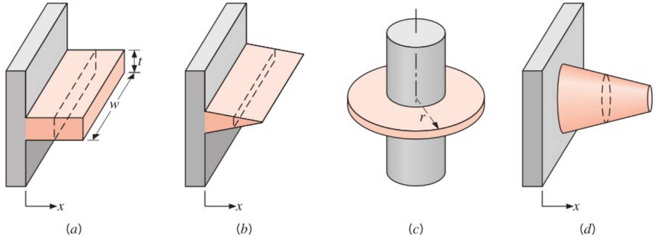








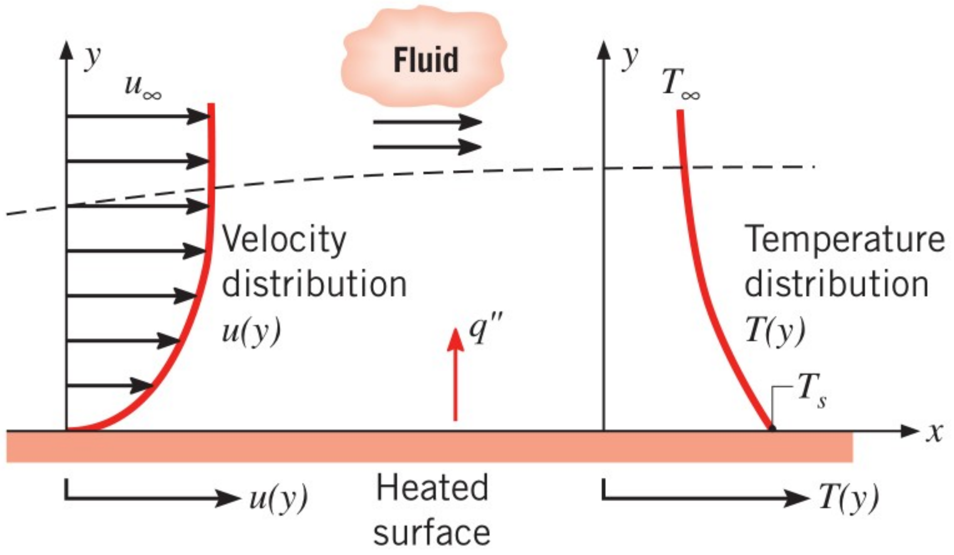




Convection

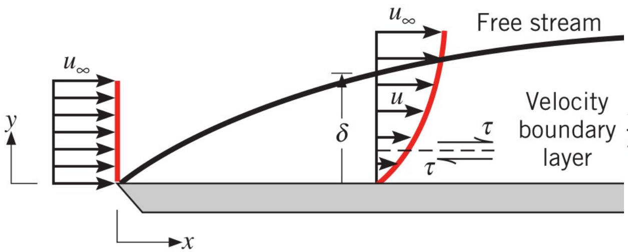
- The process by which heat is "carried" by a substance.
- If conduction deals with heat transfer at the microscopic level, convection may be thought of being at the macroscopic level.
- Heat is transferred by the bulk motion of the substance.

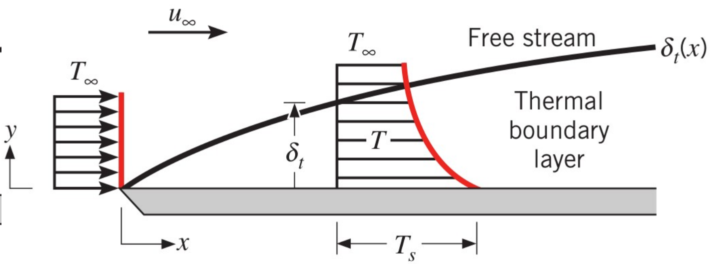
$$\dot{Q} = hA\left(T_s - T_\infty\right)$$

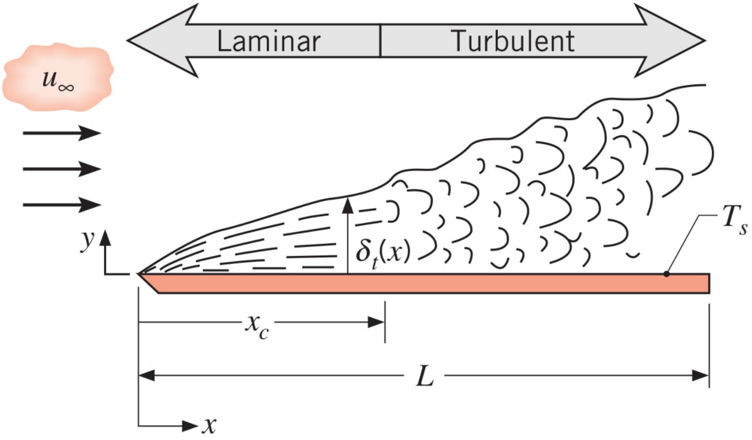


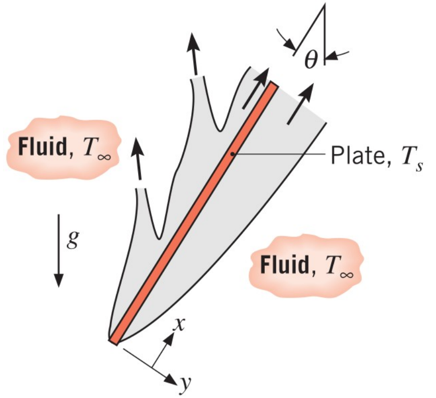
Convection Topics

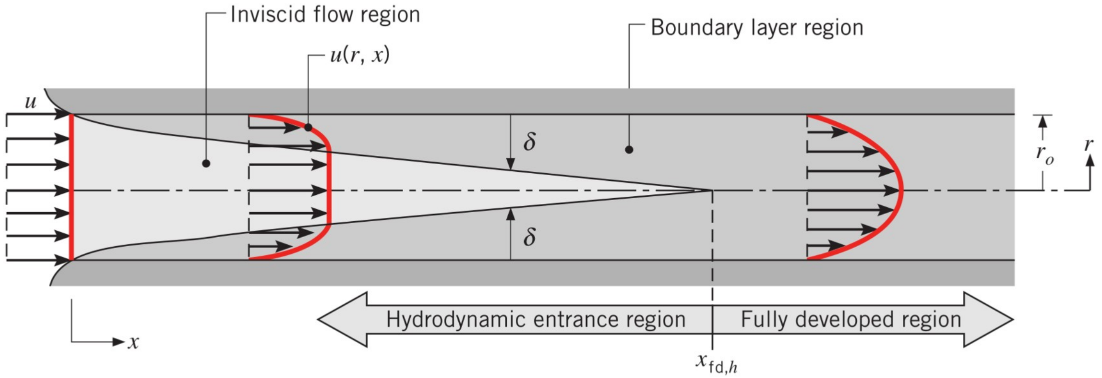
- Boundary layers
- Laminar and turbulent flow
- Non-dimensional number analysis
- Flow over flat plates
- Flow through a duct
- Free and forced flows











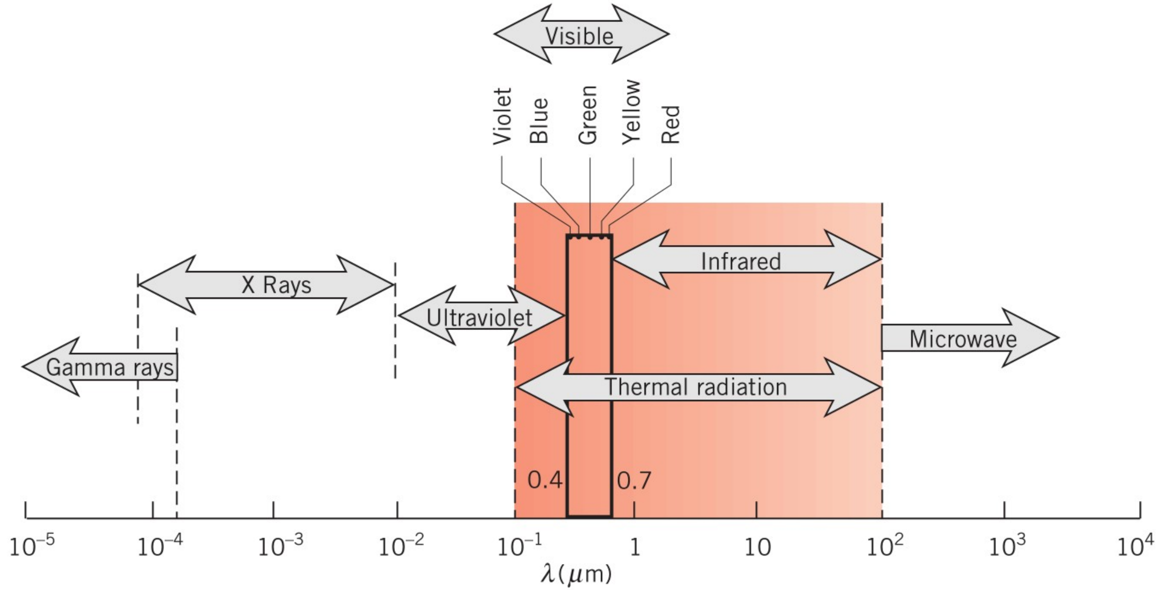
Radiation

- The process by which heat is transmitted by electromagnetic waves.
- Unlike conduction and convection, radiation does not require a specific medium to travel through.
- This is how the Sun heats the Earth.

$$\dot{Q} = \varepsilon \sigma A \left(T_s^4 - T_{sur}^4 \right)$$

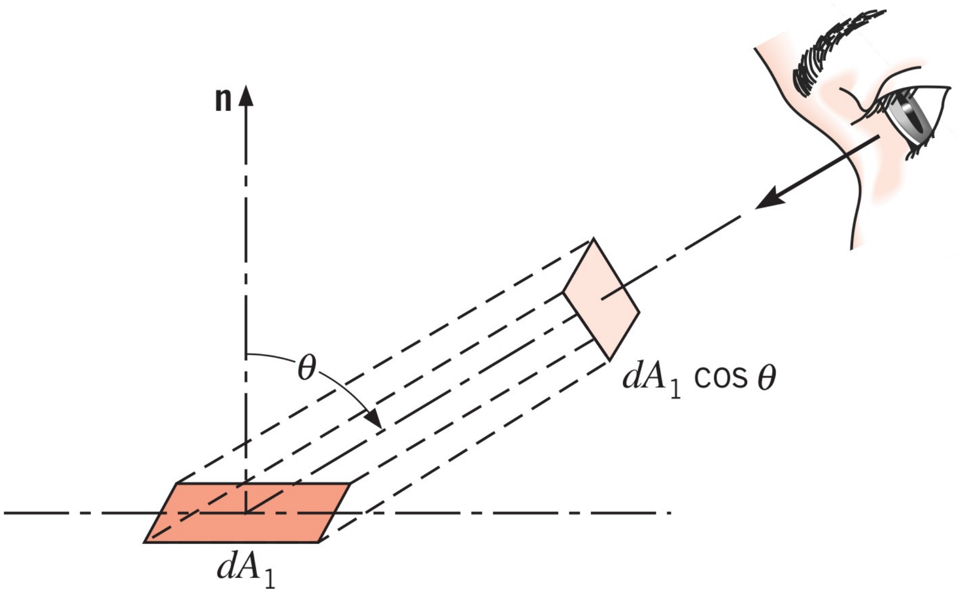
Stefan-Boltzman constant

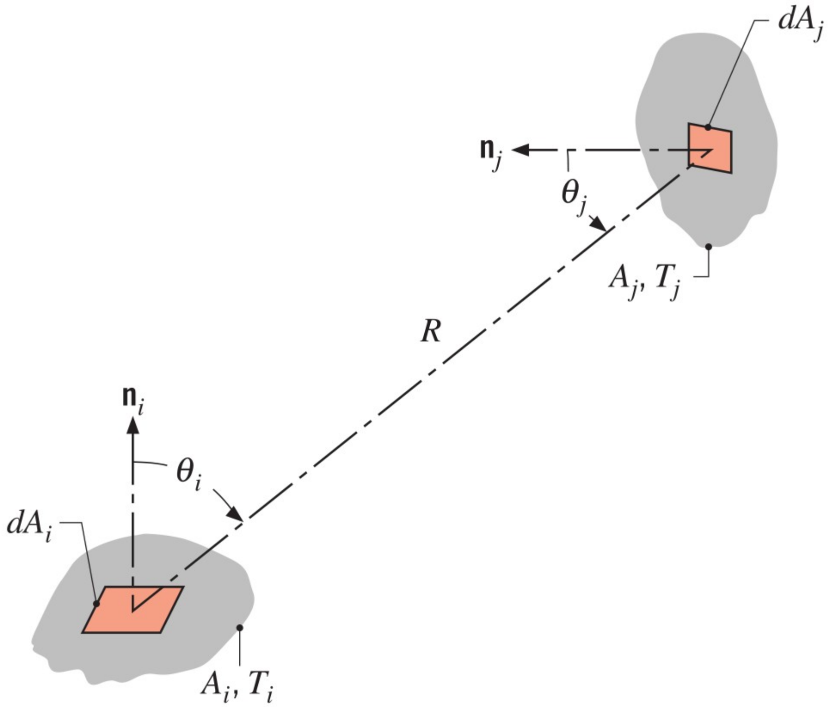
$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$



Radiation Topics

- Ideal vs Real Surfaces
- Kirchhoff's Law
- View Factors



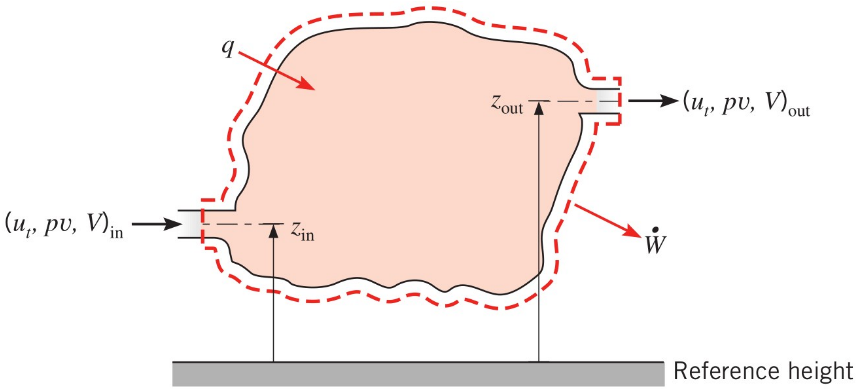


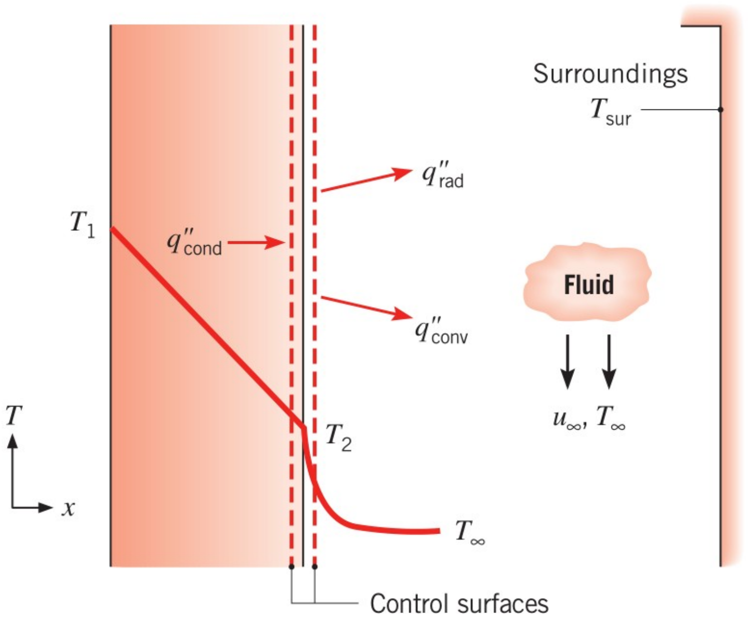
1st Law of Thermodynamics

- Conservation of Energy - Energy is neither created nor destroyed.

$$\Delta E_{sys} = \Sigma E_{in} - \Sigma E_{out}$$

- In rate form, $\dfrac{dE_{sys}}{dt} = \Sigma \dot{E}_{in} - \Sigma \dot{E}_{out}$
- 1st Law is typically applied to a control volume.
- However, sometimes it is convenient to perform a surface energy balance.





Surface Energy Balance

- A surface energy balance still uses the 1st Law but the control volume, or system, portion goes to zero.

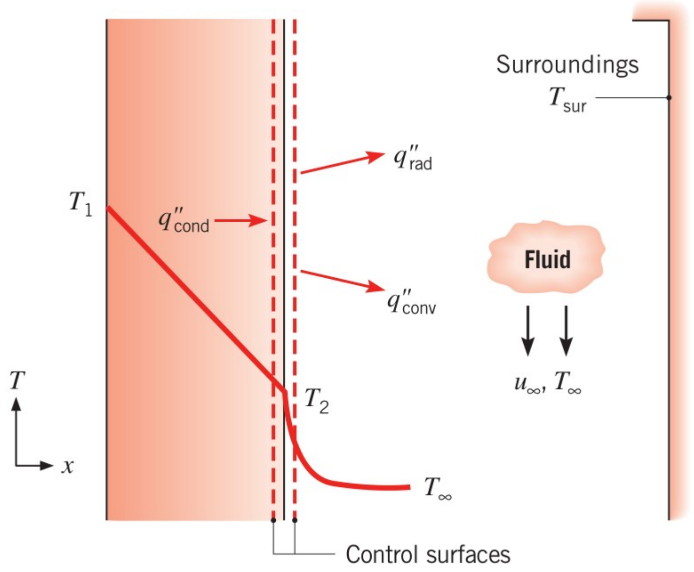
$$\Delta E_{sys} = \Sigma E_{in} - \Sigma E_{out}$$

$$0 = \Sigma E_{in} - \Sigma E_{out}$$

- Thus, the energy balance becomes

$$0 = q''_{cond} - q''_{rad} - q''_{conv}$$

- The double prime here is to indicate heat flux



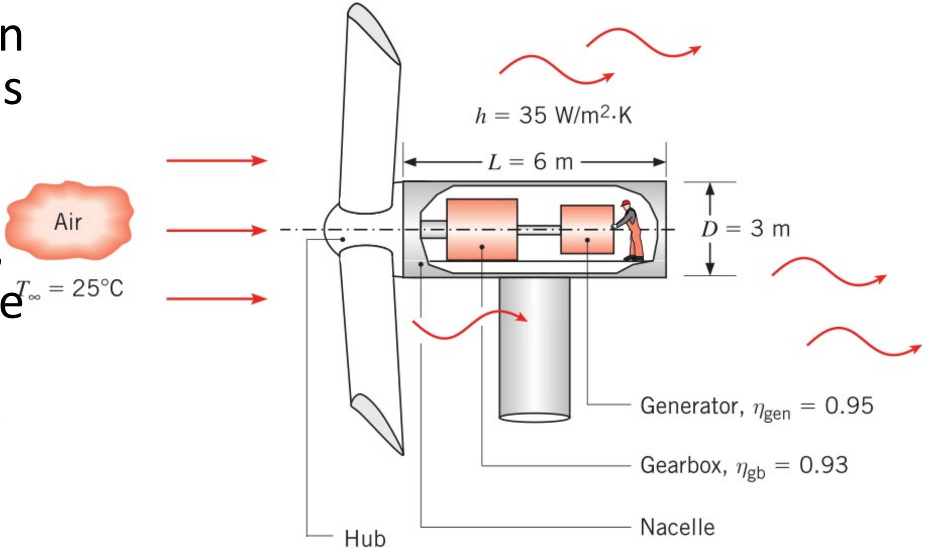
Heat Flux

- Heat flux is a quantity often used to describe heat flow.
- It is the total amount of heat over the cross sectional area that the heat is moving through.
- $q'' = \frac{Q}{A} [=] \frac{W}{m^2}$
- Double prime notation indicates that the heat is on a per area basis; Not to be confused with a double derivative.
- Technically speaking, the previous energy balance should have been written as

$$0 = q''_{cond} A_s - q''_{rad} A_s - q''_{conv} A_s$$

Example 1

The blades of a wind turbine turn a large shaft at a relatively slow speed. The rotational speed is increased by a gearbox that has an efficiency shown to the right. In turn, the gearbox output shaft drives an electric generator with an efficiency also shown to the right. The cylindrical nacelle , which houses the gearbox, generator, and associated equipment, is 6 m long and has a diameter of 3 m. If the turbine produces 2.5 MW of electrical power, and the air and surroundings temperatures are 25°C and 20°C, respectively, determine the minimum possible operating temperature inside the nacelle. The emissivity of the nacelle is 0.83 and the convective heat transfer coefficient is 35 W/m²K. The surface of the nacelle that is adjacent to the blade hub can be considered to be adiabatic.



Example 2

A long conducting rod of diameter *D* and electrical resistance per unit length R'_e is initially in thermal equilibrium with the ambient air and its surroundings. This equilibrium is disturbed when an electrical current *I* is passed through the rod. Develop an equation that could be used to compute the variation of the rod temperature with current at steady state conditions and fixed environmental conditions. Plot the resulting relationship for current ranging from *0* to *10 A*.

$D = 1\,mm \qquad L = 1\,m$

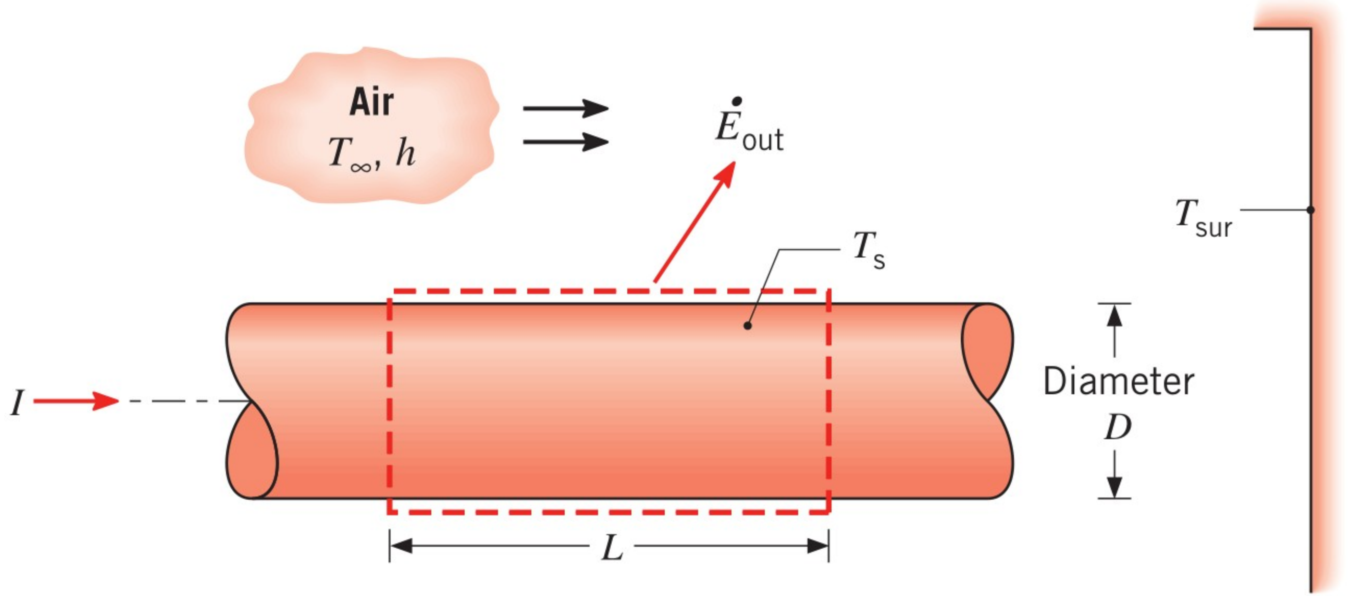
$$R'_e = 0.4\,\frac{\Omega}{m}$$

$$T_\infty = 300\,K$$

$$T_{sur} = 300\,K$$

$$h = 100\,\frac{W}{m^2 K}$$

$$\varepsilon = 0.8$$



Example 3

A $50mm$ x $45mm$ x $20mm$ cell phone charger has a surface temperature of $T_s = 33°C$ when plugged into an electrical wall outlet but not in use. The surface of the charger has an emissivity of $\varepsilon = 0.92$ and is subject to a free convection heat transfer coefficient of $h = 4.5\ W/m^2K$. The room air and wall temperatures are $T_\infty = 22°C$ and $T_{sur} = 20°C$, respectively. If electricity costs $C = \$0.18/kWhr$, determine the daily cost of leaving the charger plugged in when not in use.