Thermodynamics: An Engineering Approach
8th Edition
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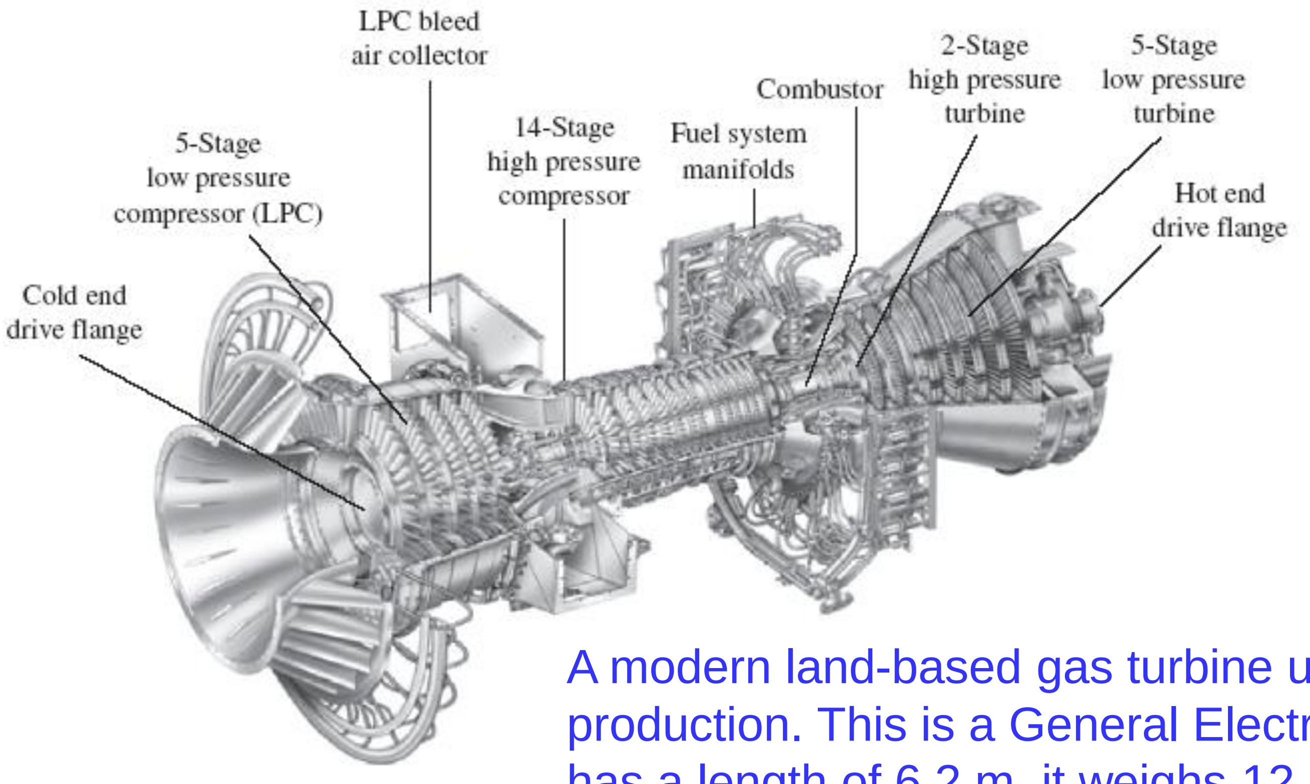
Topic 8
Steady-Flow Devices

Objectives

- Solve energy balance problems for common steady-flow devices such as nozzles, compressors, and turbines.

SOME STEADY-FLOW ENGINEERING DEVICES

Many engineering devices operate essentially under the same conditions for long periods of time. The components of a steam power plant (turbines, compressors, heat exchangers, and pumps), for example, operate nonstop for months before the system is shut down for maintenance. Therefore, these devices can be conveniently analyzed as steady-flow devices.



A modern land-based gas turbine used for electric power production. This is a General Electric LM5000 turbine. It has a length of 6.2 m, it weighs 12.5 tons, and produces 55.2 MW at 3600 rpm with steam injection.

Nozzles and Diffusers

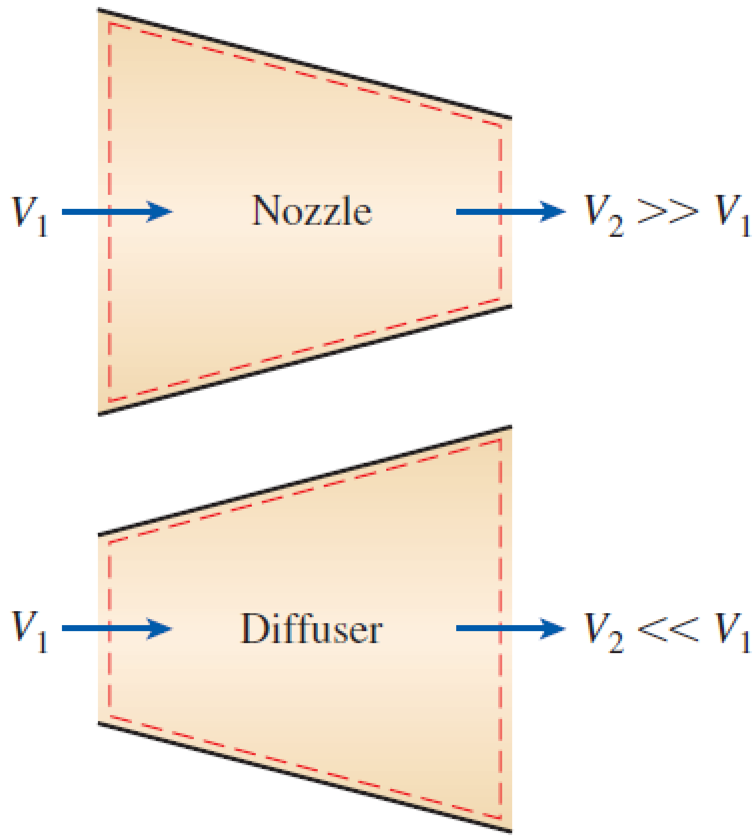


FIGURE 5–26
Nozzles and diffusers are shaped so that they cause large changes in fluid velocities and thus kinetic energies.

Nozzles and diffusers are commonly utilized in jet engines, rockets, spacecraft, and even garden hoses.

A **nozzle** is a device that *increases the velocity of a fluid* at the expense of pressure.

A **diffuser** is a device that *increases the pressure of a fluid* by slowing it down.

The cross-sectional area of a nozzle decreases in the flow direction for subsonic flows and increases for supersonic flows. The reverse is true for diffusers.

Energy balance for a nozzle or diffuser:

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right)$$

$$(\text{since } \dot{Q} \cong 0,\ \dot{W} = 0, \text{ and } \Delta\text{pe} \cong 0)$$

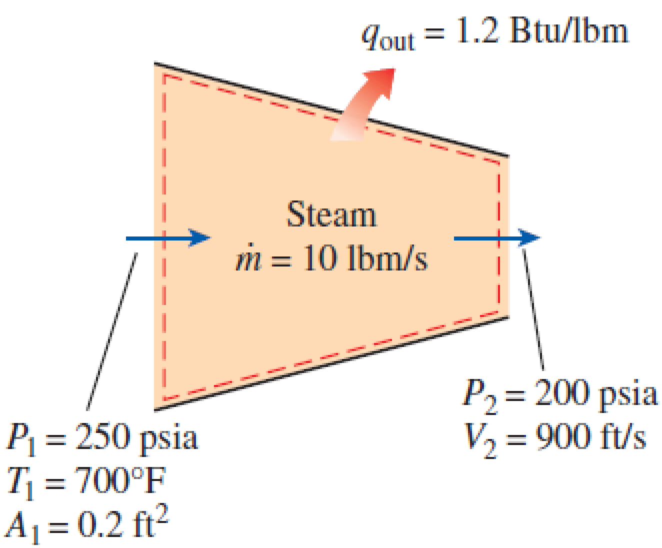
Deceleration of Air in a Diffuser

Air at 10°C and 80 kPa enters the diffuser of a jet engine steadily with a velocity of 200 m/s. The inlet area of the diffuser is 0.4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine the mass flow rate of air and the temperature of the air leaving the diffuser.

Example 1

Acceleration of Steam in a Nozzle

Steam at 250 psia and 700ºF steadily enters a nozzle whose inlet area is 0.2 ft². The mass flow rate of steam through the nozzle is 10 lbm/s. Steam leaves the nozzle at 200 psia with a velocity of 900 ft/s. Heat losses from the nozzle are estimated to be 1.2 Btu/lbm. Determine the inlet velocity and the exit temperature of the steam.



Example 2

Turbines and Compressors

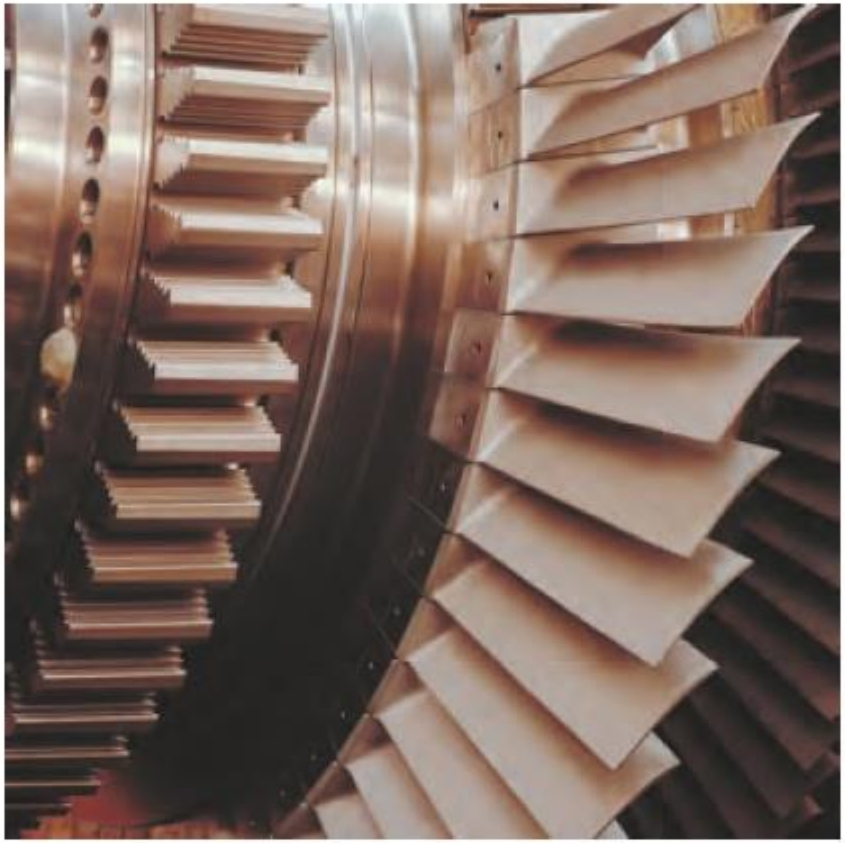


FIGURE 5–29
Turbine blades attached to the turbine shaft.

Turbine drives the electric generator In steam, gas, or hydroelectric power plants.

As the fluid passes through the turbine, work is done against the blades, which are attached to the shaft. As a result, the shaft rotates, and the turbine produces work.

Compressors, as well as **pumps** and **fans**, are devices used to increase the pressure of a fluid. Work is supplied to these devices from an external source through a rotating shaft.

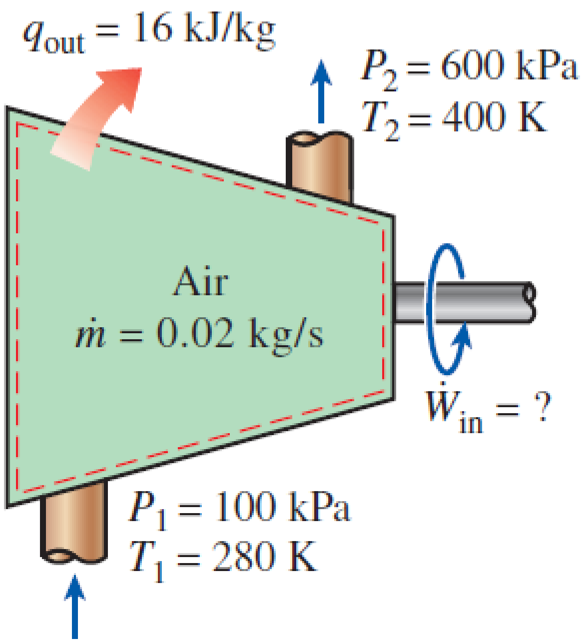
A ***fan*** increases the pressure of a gas slightly and is mainly used to mobilize a gas.

A ***compressor*** is capable of compressing the gas to very high pressures.

Pumps work very much like compressors except that they handle liquids instead of gases.

Compressing Air by a Compressor

Air at 100 kPa and 280 K is compressed steadily to 600 kPa and 400 K. The mass flow rate of the air is 0.02 kg/s, and a heat loss of 16 kJ/kg occurs during the process. Assuming changes in potential and kinetic energy are negligible, determine the necessary power input to the compressor.

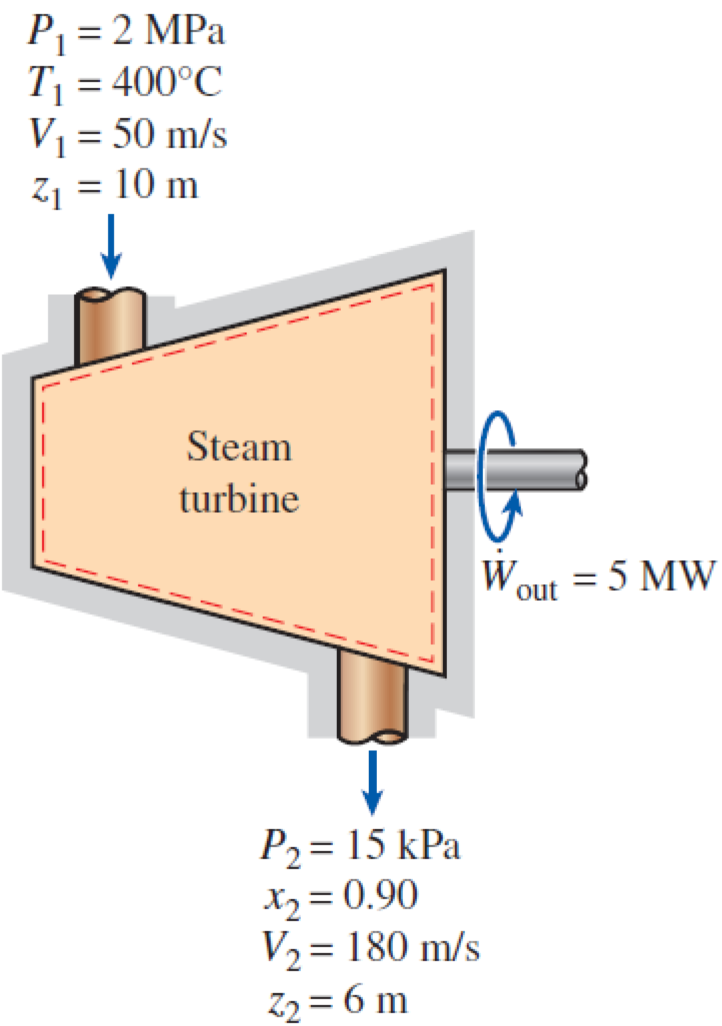


Example 3

Power Generation by a Steam Turbine

The power output of an adiabatic steam turbine is 5 MW. The inlet and the outlet conditions are shown in the figure on the right.

Determine (a) the changes in enthalpy, kinetic energy, and potential energy and (b) the mass flow rate of the steam.



Example 4

Summary

- Some steady-flow engineering devices
  - ✓ Nozzles and Diffusers
  - ✓ Turbines and Compressors