5.2. Use a Cordier analysis to evaluate candidate fan configurations for a flow rate of 10,000 cfm with a total pressure rise of 5 in. wg (standard air). Assume a belt-driven configuration and cover a wide range of equipment. Choose a best candidate based on total efficiency. If discharge velocity pressure is not recovered (base V_d on impeller outlet area), choose a best fan based on static efficiency.

5.3. A chemical process fan must deliver 5000 cfm of air ($\rho = 0.0023\,\text{slug/ft}^3$) at 32 in. wg total pressure rise. Select the proper single-stage centrifugal fan for this application, and compute the diameter, speed, efficiency, and power. Also select a simple two-stage series centrifugal fan arrangement and compute the diameter, speed, efficiency, and power. Compare the two selections as quantitatively as possible and discuss the advantages and disadvantages of both configurations. Neglect compressibility effects.

5.4. Rework Problem 5.3 using a multistage axial configuration. Justify the number of stages selected.

5.5. Reconstrain the analysis of Problem 5.4 to include a minimization of the overall fan noise.

5.6. Use Table 5.2 with a Cordier analysis to select a vane axial fan with requirements of $Q = 12{,}000$ cfm and $\Delta p_S = 0.50$ in. wg at standard density. Assume initially that the velocity pressure is 0.75 in. wg and iterate the solution once only.

5.7. Select a tube axial fan that delivers $2\,\text{m}^3/\text{s}$ at a static pressure rise of 70 Pa using a Cordier analysis aimed at Figures P5.7a and P5.7b.

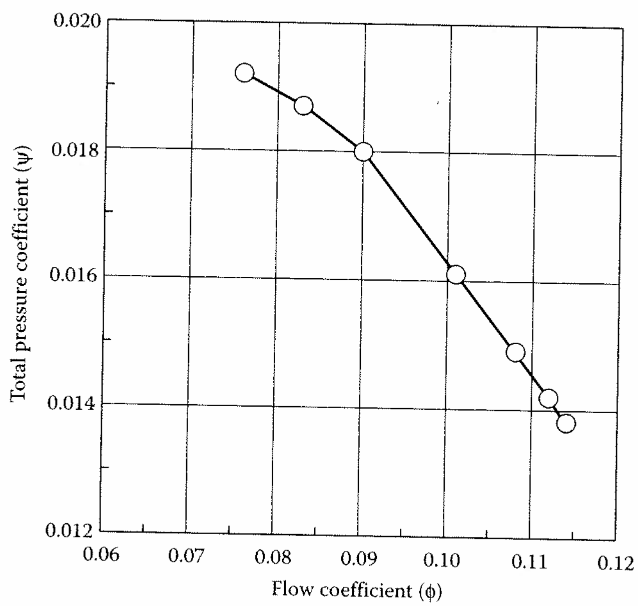


FIGURE P5.7a Dimensionless performance of a tube axial fan. Sizes available (diameter, in.):

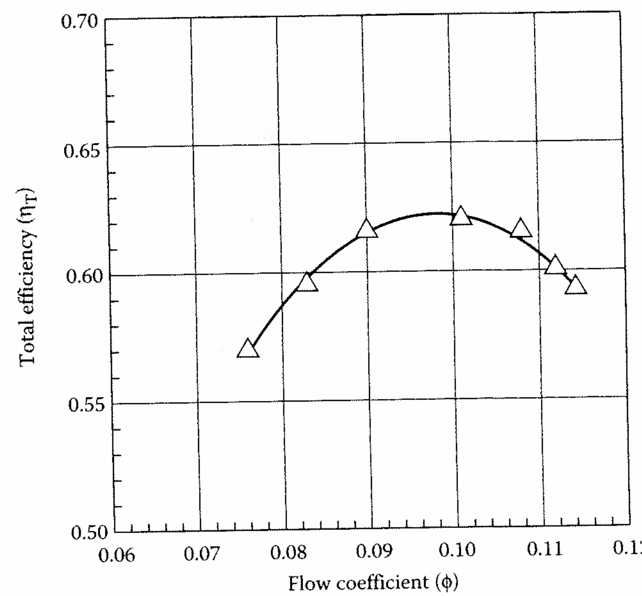


FIGURE P5.7b Total efficiency of a tube axial fan.

Analyze based on available diameters and the speed limitations. Select based on best fit to Figure P5.7 and minimum power required.

5.8. Begin with a Cordier analysis, then use Figure P5.7 to choose a tube axial fan suitable for $Q = 200{,}000$ cfm at $\Delta p_S = 3.75$ in. wg, with a low noise as a selection criterion.

5.9. Use Table 5.2 to search for a fan to provide $Q = 6250$ cfm at $\Delta p_T = 0.75$ in. wg, in standard air.

5.10. A farmer needs to pump 900 gpm of 85°F water at 100 ft of head from an open pond. A suction lift of 8 ft is required. Select a pump that can perform to this specification with an adequate cavitation margin. Try for the best efficiency attainable.

5.11. Select a fan to deliver 15,000 cfm of air (68°F at 1 atm) that provides a static pressure rise of 4.0 in. wg. To keep costs down, try to avoid a need for more than 12 hp, and choose a comparatively quiet fan.

5.12. A pump is required to supply 50 gpm of 85°F water at 50 ft of head. NPSHA is only 10 ft. Which is the smallest pump available?

5.13. Find a fan that can supply 100,000 cfm of 134°F air with $p_b = 28.7$ in. Hg (barometric pressure) at a pressure rise of 1.0 in. wg. Use minimum noise as a criterion for the best choice.

5.14. Identify a minimum sound power level blower that can deliver $25\,\text{m}^3/\text{s}$ of standard density air ($\rho = 1.2\,\text{kg/m}^3$) at 500 Pa static pressure rise.

5.15. A small-parts assembly line involves the use of solvents requiring a high level of ventilation. To achieve removal of these toxic gases, a of a 12 ft high by 30 ft wide room. The toxicants are subsequently removed in a wet scrubber or filter, which causes a pressure drop of 30 lb/ft^2. Using a Cordier analysis, select the design parameters for a fan that will provide the required flow and pressure rise, while operating at or near 90% total efficiency, and that minimizes the diameter of the fan. Give dimensions and speed of the fan and describe the type of fan chosen.

5.16. For the performance requirements stated in Problem 5.15, constrain your selection of a fan to less than $L_W = 100$ dB. Relax the size and efficiency requirements in favor of this noise requirement.

5.17. A water pump must supply 160 gpm at 50 ft of head, and the pump is provided with 4.0 ft of NPSHA. For a single-suction pump direct-connected to its motor, determine the smallest pump one can use without cavitation (define D, N, and η).

5.18. A small axial flow fan has its performance at BEP defined by $Q = 2000$ cfm, $\Delta p_S = 0.10$ in. wg, and $\rho = 0.00233$ slug/ft^3 with a diameter of 20 in.

a. Estimate the specific speed and required rpm.

b. What type of fan should one use?

c. How much motor (shaft) hp is needed for the fan?

d. Estimate the sound power level in dB.

5.19. An aircraft cabin must be equipped with a recirculation fan to move the air through the heaters, coolers, filters, and other air conditioning equipment. A typical recirculation fan for a large aircraft must handle about 0.6 m^3/s of air at 1.10 kg/m^3 (at the fan inlet) with a total pressure rise requirement of 5 kPa. The electrical system aboard the aircraft has an alternating current supply at a line frequency of 400 Hz, and the fan must be configured as a direct-connected impeller for reliability. Size the fan impeller to achieve the best possible static efficiency.

5.20. If one constrains the fan of Problem 5.16 to generate a sound power level of < 85 dB, how are design size and efficiency affected?

5.21. For the recirculation fan of Problem 5.19, if one must keep the sound power level below 90 dB, what are the design options?

5.22. The performance requirements for an air mover are stated as flow rate, $Q = 60$ m^3/min; total pressure rise, $\Delta p_T = 500$ Pa. Ambient air density, $\rho = 1.175$ kg/m^3. The machine is constrained not to exceed the 90 dB sound power level.

a. Determine a suitable speed and diameter for the fan and estimate the total efficiency.

b. Correct the total efficiency for the effects of Reynolds number, a running clearance of 2.5 × Ideal, and the influence of a belt-drive system (assume a drive efficiency of 95%).

5.23. Use the dimensionless performance curves of this chapter to select three candidates for the requirements of Problem 5.22, which

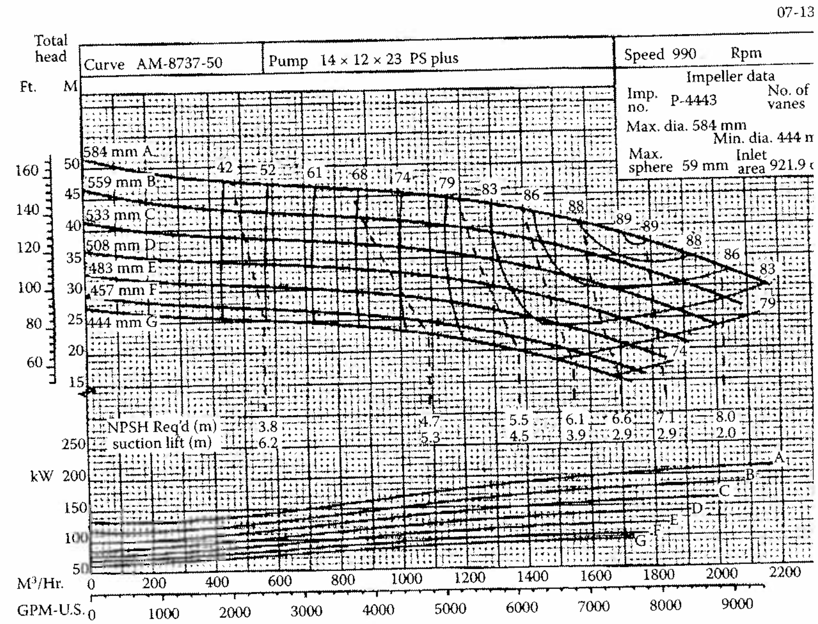
5.24. To evacuate a stone quarry (to preclude the pleasure of unauthorized swimming), we need a pump that can move at least 0.5 m^3/s against a head of 80 m. The pump must be floated on a barge with its inlet 1.125 m above the surface of the 12°C water. The atmospheric pressure during pumping may fall as low as 98 kPa. Select a noncavitating pump for this application and match your modeling of size and speed with the best available pump from Figure P5.24.

5.25. Repeat the fan selection exercise of Problem 5.7 using the flow rate of 2 m^3/s but changing the static pressure rise to 140 Pa and then again with 35 Pa. Compare the results with each other and with the results of Problem 5.7. Use the dimensionless curves of Figure P5.7 for the fans.

5.26. A water pump, which is required to provide 21 m^3/h with 16 m of head, must operate with 1.125 m of NPSHA. For a single-suction machine, directly connected to its motor, determine the smallest pump that can be used, defining the D, N, and η. What would the minimum size be for an NPSHA of 0.5 m?

5.27. The FD fan of Problem 4.27 was required to provide 25 m^3/s of air with a static pressure rise of 10 kPa subject to an inlet density of 0.57 kg/m^3. At the imposed speed of 1500 rpm, estimate the fan size, its static and total efficiencies, and the required input power.

5.28. The inlet air temperature for the fan of Problem 5.27 was $T = 265$°C. High temperature fans frequently require very large radial clearances to accommodate the thermal distortion of the inlet cone



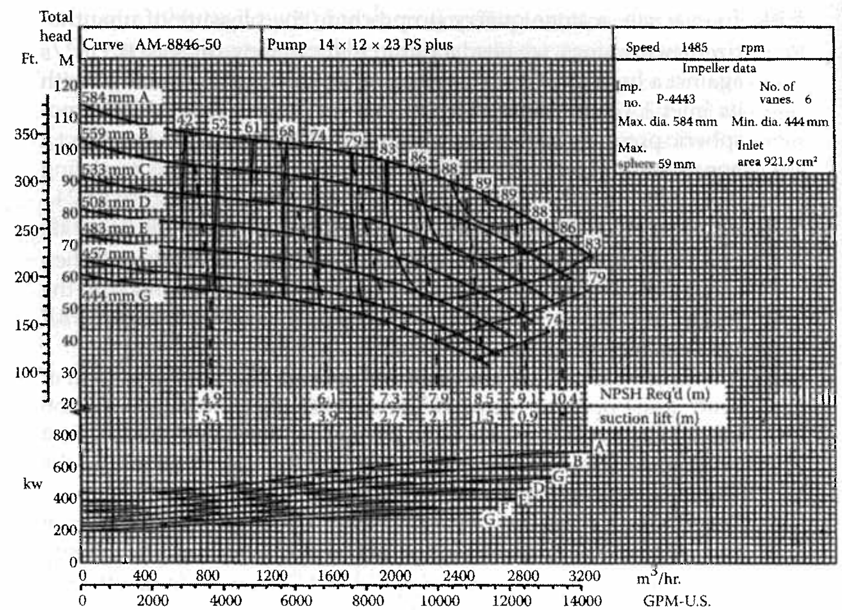


FIGURE P5.24b Pump performance curves (1485 rpm) (ITT Fluid Systems).

relative to the impeller. Use a clearance ratio of C/D = 8 and determine the actual radial clearance of this fan in mm. Use $T = 265°C$ to modify the kinematic viscosity of the air and correct the total efficiency for both Reynolds number and the generous clearance.

5.29. A lime-kiln fan similar to the one described in Problem 4.29 has performance requirements of $Q = 250{,}000$ cfm and $\Delta p_S = 45$ in. wg with an inlet density of $0.037\,\text{lbm/ft}^3$. The fan is assumed to be a double-width impeller configuration and is to be sized for high total efficiency. Determine size and power requirements for a fan to meet this specification. Correct the total efficiency and required power for the Reynolds number (set C/D = 1).

5.30. Assume that the variable pitch fan of Figure 5.15 can be arranged in a multistage configuration to achieve very high-pressure rise performance. For an FD application requiring $Q = 100{,}000$ cfm and $\Delta p_T = 28$ in. wg (at $\rho = 0.072\,\text{lbm/ft}^3$), select a variable pitch fan and specify size and number of stages from the data of Figure 5.17. Use $N = 1470$ rpm.

5.31. In the discussion of the flow regions in Section 5.2, the "hybrid" machines are mentioned. One example is the Airfoil Plenum Fan shown, along with its performance chart in Figure P5.31. These fans may offer a practical alternative for air handling or conditioning, or in retrofit applications. Elimination of the conventional

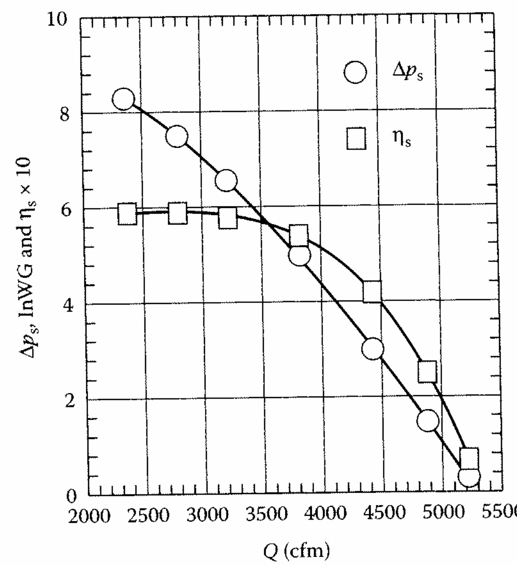


FIGURE P5.31 Configuration and static performance of a centrifugal Airfoil Plenum Fan scroll installed). $D = 15$ in., $N = 3600$ rpm, $\rho g = 0.075\,\text{lbf/ft}^3$. (From Chicago Blower Corp tion. (1998) *Fan Catalogs*. With permission.)

the specific speed and diameter of the fan and compare with the expected region for a centrifugal fan.

5.32. A small woodworking shop (similar to the one considered in Problem 4.25) has a ventilation requirement of $1.5\,\text{m}^3/\text{s}$ with a static pressure rise of 1.5 kPa. Because of very tight space constraints on the fan installation, it would be advantageous to use a compact plenum of the fan or must the more robust—and more expensive—Class II version of the fan be selected? [Hint: Work from the specific speed and diameter values of the given plenum fan in the region where $\eta_s = 0.58$.]

5.33. The small plenum fan of Problem 5.31 is rated at a sound pressure level of 79 dBA at a distance of 10 ft from the open inlet of the fan (based on a free field environment). Use the modified Graham method of Chapter 4 to estimate L_P 10 ft from the inlet of the 15-in., 3600-rpm fan and compare the estimate with the rated value. The best total efficiency was found to occur at $Q = 3,200$ cfm in Problem 5.31.

5.34. Electric power generating stations use many different pumps (one expert estimates that at least 100 pumps may be used in a 500 MW unit). The three main types used in the plant cycle are boiler feed pumps, condensate pumps, and (condenser) circulating water pumps. The following paragraphs describe the performance requirements for these three types of pumps as applied in a 500-MW generating unit.

Boiler feed pump. This pump delivers water through the high-pressure feedwater heaters and into the boiler. The pump takes suction from the deaerating feedwater heater (essentially an open tank where liquid water and steam are mixed at approximately 200 psia) and delivers water at approximately 3200 psia. As the hot water has a specific weight of about 58 lb/ft^3, the pump's head is about 7500 ft. The flow rate is about 4,200,000 lb/h or 9000 gpm.

Condensate pump. This pump takes suction from the condenser hotwell, where the just-condensed water has a pressure of about 1.5 psia, and delivers it through the low-pressure feedwater heaters into the deaerating feedwater heater. The deaerator is at about 200 psia and is typically located about 175 ft above the pump. Accounting for friction losses, and with a water density of about 61 lb/ft^3, the condensate pump must develop a head of about 700 ft. The flow is about 6900 gpm.

Circulating water pump. This pump supplies cooling water to the condenser. Water is drawn from a lake or river (or from a cooling tower), pumped through the tubes in the condenser, and returned to the source. The head is only about 30 ft and is due only to friction losses. The flow rate is in the neighborhood of 200,000 gpm.

a. If all pumps have efficiency of 85%, estimate the power required for each. [Use efficiency of 85% only for part (a).]

b. Which pump is the largest (impeller diameter)? Which is the smallest? Explain.

c. Which pump is the fastest (rpm)? Which is the slowest? Explain.

d. Which pump is more likely employed in parallel with oth identical pumps? Why?

e. Which pump is almost certainly built in several stages? Why? (multistage pump has several impellers in series—all containe in the same casing and mounted on a common shaft— a multistage pump is really the same as several pumps series.)

f. Which pump(s) is likely driven by a steam turbine? Which a likely driven by electric motors? Explain.

g. To save initial cost, the condensate pump is built as a sing one-stage pump and driven at about 1800 rpm (so the speci speed of the condensate pump is around 0.4). Of the remaini pumps, one has impeller(s) designed for a specific speed of (and the other has impeller(s) designed for a specific speed of 3 Which pump (boiler feed or circulating water) has which speci speed (0.6 or 3.0)? Sketch the impeller shape for each of the thr pumps.

h. For each pumping system, using the appropriate speci speed for each, specify a reasonable rotating speed, a reaso able number of stages if multistage, or a reasonable numb of identical pumps in parallel if applied in parallel. (Hi 300 rpm <reasonable speed <6000 rpm; reasonable number stages or machines in parallel <8.)

5.35. A plant has a water pump that has been in service for a few yea The pump is driven by an AC electric motor. A check of plant mo toring instruments indicates the following performance data: Fl ≈4300 gpm; Head ≈50 ft; and Motor power input ≈52 kW. A ch of the motor nameplate reveals that it operates at 1750 rpm and l a maximum output capacity of 60 kW. A change in plant operat strategy now requires that the pump operates at 50% capacity 12 h per day and full capacity for the other 12 h per day. Modifi tions must be made to the pumping system to accommodate th changes. Options to be considered are (1) install a throttling va and (2) install a variable speed drive between the pump and motor. Unfortunately, all manufacturers' information on the pu has been lost.

a. Assuming that the pump was originally optimally matched v the system (i.e., it operated at BEP), sketch a set of performa curves (Head–Flow and Power–Flow) for the pump. The cur must be as realistic as possible.

Now consider the expected pump performance at 50% flow.

b. Estimate the pump head for the throttling option, the requ pump speed for the variable-speed option, and the po for both options (assume that the variable-speed drive has efficiency of 95%).

with $\rho = 0.00233$ slug/ft^3. Lower speeds of 1750 and 1175 rpm are also available.

a. Estimate the size of the fan and its efficiency at 3550 rpm.

b. Estimate the flow rate and pressure rise at the low speed of 1175 rpm.

c. Use the Reynolds numbers of the fan at 1750 and 1175 rpm to estimate the efficiency of the fan at these lower speeds.

3.40. The low-pressure section of a steam turbine has nine stages. Steam enters the section at 380 lbm/s (173 kg/s), 160 psia (1.30 MPa), 755°F (401°C). The turbine spins at 3600 rpm. The steam leaves the section (after the ninth stage) at 4 psia (27.5 kPa).

a. Assuming that each of the nine stages has the same pressure ratio, find the pressure ratio for the first stage.

b. Find the first stage volume flow (use average density for the first stage).

c. Determine an expected diameter for the first stage.

d. Estimate the efficiency of the first stage.

e. Assuming that all nine stages have the same efficiency, calculate the efficiency for the entire section.

f. Calculate the specific work in the first stage.

3.41. A gas-turbine engine has an 8-stage axial flow compressor. Each stage has a pressure ratio of 1.24 and a polytropic efficiency of 87.2%. The compressor's rated air flow is 30 lb/s.

a. Calculate the overall pressure ratio of the compressor and its isentropic efficiency.

b. The engine is rated with inlet air at 59°F and 14.696 psia. Calculate the power consumed at rated conditions.

c. The compressor is operated at a location where the inlet air conditions are 90°F and 13.8 psia. Calculate the new values of mass flow and input power.

3.42. A turbocharger is used to increase the power output of a reciprocating engine by compressing the air/fuel mixture prior to induction into the engine. The power to run the compressor is provided by a turbine in the exhaust gas stream. The compressor and the turbine share a common shaft and hence rotate at the same speed. Consider a turbocharger with the following specifications: Compressor inlet air—14.0 psia, 70°F, $c_p = 0.24$ Btu/lbm °R, $\gamma = 1.4$, $\dot{m} = 0.5$ lbm/s; Compressor discharge pressure = 28 psia; Turbine exhaust gas properties are 1100°F, $c_p = 0.27$ Btu/lbm °R, and $\gamma = 1.3$; the turbine exhausts to atmospheric pressure. Neglect the fuel mass added between the compressor discharge and the turbine inlet.

a. Assuming an optimum choice for the compressor, estimate its speed and size.

b. What power must the turbine supply to run the compressor?

c. Since turbines are naturally more efficient than compressors, assume that ($\eta_{t,s} = \eta_{c,s} + 0.05$) and estimate the pressure at the turbine inlet.

d. What type of turbine would be expected to yield this efficiency? What would be its size?

3.43. A centrifugal compressor is being designed to handle high-temperature air ($T_{inlet} = 800$°F, $p_{inlet} = 14.7$ psia). The design pressure ratio is to be 5:1, the design speed is to be 25,000 rpm, and the design mass flow is 25 lbm/s.

a. Estimate the size of the compressor and sketch the impeller.

b. A rating test is to be conducted with cold air (59°F). At what speed, pressure ratio, and flow rate should the test be conducted?

c. Assume that the test yields an *isentropic* efficiency of 84.2%. Determine the efficiency at design conditions. Include effects of Reynolds number, if any.

3.44. Use the pump from Problem 2.3 operating at 1200 rpm. Assume that the pump's NPSHR is given by

$$\text{NPSHR} = 5 + 20\left(\frac{Q}{100}\right)^{1.8}$$

and determine how far downstream from the system inlet that the pump can safely be located. Assume 90°F water.

3.45. Consider once again the Taco Model 4013 family (series) of pumps in Figure P1.41 (Problem 1.41).

a. Calculate the specific speed for this type pump. Use the 13.0-in. impeller.

b. Compare the actual efficiency of this pump with the expected efficiency from the $\eta - N_s$ correlation in Figure 2.9.

c. Compare the shape of the performance curve for this pump to that expected for a pump with this specific speed.

d. Make a sketch of the probable shape of the impeller.

e. Calculate the specific speed using the 10.6-in. impeller. Compare with your answer from part "a" and discuss any differences.

3.46. Consider using a number of the Taco pumps (in Figure P1.41) to deliver 500 gpm of water through a system that has a 300 ft elevation rise and a (minimum) head loss of (approximately) 50 ft. In order to save capital costs, it is contemplated to use a single 13.0-in. pump of this family and to use either a 1750-rpm (4-pole) or a 3550-rpm (2-pole) motor. The flow requirement is still 500 gpm; the head loss can be increased if necessary by closing a valve.