Chapter 1

Problems **1-1** through **1-6** are for student research. No standard solutions are provided.

1-7 From Fig. 1-2, cost of grinding to ± 0.0005 in is 270%. Cost of turning to ± 0.003 in is 60%.

Relative cost of grinding vs. turning = 270/60 = 4.5 times *Ans.*

1-8 $C_A = C_B$,

$$10 + 0.8\,P = 60 + 0.8\,P - 0.005\,P^2$$

$$P^2 = 50/0.005 \qquad \Rightarrow \qquad P = 100 \text{ parts} \quad \textit{Ans.}$$

1-9 Max. load = 1.10 P
Min. area = $(0.95)^2 A$
Min. strength = 0.85 S
To offset the absolute uncertainties, the design factor, from Eq. (1-1) should be

$$n_d = \frac{1.10}{0.85(0.95)^2} = 1.43 \qquad \textit{Ans.}$$

1-10 (**a**) $X_1 + X_2$:

$$x_1 + x_2 = X_1 + e_1 + X_2 + e_2$$

$$\text{error } = e = (x_1 + x_2) - (X_1 + X_2)$$

$$= e_1 + e_2 \qquad \textit{Ans.}$$

(**b**) $X_1 - X_2$:

$$x_1 - x_2 = X_1 + e_1 - (X_2 + e_2)$$

$$e = (x_1 - x_2) - (X_1 - X_2) = e_1 - e_2 \qquad \textit{Ans.}$$

(**c**) $X_1\,X_2$:

$$x_1 x_2 = (X_1 + e_1)(X_2 + e_2)$$

$$e = x_1 x_2 - X_1 X_2 = X_1 e_2 + X_2 e_1 + e_1 e_2$$

$$\doteq X_1 e_2 + X_2 e_1 = X_1 X_2 \left(\frac{e_1}{X_1} + \frac{e_2}{X_2} \right) \qquad \textit{Ans.}$$

(d) X_1/X_2:

$$\frac{x_1}{x_2} = \frac{X_1 + e_1}{X_2 + e_2} = \frac{X_1}{X_2}\left(\frac{1 + e_1/X_1}{1 + e_2/X_2}\right)$$

$$\left(1 + \frac{e_2}{X_2}\right)^{-1} \doteq 1 - \frac{e_2}{X_2} \quad \text{then} \quad \left(\frac{1 + e_1/X_1}{1 + e_2/X_2}\right) \doteq \left(1 + \frac{e_1}{X_1}\right)\left(1 - \frac{e_2}{X_2}\right) \doteq 1 + \frac{e_1}{X_1} - \frac{e_2}{X_2}$$

Thus, $e = \dfrac{x_1}{x_2} - \dfrac{X_1}{X_2} \doteq \dfrac{X_1}{X_2}\left(\dfrac{e_1}{X_1} - \dfrac{e_2}{X_2}\right)$ *Ans.*

1-11 **(a)** $x_1 = \sqrt{7} = 2.645\ 751\ 311\ 1$

$X_1 = 2.64$ (3 correct digits)

$x_2 = \sqrt{8} = 2.828\ 427\ 124\ 7$

$X_2 = 2.82$ (3 correct digits)

$x_1 + x_2 = 5.474\ 178\ 435\ 8$

$e_1 = x_1 - X_1 = 0.005\ 751\ 311\ 1$

$e_2 = x_2 - X_2 = 0.008\ 427\ 124\ 7$

$e = e_1 + e_2 = 0.014\ 178\ 435\ 8$

Sum $= x_1 + x_2 = X_1 + X_2 + e$

$= 2.64 + 2.82 + 0.014\ 178\ 435\ 8 = 5.474\ 178\ 435\ 8$ <u>Checks</u>

(b) $X_1 = 2.65,\ X_2 = 2.83$ (3 digit significant numbers)

$e_1 = x_1 - X_1 = -\ 0.004\ 248\ 688\ 9$

$e_2 = x_2 - X_2 = -\ 0.001\ 572\ 875\ 3$

$e = e_1 + e_2 = -\ 0.005\ 821\ 564\ 2$

Sum $= x_1 + x_2 = X_1 + X_2 + e$

$= 2.65 + 2.83 - 0.001\ 572\ 875\ 3 = 5.474\ 178\ 435\ 8$ <u>Checks</u>

1-12 $\sigma = \dfrac{S}{n_d} \quad \Rightarrow \quad \dfrac{16(1000)}{\pi d^3} = \dfrac{25(10^3)}{2.5} \quad \Rightarrow \quad d = 0.799 \text{ in}$ *Ans.*

Table A-17: $d = \frac{7}{8}$ in *Ans.*

Factor of safety: $n = \dfrac{S}{\sigma} = \dfrac{25(10^3)}{\dfrac{16(1000)}{\pi\left(\frac{7}{8}\right)^3}} = 3.29$ *Ans.*

1-13 Eq. (1-5): $R = \displaystyle\sum_{i=1}^{n} R_i = 0.98(0.96)0.94 = 0.88$

Overall reliability = 88 percent *Ans.*

1-14 a = 1.500 ± 0.001 in
b = 2.000 ± 0.003 in
c = 3.000 ± 0.004 in
d = 6.520 ± 0.010 in

(**a**) $\bar{w} = \bar{d} - \bar{a} - \bar{b} - \bar{c}$ = 6.520 – 1.5 – 2 – 3 = 0.020 in

$t_w = \sum t_{\text{all}}$ = 0.001 + 0.003 + 0.004 +0.010 = 0.018

w = 0.020 ± 0.018 in *Ans.*

(**b**) From part (a), $w_{\min}$ = 0.002 in. Thus, must add 0.008 in to $\bar{d}$. Therefore,

$\bar{d}$ = 6.520 + 0.008 = 6.528 in *Ans.*

1-15 $V = xyz$, and $x = a \pm \Delta a$, $y = b \pm \Delta b$, $z = c \pm \Delta c$,

$$\bar{V} = abc$$

$$V = (a \pm \Delta a)(b \pm \Delta b)(c \pm \Delta c)$$
$$= abc \pm bc\Delta a \pm ac\Delta b \pm ab\Delta c \pm a\Delta b\Delta c \pm b\Delta c\Delta a \pm c\Delta a\Delta b \pm \Delta a\Delta b\Delta c$$

The higher order terms in Δ are negligible. Thus,

$$\Delta V \doteq bc\Delta a + ac\Delta b + ab\Delta c$$

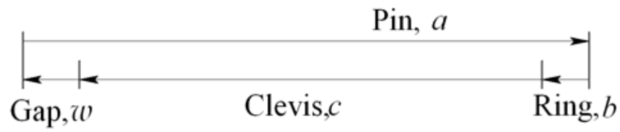
and, $$\frac{\Delta V}{\bar{V}} \doteq \frac{bc\Delta a + ac\Delta b + ab\Delta c}{abc} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} = \frac{\Delta a}{\bar{a}} + \frac{\Delta b}{\bar{b}} + \frac{\Delta c}{\bar{c}} \quad Ans.$$

For the numerical values given, $\bar{V} = 1.500(1.875)3.000 = 8.4375 \text{ in}^3$

$$\frac{\Delta V}{\bar{V}} = \frac{0.002}{1.500} + \frac{0.003}{1.875} + \frac{0.004}{3.000} = 0.00427 \quad \Rightarrow \quad \Delta V = 0.00427(8.4375) = 0.036 \text{ in}^3$$

V = 8.438 ± 0.036 in^3 *Ans.*

1-16



w_{max} = 0.05 in, w_{min} = 0.004 in

$$\bar{w} = \frac{0.05 + 0.004}{2} = 0.027 \text{ in}$$

Thus, Δ w = 0.05 – 0.027 = 0.023 in, and then, w = 0.027 ± 0.023 in.

$$\bar{w} = \bar{a} - \bar{b} - \bar{c}$$

$$0.027 = \bar{a} - 0.042 - 1.5$$

$$\bar{a} = 1.569 \text{ in}$$

$$t_w = \sum t_{\text{all}} \quad \Rightarrow \quad 0.023 = t_a + 0.002 + 0.005 \quad \Rightarrow \quad t_a = 0.016 \text{ in}$$

Thus, a = 1.569 ± 0.016 in *Ans.*

1-17

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 3.734 + 2(0.139) = 4.012 \quad \text{in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.028 + 2(0.004) = 0.036 \quad \text{in}$$

D_o = 4.012 ± 0.036 in *Ans.*

1-18 From O-Rings, Inc. (oringsusa.com), D_i = 9.19 ± 0.13 mm, d = 2.62 ± 0.08 mm

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 9.19 + 2(2.62) = 14.43 \quad \text{mm}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.13 + 2(0.08) = 0.29 \quad \text{mm}$$

D_o = 14.43 ± 0.29 mm *Ans.*

1-19 From O-Rings, Inc. (oringsusa.com), D_i = 34.52 ± 0.30 mm, d = 3.53 ± 0.10 mm

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 34.52 + 2(3.53) = 41.58 \quad \text{mm}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.30 + 2(0.10) = 0.50 \quad \text{mm}$$

D_o = 41.58 ± 0.50 mm *Ans.*

1-20 From O-Rings, Inc. (oringsusa.com), D_i = 5.237 ± 0.035 in, d = 0.103 ± 0.003 in

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 5.237 + 2(0.103) = 5.443 \quad \text{in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.035 + 2(0.003) = 0.041 \quad \text{in}$$

D_o = 5.443 ± 0.041 in *Ans.*

1-21 From O-Rings, Inc. (oringsusa.com), D_i = 1.100 ± 0.012 in, d = 0.210 ± 0.005 in

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 1.100 + 2(0.210) = 1.520 \quad \text{in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.012 + 2(0.005) = 0.022 \quad \text{in}$$

D_o = 1.520 ± 0.022 in *Ans.*

1-22 From Table A-2,

(**a**) σ = 150/6.89 = 21.8 kpsi *Ans.*

(**b**) F = 2 /4.45 = 0.449 kip = 449 lbf *Ans.*

(**c**) M = 150/0.113 = 1330 lbf · in = 1.33 kip · in *Ans.*

(**d**) A = 1500/ 25.4^2 = 2.33 in^2 *Ans.*

(**e**) I = 750/2.54^4 = 18.0 in^4 *Ans.*

(**f**) E = 145/6.89 = 21.0 Mpsi *Ans.*

(**g**) v = 75/1.61 = 46.6 mi/h *Ans.*

(**h**) V = 1000/946 = 1.06 qt *Ans.*

1-23 From Table A-2,

(**a**) l = 5(0.305) = 1.53 m *Ans.*

(**b**) σ = 90(6.89) = 620 MPa *Ans.*

(**c**) p = 25(6.89) = 172 kPa *Ans.*

(**d**) $Z = 12(16.4) = 197\ \text{cm}^3$ *Ans.*

(**e**) $w = 0.208(175) = 36.4$ N/m *Ans.*

(**f**) $\delta = 0.001\,89(25.4) = 0.0480$ mm *Ans.*

(**g**) $v = 1200(0.0051) = 6.12$ m/s *Ans.*

(**h**) $\epsilon = 0.002\,15(1) = 0.002\,15$ mm/mm *Ans.*

(**i**) $V = 1830(25.4^3) = 30.0\,(10^6)\ \text{mm}^3$ *Ans.*

1-24

(**a**) $\sigma = M/Z = 1770/0.934 = 1895$ psi $= 1.90$ kpsi *Ans.*

(**b**) $\sigma = F/A = 9440/23.8 = 397$ psi *Ans.*

(**c**) $y = Fl^3/3EI = 270(31.5)^3/[3(30)10^6(0.154)] = 0.609$ in *Ans.*

(**d**) $\theta = Tl/GJ = 9740(9.85)/[11.3(10^6)(\pi/32)1.00^4] = 8.648(10^{-2})$ rad $= 4.95°$ *Ans.*

1-25

(**a**) $\sigma = F/wt = 1000/[25(5)] = 8$ MPa *Ans.*

(**b**) $I = bh^3/12 = 10(25)^3/12 = 13.0(10^3)\ \text{mm}^4$ *Ans.*

(**c**) $I = \pi d^4/64 = \pi(25.4)^4/64 = 20.4(10^3)\ \text{mm}^4$ *Ans.*

(**d**) $\tau = 16T/\pi d^3 = 16(25)10^3/[\pi(12.7)^3] = 62.2$ MPa *Ans.*

1-26

(**a**) $\tau = F/A = 2\,700/[\pi(0.750)^2/4] = 6110$ psi $= 6.11$ kpsi *Ans.*

(**b**) $\sigma = 32Fa/\pi d^3 = 32(180)31.5/[\pi(1.25)^3] = 29\,570$ psi $= 29.6$ kpsi *Ans.*

(**c**) $Z = \pi(d_o^4 - d_i^4)/(32\,d_o) = \pi(1.50^4 - 1.00^4)/[32(1.50)] = 0.266\ \text{in}^3$ *Ans.*

(**d**) $k = (d^4G)/(8D^3N) = 0.0625^4(11.3)10^6/[8(0.760)^3\,32] = 1.53$ lbf/in *Ans.*
