Final_ EJMA.ppt

EJMA vs. NASTRAN Calculations
Used to check the Finite Element simulation

| | EJMA -Stress | | NASTRAN -Stress | | Shear rate | Torque |
|---|---|---|---|---|---|---|
| | psi | | psi | | lbs/in | in-lbs |
| Thickness | Pressure | Axial | Pressure | Axial | | |
| .020 in | 15,200.0 | 25,600.0 | 15,600 | 23.300.0 | 71,120.0 | 98,211.0 |
| | | | | | 2800#/mm | |
| .025 in | 9,736.0 | 31,990.6 | 9,640.0 | 28,800.0 | 128,200.0 | 122,800.0 |
| | | | | | 5040#/mm | |
| .030 in | 6,762.0 | 38,386.0 | 6,970.0 | 34,400.0 | 204,200.0 | 147,400.0 |
| | | | 8,190.0 | | 8,040#/mm | |
| | Note: | w= 1.095 for all calculations | | | | |
| | | q=1.0 inches | | Torsional delta = .00315in = .8e-4m | | |
| | | 1.0 mm= .0394 in | | | | |

Results From Pressure and Axial Loads only

| | EJMA Equations | | | | | |
|---|---|---|---|---|---|---|
| Thickness | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_t$ | Spring Rate |
| inch | psi | psi | psi | psi | psi | lbs/in |
| 0.02 | 269.0 | 15,211.0 | 137.0 | 25,594.2 | 36,567.0 | 1,136.5 |
| 0.025 | 322.2 | 9,737.0 | 213.4 | 31,991.0 | 39,245.0 | 2,219.6 |
| 0.03 | 269 | 6,762.4 | 307.2 | 38,386.3 | 43,615.2 | 3,835.2 |

All equations are listed in the EJMA spread sheets

"St" Is Total stress used for Fatigue Life ( Nc )

Equations are from Section 4.13 of the EJMA manual

Slides #3 and #4 present calculation for , t = .02, w = 1.095, q = 1.0 inches
Slides #5 and #6 present calculation for , t = .025, w = 1.095, q = 1.0 inches
Slides #7 and #8 present calculation for , t = .03, w = 1.095, q = 1.0 inches

Slides #9 to #11 present data for various coefficients which are used in the above calculations.

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 2 | | | EJMA Calculations for t=.02 , w=1.095, q= 1.0 inches | | | | | | |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | |
| 5 | | Db | | 38 | in | Inside diameter | | | |
| 6 | | | | | | | | | |
| 7 | | Dm= Db+w+nt | | 39.115 | in | Mean diameter | | | |
| 8 | | | | | | | | | |
| 9 | | tp=t(Db/Dm)^-2 | | 0.01971 | in | | | | |
| 10 | | tp^2 | | 0.00039 | | | | | |
| 11 | | Cp | | 0.68 | | from curves, Figure 4.16 EJMA | | | |
| 12 | | | | | | | | | |
| 13 | | n | | 1 | | material plies of thickness "t" | | | |
| 14 | | t | | 0.02 | in | | | | |
| 15 | | w | | 1.095 | in | | | | |
| 16 | | w^3 | | 1.31293 | | | | | |
| 17 | | | | | | | | | |
| 18 | | q | | 1 | in | | | | |
| 19 | | P | | 14.5 | psi | | | | |
| 20 | | | | | | | | | |
| 21 | | S3=Pw/2ntp | | | | Meridional Membrane due to pressure | | | |
| 22 | | | | | | | Eq. 4-30 | | |
| 23 | | | S3 | 268.56 | psi | | | | |
| 24 | | | | | | | | | |
| 25 | | P/2 | | 7.25 | | | | | |
| 26 | | | | | | | | | |
| 27 | | (w/tp)^2 | | 3085.52 | | | | | |
| 28 | | | | | | | | | |
| 29 | | S4=P/2n(w/tp)^2Cp | | | | Meridional Bending due to pressure | | | |
| 30 | | | | | | | Eq.4-31 | | |
| 31 | | | S4 | 15211.6 | psi | | | | |
| 32 | | | | | | | | | |
| 33 | | Eb | | 2.9E+07 | psi | Elastic modulus | | | |
| 34 | | | | | | | | | |
| 35 | | e=X/N | | 0.0525 | in | Per convolution | | | |
| 36 | | X | | 0.315 | in | | | | |
| 37 | | N | | 6 | | Number of convolutions | | | |
| 38 | | Cf | | 1.65 | | from curve, Figure 4.17 EJMA | | | |
| 39 | | | | | | | | | |
| 40 | | S5=Eb(tp)^2(e))/2(w)^3*Cf | | | | Meridional membrane due to deflection | | | |
| 41 | | | | | | | Eq. 4-32 | | |
| 42 | | | S5 | 136.55 | psi | | | | |
| 43 | | | | | | | | | |

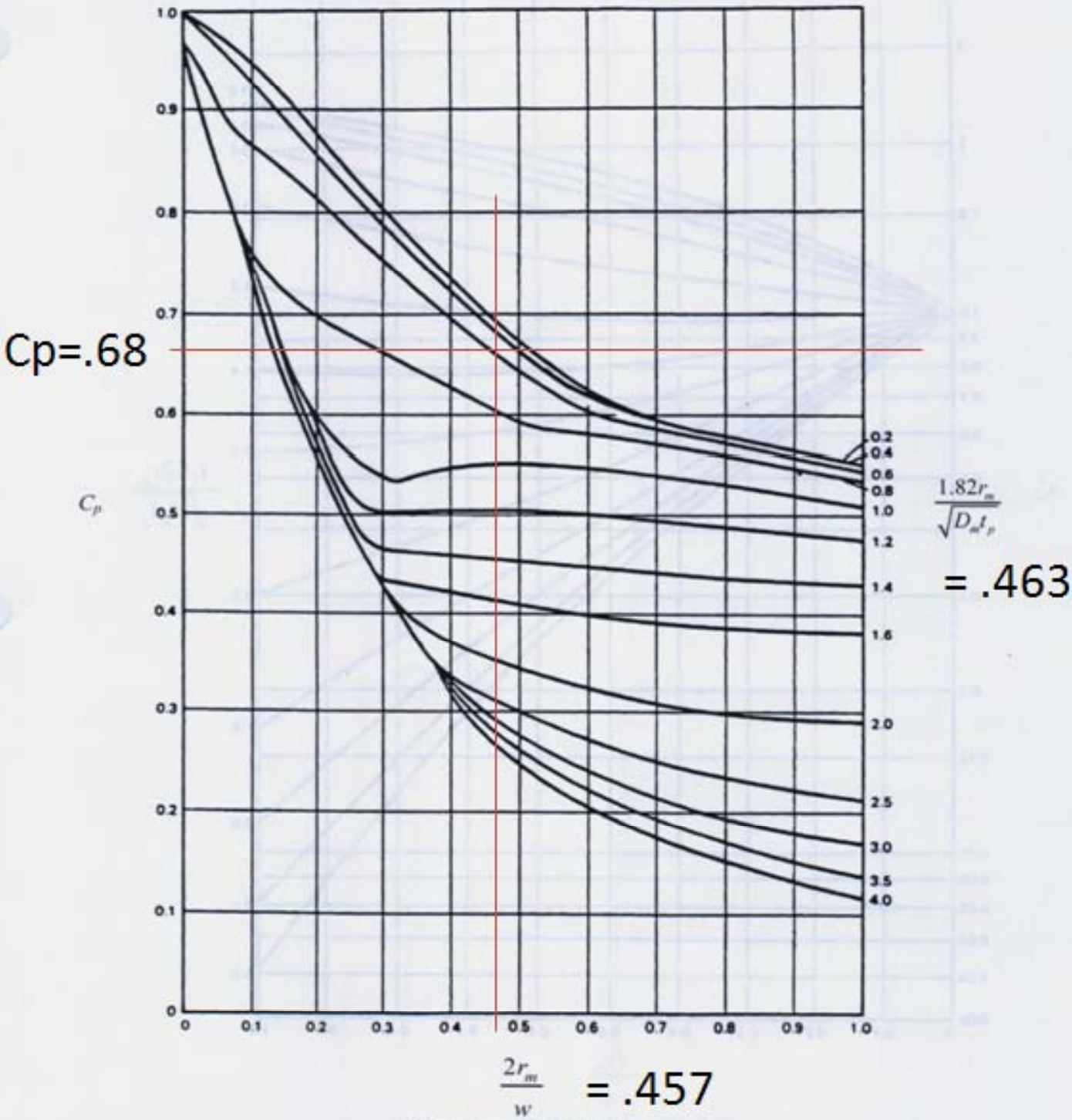
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 44 | | | | | | | | |
| 45 | | | | | | | | |
| 46 | | S6=5(Eb)(tp)e/3(w^2)Cd | | | | Meridional Bending due to deflection | | |
| 47 | | | | | | | Eq.4-33 | |
| 48 | | | S6 | 25594.13 | psi | | | |
| 49 | | | | | | | | |
| 50 | | Cd | | 1.63 | | from curve, Figure 4-18 | | |
| 51 | | | | | | | | |
| 52 | | | | Spring Rate | | | | |
| 53 | | | | | | | | |
| 54 | | fiu=1.7 ((DmEb(tp^3)n)/(w^3)Cf)) | | | | Bellows Theoretical Axial Spring Rate | | |
| 55 | | | | | | | Eq.4-37 | |
| 56 | | tp^3 | 7.7E-06 | | | | | |
| 57 | | DmEb | 1.1E+09 | | | | | |
| 58 | | DmEb*(tp | 8689.44 | | | | | |
| 59 | | w^3Cf | 2.16634 | | | | | |
| 60 | | | | | | | | |
| 61 | | | fiu | 6818.9 | lbs/in | | Note: Per convolution | |
| 62 | | | | | | | | |
| 63 | | | Ktotal | 1136.48 | lbs/in | | For N=6 (total convolutions) | |
| 64 | | | | | | | | in series |
| 65 | | 6818.9 | 3409.45 | 1704.73 | 1136.48 | | | |
| 66 | | 6818.9 | | | | | | |
| 67 | | 6818.9 | 3409.45 | | | | | |
| 68 | | 6818.9 | | | | | | |
| 69 | | 6818.9 | 3409.45 | | | | | |
| 70 | | 6818.9 | | | | | | |
| 71 | | | | | | | | |
| 72 | | | | | | | | |
| 73 | | | Required Parameters for all Curve Constants | | | | | |
| 74 | | | | | | | | |
| 75 | | | 1.82rm/(Dmtp)^-2 | | 0.518 | | | |
| 76 | | | rm | | 0.25 | in | | |
| 77 | | | | | | | | |
| 78 | | | 2rm/w | | 0.457 | | | |
| 79 | | | | | | | | |
| 80 | | | Fatigue Life Calculations | | | | | |
| 81 | | | | | | | | |
| 82 | | | St = 0.7 (S3 +S4) + (S5 +S6) | | | | See Figure 4-20 | |
| 83 | | | | | | | | |
| 84 | | | | St= | 36566.8 | psi | | |
| 85 | | | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 2 | EJMA Calculations for t=.025 , w=1.095, q= 1.0 inches | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | Db | | 38 | in | Inside diameter |
| 6 | | | | | |
| 7 | Dm= Db+w+nt | | 39.12 | in | Mean diameter |
| 8 | | | | | |
| 9 | tp=t(Db/Dm)^-2 | | 0.02464 | in | |
| 10 | tp^2 | | 0.00061 | | |
| 11 | Cp | | 0.68 | | from curves, Figure 4.16 EJMA |
| 12 | | | | | |
| 13 | n | | 1 | | material plies of thickness "t" |
| 14 | t | | 0.025 | in | |
| 15 | w | | 1.095 | in | |
| 16 | w^3 | | 1.31293 | | |
| 17 | | | | | |
| 18 | q | | 1 | in | |
| 19 | P | | 14.5 | psi | |
| 20 | | | | | |
| 21 | S3=Pw/2ntp | | | | Meridional Membrane due to pressure |
| 22 | | | | | Eq. 4-30 |
| 23 | | S3 | 322.20 | psi | |
| 24 | | | | | |
| 25 | P/2 | | 7.25 | | |
| 26 | | | | | |
| 27 | (w/tp)^2 | | 1974.98 | | |
| 28 | | | | | |
| 29 | S4=P/2n(w/tp)^2Cp | | | | Meridional Bending due to pressure |
| 30 | | | | | Eq.4-31 |
| 31 | | S4 | 9736.67 | psi | |
| 32 | | | | | |
| 33 | Eb | | 2.9E+07 | psi | Elastic modulus |
| 34 | | | | | |
| 35 | e=X/N | | 0.0525 | in | Per convolution |
| 36 | X | | 0.315 | in | |
| 37 | N | | 6 | | Number of convolutions |
| 38 | Cf | | 1.65 | | from curve, Figure 4.17 EJMA |
| 39 | | | | | |
| 40 | S5=Eb(tp)^2(e))/2(w)^3*Cf | | | | Meridional membrane due to deflection |
| 41 | | | | | Eq. 4-32 |
| 42 | | S5 | 213.34 | psi | |
| 43 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 43 | | | | | | |
| 44 | | | | | | |
| 45 | | | | | | |
| 46 | $S_6$=5(Eb)(tp)e/3(w^2)$C_d$ | | | | Meridional Bending due to deflection | |
| 47 | | | | | | Eq.4-33 |
| 48 | | $S_6$ | 31990.62 | psi | | |
| 49 | | | | | | |
| 50 | $C_d$ | | 1.63 | | from curve, Figure 4-18 | |
| 51 | | | | | | |
| 52 | | | Spring Rate | | | |
| 53 | | | | | | |
| 54 | $f_{iu}$=1.7 ((DmEb(tp^3)n)/(w^3)$C_f$)) | | | | Bellows Theoretical Axial Spring Rate | |
| 55 | | | | | | Eq.4-37 |
| 56 | tp^3 | 1.5E-05 | | | | |
| 57 | DmEb | 1.1E+09 | | | | |
| 58 | DmEb*(tp^ | 16970.5 | | | | |
| 59 | w^3Cf | 2.16634 | | | | |
| 60 | | | | | | |
| 61 | | $f_{iu}$ | 13317.3 | lbs/in | | Note: Per convolution |
| 62 | | | | | | |
| 63 | | $K_{total}$ | 2219.55 | lbs/in | | For N=6 (total convolutions) |
| 64 | | | | | | in series |
| 65 | 13317.3 | 6658.66 | 3329.33 | 2219.55 | | |
| 66 | 13317.3 | | | | | |
| 67 | 13317.3 | 6658.66 | | | | |
| 68 | 13317.3 | | | | | |
| 69 | 13317.3 | 6658.66 | | | | |
| 70 | 13317.3 | | | | | |
| 71 | | | | | | |
| 72 | | | | | | |
| 73 | | Required Parameters for all Curve Constants | | | | |
| 74 | | | | | | |
| 75 | | 1.82rm/(Dmtp)^-2 | | 0.463 | | |
| 76 | | rm | 0.25 | in | | |
| 77 | | | | | | |
| 78 | | 2rm/w | | 0.457 | | |
| 79 | | | | | | |
| 80 | | Fatigue Life Calculations | | | | |
| 81 | | | | | | |
| 82 | | $S_f = 0.7\ (S_3 + S_4) + (S_5 + S_6)$ | | | | See Figure 4-20 |
| 83 | | | | | | |
| 84 | | | $S_f$= | 39245.2 | psi | |
| 85 | | | | | | |

| | | | | |
|---|---|---|---|---|
| 2 | EJMA Calculations for t=.03 , w=1.095, q= 1.0 inches | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | Db | 38 | in | Inside diameter |
| 6 | | | | |
| 7 | Dm= Db+w+nt | 39.125 | in | Mean diameter |
| 8 | | | | |
| 9 | tp=t(Db/Dm)^-2 | 0.02957 | in | |
| 10 | tp^2 | 0.00087 | | |
| 11 | Cp | 0.68 | | from curves, Figure 4.16 EJMA |
| 12 | | | | |
| 13 | n | 1 | | material plies of thickness "t" |
| 14 | t | 0.03 | in | |
| 15 | w | 1.095 | in | |
| 16 | w^3 | 1.31293 | | |
| 17 | | | | |
| 18 | q | 1 | in | |
| 19 | P | 14.5 | psi | |
| 20 | | | | |
| 21 | S3=Pw/2ntp | | | Meridional Membrane due to pressure |
| 22 | | | | Eq. 4-30 |
| 23 | S3 | 268.56 | psi | |
| 24 | | | | |
| 25 | P/2 | 7.25 | | |
| 26 | | | | |
| 27 | (w/tp)^2 | 1371.69 | | |
| 28 | | | | |
| 29 | S4=P/2n(w/tp)^2Cp | | | Meridional Bending due to pressure |
| 30 | | | | Eq.4-31 |
| 31 | S4 | 6762.44 | psi | |
| 32 | | | | |
| 33 | Eb | 2.9E+07 | psi | Elastic modulus |
| 34 | | | | |
| 35 | e=X/N | 0.0525 | in | Per convolution |
| 36 | X | 0.315 | in | |
| 37 | N | 6 | | Number of convolutions |
| 38 | Cf | 1.65 | | from curve, Figure 4.17 EJMA |
| 39 | | | | |
| 40 | S5=Eb(tp)^2(e))/2(w)^3*Cf | | | Meridional membrane due to deflection |
| 41 | | | | Eq. 4-32 |
| 42 | S5 | 307.17 | psi | |
| 43 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 43 | | | | | | | | |
| 44 | | | | | | | | |
| 45 | | | | | | | | |
| 46 | | $S_6$=5(Eb)(tp)e/3(w^2)$C_d$ | | | Meridional Bending due to deflection | | | |
| 47 | | | | | | Eq.4-33 | | |
| 48 | | | $S_6$ | 38386.29 | psi | | | |
| 49 | | | | | | | | |
| 50 | | $C_d$ | | 1.63 | from curve, Figure 4-18 | | | |
| 51 | | | | | | | | |
| 52 | | | | Spring Rate | | | | |
| 53 | | | | | | | | |
| 54 | | $f_{iu}$=1.7 ((DmEb(tp^3)n)/(w^3)$C_f$)) | | | Bellows Theoretical Axial Spring Rate | | | |
| 55 | | | | | | Eq.4-37 | | |
| 56 | | tp^3 | 2.6E-05 | | | | | |
| 57 | | DmEb | 1.1E+09 | | | | | |
| 58 | | DmEb*(tp' | 29323.1 | | | | | |
| 59 | | w^3Cf | 2.16634 | | | | | |
| 60 | | | | | | | | |
| 61 | | | $f_{iu}$ | 23010.8 | lbs/in | | Note: Per convolution | |
| 62 | | | | | | | | |
| 63 | | | $K_{total}$ | 3835.14 | lbs/in | | For N=6 (total convolutions) | |
| 64 | | | | | | | | in series |
| 65 | | 23010.8 | 11505.4 | 5752.71 | 3835.14 | | | |
| 66 | | 23010.8 | | | | | | |
| 67 | | 23010.8 | 11505.4 | | | | | |
| 68 | | 23010.8 | | | | | | |
| 69 | | 23010.8 | 11505.4 | | | | | |
| 70 | | 23010.8 | | | | | | |
| 71 | | | | | | | | |
| 72 | | | | | | | | |
| 73 | | | Required Parameters for all Curve Constants | | | | | |
| 74 | | | | | | | | |
| 75 | | | 1.82rm/(Dmtp)^-2 | | 0.423 | | | |
| 76 | | | rm | 0.25 | in | | | |
| 77 | | | | | | | | |
| 78 | | | 2rm/w | | 0.457 | | | |
| 79 | | | | | | | | |
| 80 | | | Fatigue Life Calculations | | | | | |
| 81 | | | | | | | | |
| 82 | | | $S_f = 0.7\ (S_3 + S_4) + (S_5 + S_6)$ | | | See Figure 4-20 | | |
| 83 | | | | | | | | |
| 84 | | | | $S_f$= | 43615.2 | psi | | |
| 85 | | | | | | | | |




$C_p$ for Convoluted Bellows
FIGURE 4.16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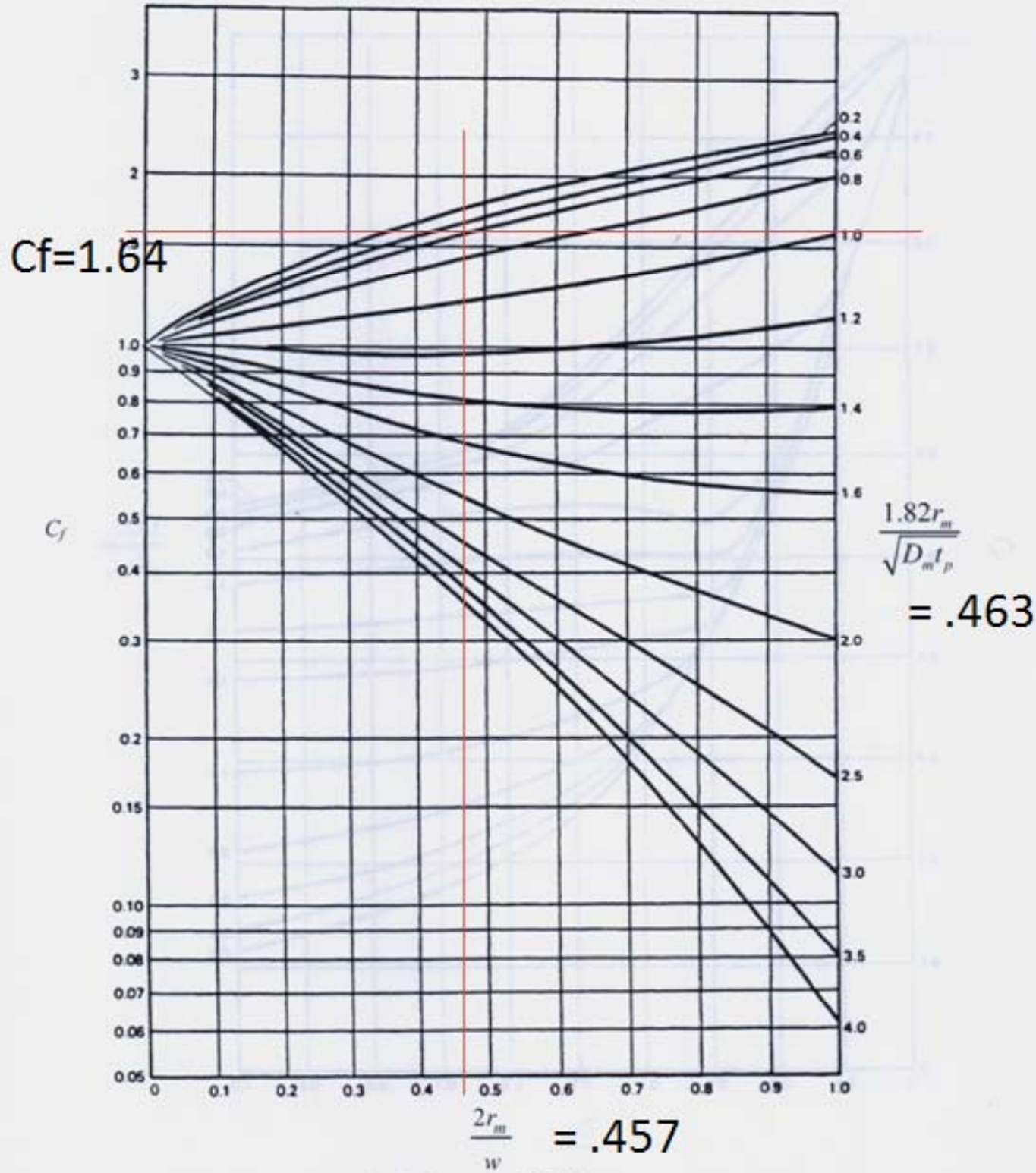


$C_f$ for Convoluted Bellows
FIGURE 4.17


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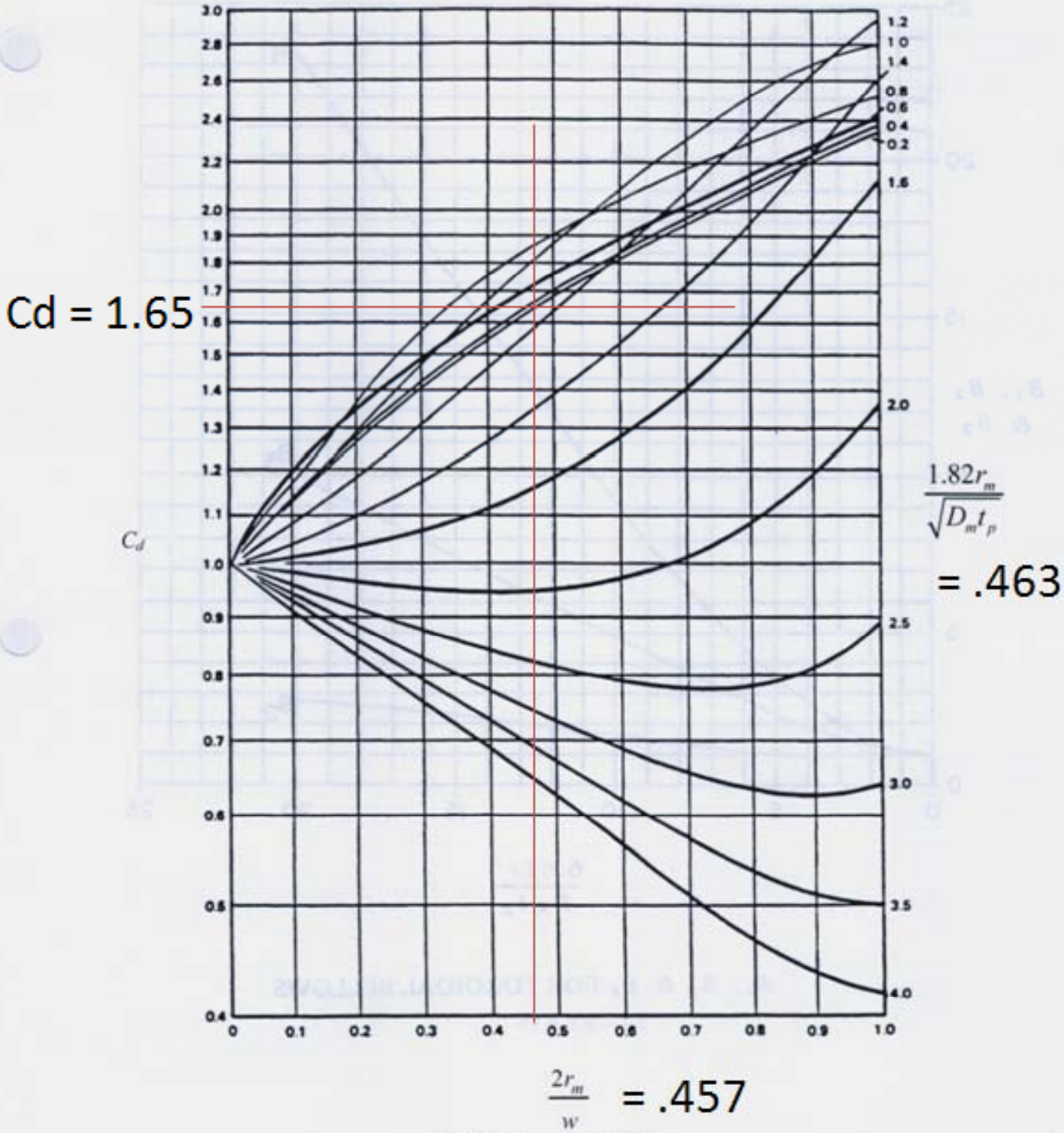


$C_d$ for Convoluted Bellows

FIGURE 4.18


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# EJMA Fatigue Life estimate for combined Axial and Pressure loads only



These curves are intended to predict average fatigue life at temperatures below 800°F for austenitic stainless steel bellows which have not been heat treated and have not more than 5 plies. They are considered valid primarily in the range of $10^3$ to $10^5$ cycles, due to the limited data available for the very low and very high cyclic ranges.

The equations are of the form provided in Design of Pressure Vessels for Low Fatigue by B.F. Langer, ASME paper 61-WA-18. The constants were modified to reflect the experience of EJMA members for bellows fatigue life.

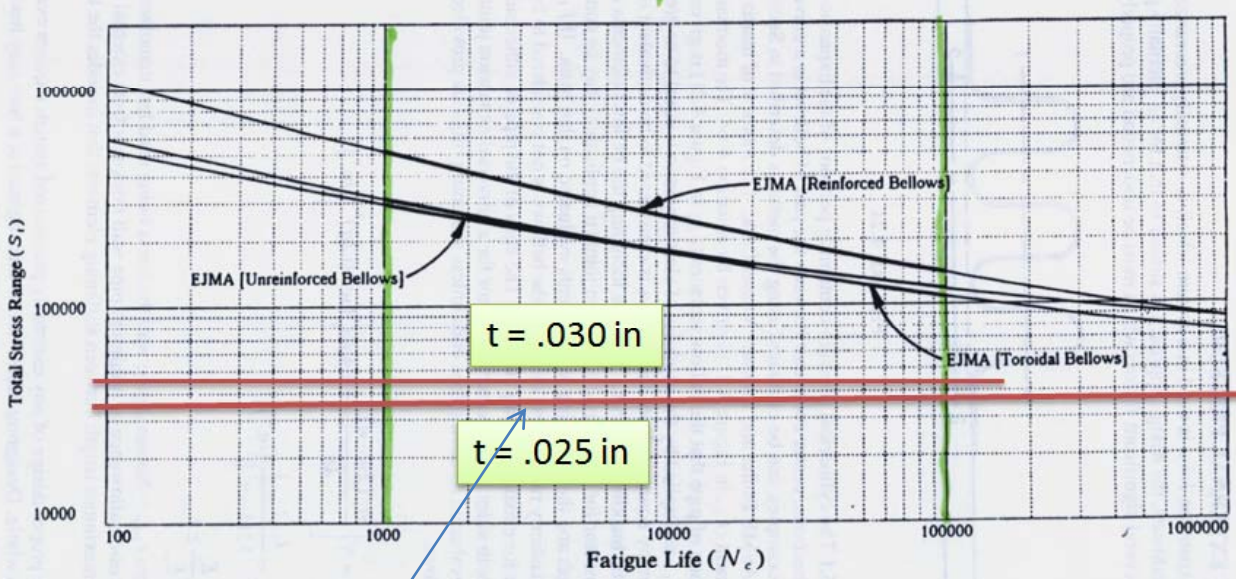


FIGURE 4.20

**UNREINFORCED**

$$N_c = \left(\frac{1.86 \times 10^6}{S_t - 54000}\right)^{3.4}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

**REINFORCED**

$$N_c = \left(\frac{5.18 \times 10^6}{S_t - 41800}\right)^{2.9}$$

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6)$$

**TOROIDAL**

$$N_c = \left(\frac{2.30 \times 10^6}{S_t - 41800}\right)^{3.25}$$

$$S_t = 3S_3 + S_5 + S_6$$


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See slide #2 for "St" values