July 8, 2022

INSTRUCTIONS

Begin each problem in the space provided.

If your solution does not follow a logical thought process, it will be assumed to be in error.

Your submitted exam must be your work and must not be copied from other sources.

GUIDELINES FOR ZOOM PROCTORING

— Mute yourself but your audio should remain on for the duration of the exam in order to hear any instructions or announcements of clarifications.

— Your webcam and audio should remain on for the duration of the exam. Webcams should be located off to one side so that your hands and desk materials are visible in the frame. Your face does not need to be visible in the frame.

— Open a chat window at the start of the exam and keep it visible throughout the exam. The chat window will allow you to correspond with the proctor, but you will not be allowed to correspond with your peers.

— The proctor may ask you to show the room in which you are working as well as other materials in order to ensure academic integrity of the assessment.

— The exam will be e-mailed to you at the beginning of the exam.

— You may print the exam and work on those pages, view the exam on your computer and work problems on blank pages, or work the exam on a tablet.

— Questions for the proctor should be asked during the exam using the chat window.

— Clarifications made by the proctor during the exam will be made vocally and in the chat window.

— When you have completed the exam, you should scan/save your work as a single PDF file and upload the exam to Gradescope.

— If you lose your connection during the exam, be patient, continue working, and wait for the connection to return. If the connection does not recover within a couple of minutes, then you may be asked to take a make-up oral exam (via Zoom) in place of the written exam.

— The exam will be recorded, with only the course instructor having preliminary access to the recording. The video recording will only be reviewed for the purpose of identifying potential cheating incidents and will be deleted after one week from when the exam was completed if no cheating allegations have been made. If a cheating allegation has been made, then the recording will be retained until the cheating incident has been resolved. Any student accused of cheating will be allowed to review the video recording as part of their due process. All incidents of academic misconduct will be referred to the Office of the Dean of Students who will be provided access to recordings, as well as other supporting documentation to utilize in their process of determining potential violations of University policies on academic dishonesty.

PROBLEM No. 1 (25 points)

Problem 1 consists of 10 questions. Each question is worth 2.5 points.

(a) When designing a part, you find the "loss-of-function parameter" to be 59 N and the "maximum allowed, or predicted, parameter value" is 43 N.

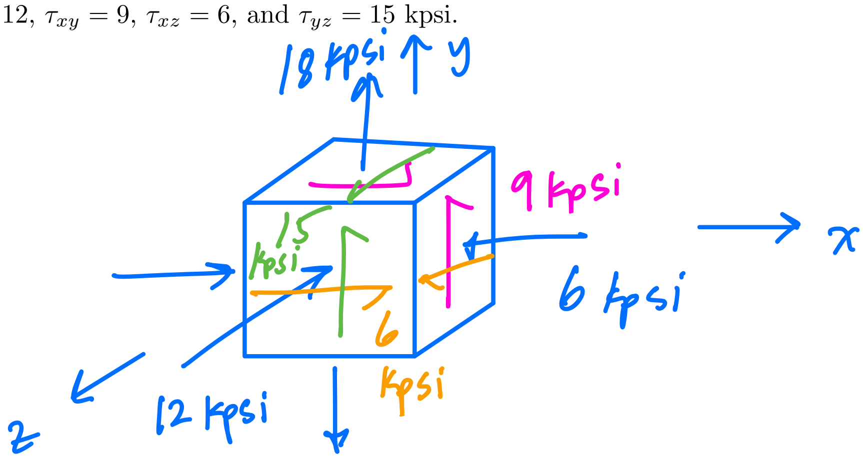
Select the most appropriate factor of safety to report if you are wanting to be conservative with your analysis.

- ◯ 0.7
- ◯ 0.73
- ◯ 0.729
- ◯ 0.72881356
- ◯ 0.8
- ● 1.3
- ◯ 1.37
- ◯ 1.372
- ◯ 1.37209302
- ◯ 1.4

$n = \frac{59}{43} = 1.372$

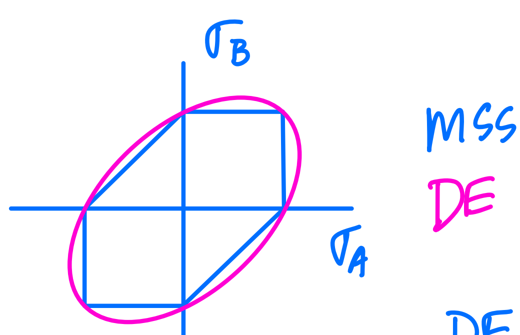
round down to be conservative

(b) Draw and label a stress element representing the three dimensional state of stress $\sigma_x = -6$, $\sigma_y = 18$, $\sigma_z = -12$, $\tau_{xy} = 9$, $\tau_{xz} = 6$, and $\tau_{yz} = 15$ kpsi.



(c) When analyzing a steel part subjected to static loading, you find the factor of safety to be 2.1 using the MSS theory. The factor of safety using the DE theory is most likely which of the following?

- ◯ 1.0
- ◯ 1.5
- ◯ 2.1
- ● 2.3
- ◯ 4



DE will predict a slightly larger factor of safety given the larger envelope.

(d) A plane stress state is characterized by principal stresses $\sigma_1 = 25$ MPa, $\sigma_2 = 0$ and $\sigma_3 = -50$ MPa. For this stress state, the MM and BCM theories will give identical results.

○ True
● False

MM and BCM are identical in the 1st and 3rd quadrants; this stress state is in the 4th quadrant.

(e) Fatigue failures occur due to changes in a part's material properties.

○ True
● False

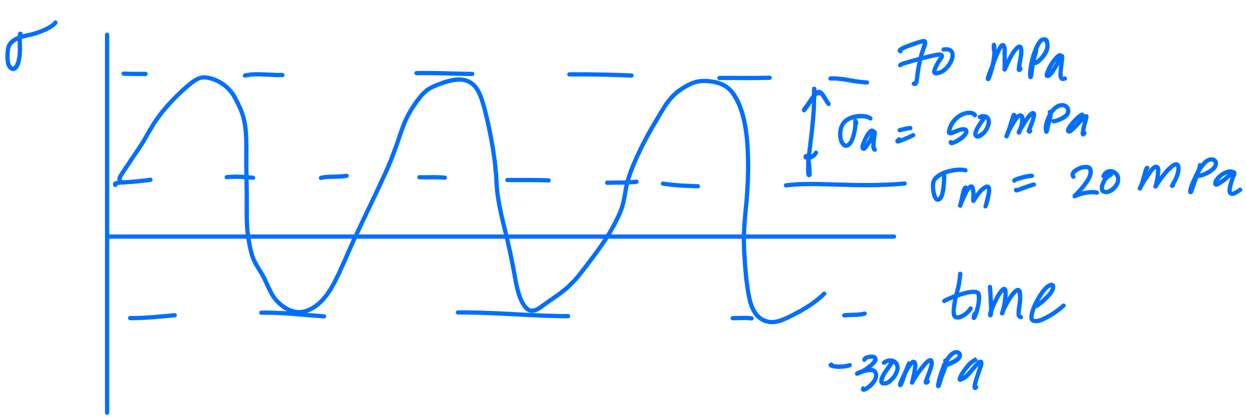
(f) How do $S-N$ diagrams differ for ferrous and nonferrous materials?

ferrous materials have endurance limits. nonferrous do not.

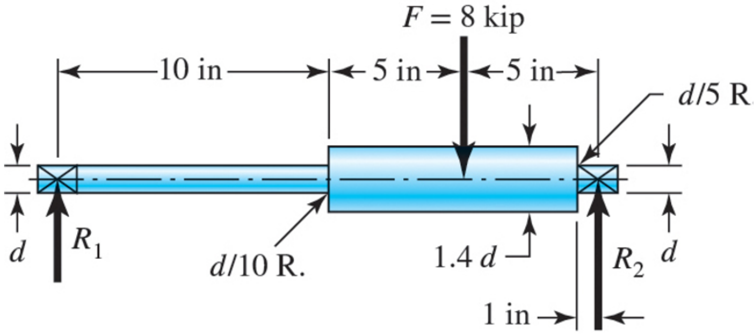
(g) Describe the difference between S_e and S'_e.

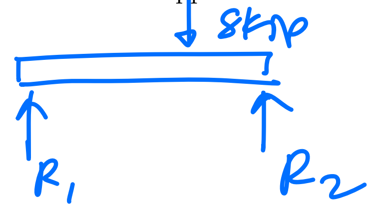
Se′ is the endurance limit of a test specimen. Se is corrected for a real part in a real environment.

(h) A part is subjected to a sinusoidal bending load with $\sigma_a = 50$ MPa and $\sigma_m = 20$ MPa. Make a sketch of σ as a function of time.



(i) For the rotating shaft shown, determine σ_a and σ_m at the location where force F is applied. Include units in your answers. Use $d = 1$ inch.





$\Sigma M_{LHS} = -8 \cdot 15 + 20 \cdot R_2$

$R_2 = 6$ kip

$R_1 = 2$ kip

$\sigma_m = 0$ for a rotating shaft

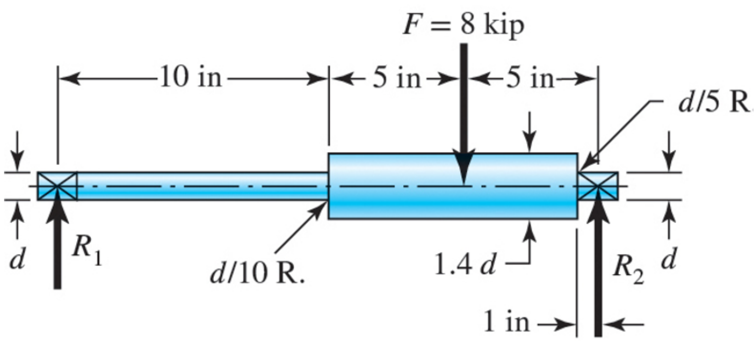
$\sigma_a = \frac{Mc}{I} = 111.3$ MPa

$M = 2$ kip $\cdot$ 15 in $= 30$ kip-in $\quad c = 0.7$ in $\quad I = \frac{\pi}{64}(1.4^4)$

(j) The rotating shaft shown is driven by a torque that varies between 0 and T_{max}.

For $d = 1$ inch, determine the fatigue stress concentration factors (K_f and K_{fs}) at the location where the 8 kip load is applied.

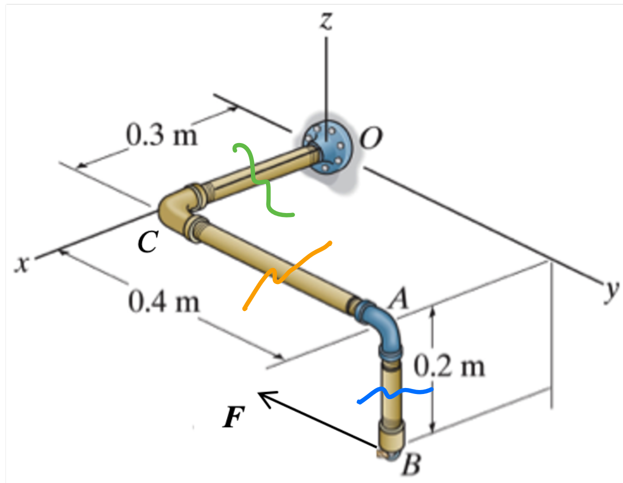
The material is 1018 CD steel.



K_f and K_{fs} are both 1 because there is not a stress raiser where the 8 kip load is applied.

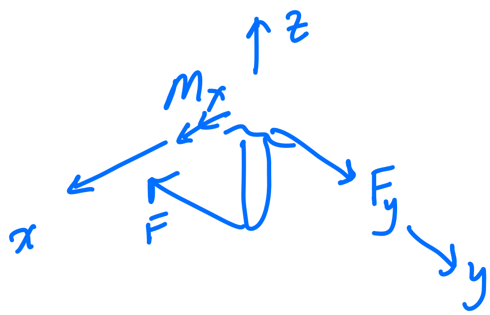
PROBLEM No. 2 (10 points)

Bar $OCAB$ is acted on by force F at B. Force F acts in the -y-direction



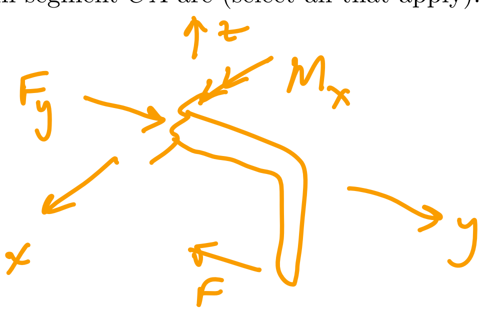
The internal loads acting in segment AB are (select all that apply):

- ◯ Axial
- ◯ Torsion
- ● Bending
- ● Transverse shear



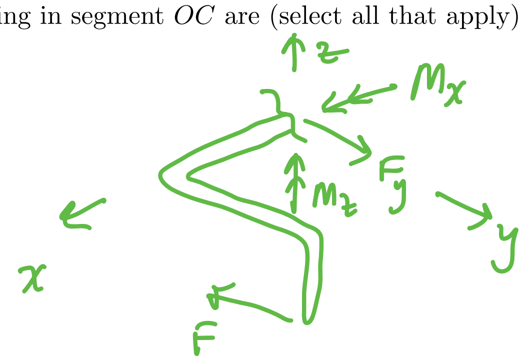
The internal loads acting in segment CA are (select all that apply):

- ● Axial
- ◯ Torsion
- ● Bending
- ◯ Transverse shear



The internal loads acting in segment OC are (select all that apply):

- ◯ Axial
- ● Torsion
- ● Bending
- ● Transverse shear



PROBLEM No. 3 (30 points)

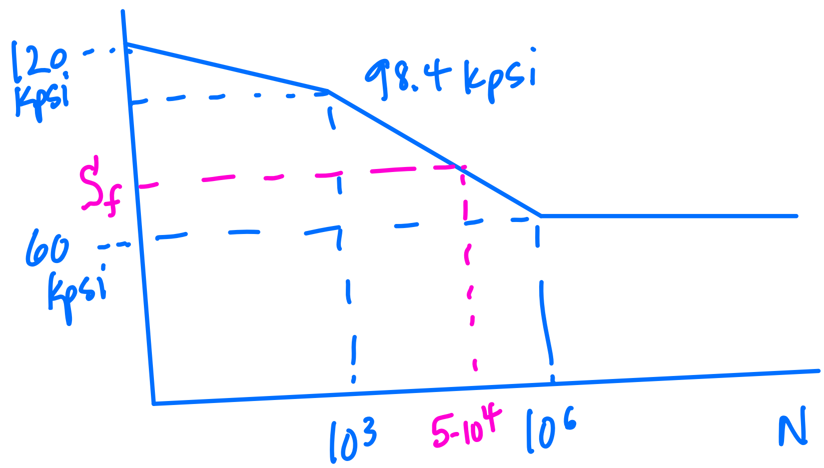
A rotating-beam test specimen is made of AISI 1030 steel that has been quenched and tempered to 400°F. The specimen's ultimate tensile strength is $S_{ut} = 120$ kpsi.

Determine the following.

a) Draw and label the $S - N$ curve for the test specimen.

b) The stress that can be applied to the material in order to achieve a life of 50,000 cycles.

a)



$f = 0.82$ for $S_{ut} = 120$ kpsi from Fig 6-23

$f S_{ut} = 98.4$ kpsi

$S_e' = 0.5\, S_{ut} = 60$ kpsi

b) $S_f = a N^b$

$$a = \frac{(f S_{ut})^2}{S_e} = \frac{(98.4)^2}{60} = 161.376 \text{ kpsi}$$

$$b = -\frac{1}{3}\log\left(\frac{f S_{ut}}{S_e}\right) = -0.0716$$

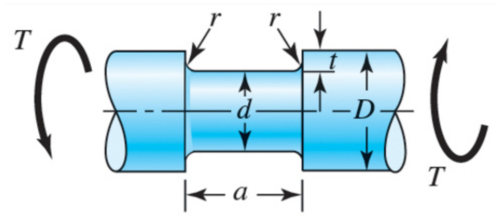
$$S_f = 161.376\,(50000)^{-0.0716} = 74.4 \text{ kpsi}$$

PROBLEM No. 4 (30 points)

A segment of a rotating shaft is shown below. The round shaft with flat-bottom groove is loaded with torque ranging from $T_{min} =$ 1200 to $T_{max} =$. 3000 lbf-in

The dimensions of the segment include $a = 1$ in, $r = 0.1$ in, $t = 0.5$ in, $D = 2.5$ in, and $d = 1.5$ in.

The shaft is made of AISI 1018 HR steel. The groove has been machined.



Determine the following.

a) The fully corrected endurance limit, S_e.

b) The fatigue stress concentration factor.

c) The factor of safety for infinite life using the Goodman criterion, n_f. If infinite life is not predicted, calculate the number of cycles to failure.

d) Check for first-cycle yielding.

a) $S_e = k_a k_b k_c k_d k_e S_e'$

$S_{ut} = 58$ kpsi $S_y = 32$ kpsi for 1018 HR

$k_a = 2.00(58)^{-0.217} = 0.856$ for machined groove

(or $k_a = 11(58)^{-0.650} = 0.786$ for HR steel)

$k_b = 0.879(1.5)^{-0.107} = 0.842$ for groove

(or $k_b = 0.91(2.5)^{-0.157} = 0.788$ to be more conservative)

$k_c = 0.59$ for torsion

$k_d = 1$ for room temp

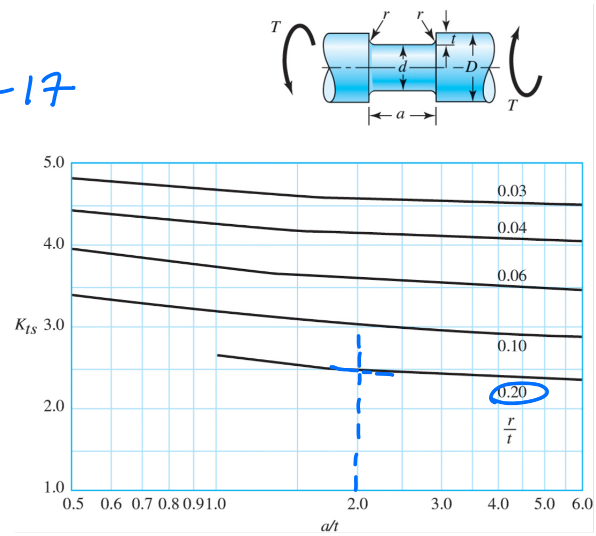
$k_e = 1$ for 50% reliability

$S_e' = 0.5\, S_{ut} = 29$ kpsi

$S_e = (0.856)(0.842)(0.59)(1)(1) \cdot 29$ kpsi $= 12.3$ kpsi

b) $K_{fs} = 1 - q_s(K_{ts} - 1)$

K_{ts} from figure A-15-17



$a/t = 1/0.5 = 2$

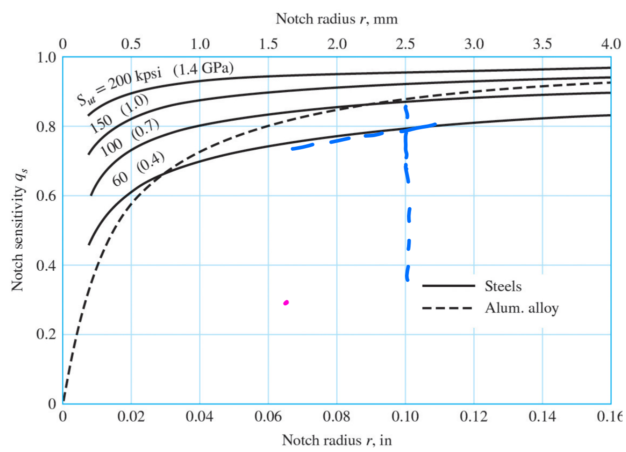
$r/t = 0.1/0.5 = 0.2$

$K_{ts} = 2.5$

q_s from figure 6-27

for $S_{ut} = 58$ kpsi and $r = 0.1$ in

$q_s = 0.8$



$K_{fs} = 1 + 0.8(2.5 - 1) = 2.2$

c) $\dfrac{1}{n_f} = \dfrac{\sigma_a}{S_e} + \dfrac{\sigma_m}{S_{ut}}$ → τ_a, τ_m, $0.67 S_{ut}$

for pure shear

from caption for figure A-15-17

$\tau_0 = \dfrac{16T}{\pi d^3}$ with $d = 1.5$ in

$$T_a = \frac{|T_{max} - T_{min}|}{2} = \frac{|3000 - 1200|}{2} = 900 \text{ lbf-in}$$

$$T_m = \frac{T_{max} + T_{min}}{2} = \frac{3000 + 1200}{2} = 2100 \text{ lbf-in}$$

$$\tau_a = K_{fs} \cdot \frac{16 T_a}{\pi d^3} = 2.2 \cdot \frac{16 \cdot 900 \text{ lbfin}}{\pi (1.5 \text{ in})^3} = 2988 \text{ psi}$$

$$\tau_m = K_{fs} \cdot \frac{16 T_m}{\pi d^3} = 2.2 \cdot \frac{16 \cdot 2100 \text{ lbfin}}{\pi (1.5 \text{ in})^3} = 6972 \text{ psi}$$

$$\frac{1}{n_f} = \frac{2.988}{12.3} + \frac{6.972}{0.67 \cdot 58} \rightarrow n_f = 2.4$$

d) $$n_y \approx \frac{\cancel{S'_y} \rightarrow 0.577 S_y}{\cancel{\sigma_a} \rightarrow \tau_a + \cancel{\sigma_m} \rightarrow \tau_m} = \frac{0.577 \cdot 32 \text{ kpsi}}{2.988 + 6.972} = 1.8$$

PROBLEM No. 5 (XX points)

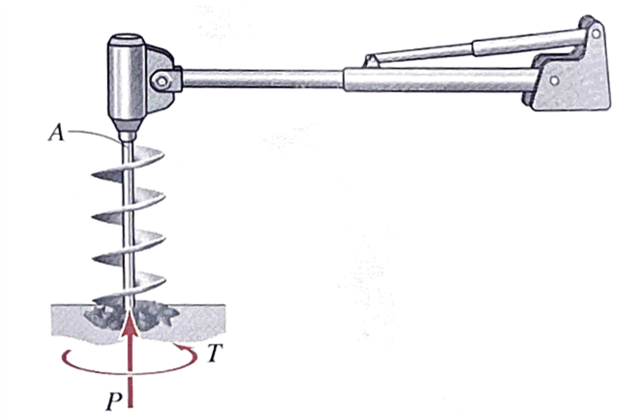
A post-hole digger is mounted on a tractor (not shown).

When the digger is engaged, the power unit of the machine applies a torque of $T_{max} = 800$ in-lbf to the auger and it also exerts a downward force of $P_{max} = 1500$ lbf on the auger. When the digger is not engaged, $T_{min} = 0$ and $P_{min} = 0$.

The auger shaft is a solid circular rod with cross-sectional area A and diameter $d = 2$ in.

The shaft is made of AISI 1040 HR steel with $S_{ut} = 76$ kpsi and $S_y = 42$ kpsi.

Neglect any stress raisers between the shaft and the cutting surfaces.



Determine the following.

a) The fully corrected endurance limit, S_e.

b) The factor of safety for infinite life using the Goodman criterion, n_f. If infinite life is not predicted, calculate the number of cycles to failure.

c) Check for first-cycle yielding.

a) $S_e = k_a k_b k_c k_d k_e S_e' = 20.4$ kpsi

$k_a = 11(76)^{-0.650} = 0.659$ for HR

$k_b = 0.879(2)^{-0.107} = 0.816$

$k_c = 1$ for combined loading

$k_d = 1$ for room temp

$k_e = 1$ for 50% reliability

$S_e' = 0.5\, S_{ut} = 0.5 \cdot 76 = 38$ kpsi

b) $\frac{1}{n_f} = \frac{\sigma_a'}{S_e} + \frac{\sigma_m'}{S_{ut}}$

axial load: $\sigma_{min} = \frac{-P_{max}}{A} = \frac{-1500 \text{ lbf}}{\frac{\pi}{4} \cdot (2\text{in})^2} = -477$ psi

$\sigma_{max} = 0$

$\sigma_a = \frac{|\sigma_{max} - \sigma_{min}|}{2} = 238$ psi

$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = -238$ psi

torsional load: $\tau_{min} = 0$

$\tau_{max} = \frac{Tc}{J} = \frac{800 \text{ in-lbf} \cdot 1\text{in}}{\frac{\pi}{32} \cdot (2\text{in})^4} = 509$ psi

$\tau_a = \frac{|\tau_{max} - \tau_{min}|}{2} = 254.6$ psi

$\tau_m = \frac{\tau_{max} + \tau_{min}}{2} = 254.6$ psi

$\sigma_a' = [\sigma_{a,axial}{}^2 + 3(\tau_{a,axial})^2]^{1/2}$

$= [(238)^2 + 3(254.6)^2]^{1/2} = 501$ kpsi

$\sigma_m' = \sigma_a'$

$$\frac{1}{n_f} = \frac{0.5}{20.4} + \frac{0.5}{76} \rightarrow n_f = 32$$

d) $n_y = \frac{S_y}{\sigma_a' + \sigma_m'} = \frac{42 \text{ kpsi}}{0.5 + 0.5} = 42 \rightarrow$ 1st cycle yielding is not predicted.