

# AE 737: Mechanics of Damage Tolerance

## Lecture 10 - Residual Strength

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## schedule

- 26 Feb - Residual Strength, Homework 4 Due
- 28 Feb - Multiple Site Damage, Mixed-Mode Fracture
- 5 Mar - Exam Review, Homework 5 Due
- 7 Mar - Exam 1

# outline

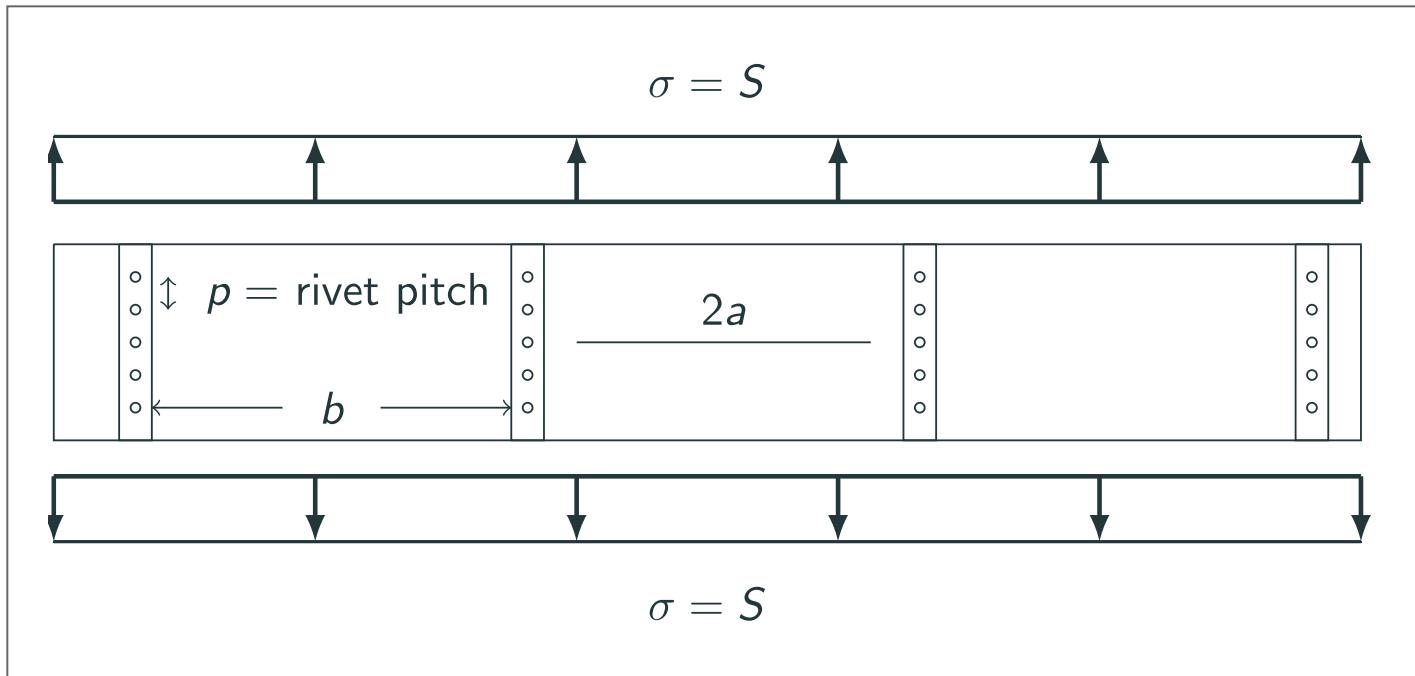
- stiffeners
- severed  
stiffeners
- crack stoppers

# stiffeners

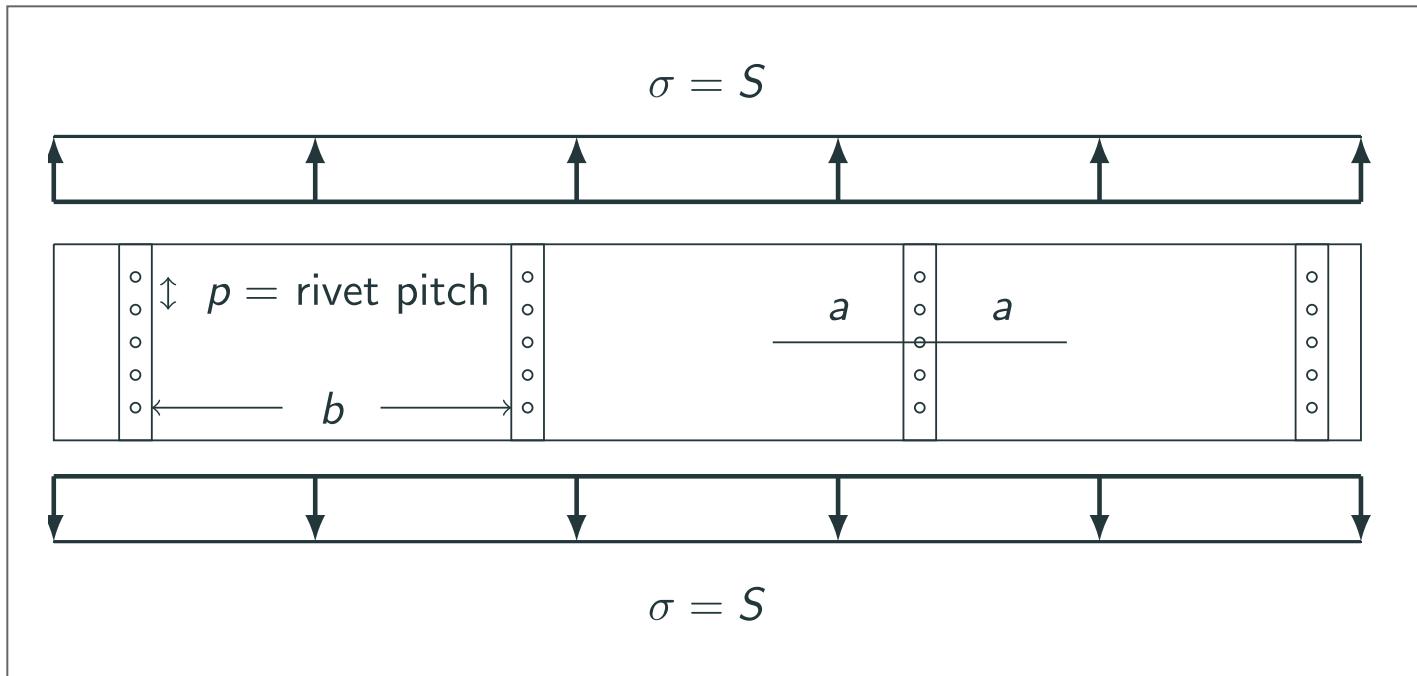
## stiffened panels

- In aircraft the skin/stringer system provides many benefits (resistance to buckling)
- Stringers also act as stiffeners to resist crack propagation in the skin
- Panels in these configurations are generally very wide relative to expected crack dimensions
- Cracks are generally modeled either as centered between stiffeners or centered under a stiffener
- We need to consider the residual strength of the panel, the stiffener, and the rivets

# centered between stiffeners



# centered under stiffener



## remote stress

- For equilibrium to be satisfied, we know that

$$\left( \frac{PL}{AE} \right)_{Skin} = \left( \frac{PL}{AE} \right)_{Stiffener}$$

- Since  $L$  is the same, we find

$$\frac{S}{E} = \frac{S_S}{E_S}$$

- Where the subscript  $S$  indicates stiffener values, we can express the remote stress in the stiffener as

$$S_S = S \frac{E_S}{E}$$

## skin

- The critical stress in the skin is determined the same way as it was in the residual strength chapter
- The only exception is that the stiffener contributes to  $\beta$

$$S_C = \frac{K_C}{\sqrt{\pi a} \beta}$$

## stiffener

- The maximum stress in a stiffener will be increased near a crack
- We represent the ratio of maximum force in stiffener to remote force with the Stiffener Load Factor,  $L$

# stiffener

$$\begin{aligned} L &= \frac{\text{max force in stiffener}}{\text{remote force applied to stiffener}} \\ &= \frac{S_{S,max} A_S}{S_S A_S} \\ &= \frac{S_{S,max}}{S \frac{E_S}{E}} \end{aligned}$$

$$LS \frac{E_S}{E} = S_{S,max}$$

$$LS \frac{E_S}{E} = \sigma_{YS}$$

$$S_C = \frac{\sigma_{YS} E}{L E_S}$$

## rivet

- We can define a similar rivet load factor to relate maximum stress in the rivet to remote stress in the skin

$$L_R = \frac{\tau_{max} A_R}{Sbt}$$

$$L_R = \frac{\tau_{YS} A_R}{Sbt}$$

$$S_c = \frac{\tau_{YS} A_R}{L_R bt}$$

## finite element analysis

- CC Poe found that panels could be related by a parameter he defines as  $\mu$

$$\mu = \frac{A_S E_S}{A_S E_S + A E}$$

- Where  $A_S$  is the cross-sectional area of a stiffener,  $E_S$  is stiffener modulus
- $A$  is the skin cross-sectional area (per stiffener)  $A=bt$  and  $E$  is the modulus of the skin

## finite element analysis

- pp 167 - 178 give  $\beta$ ,  $L$  and  $L_R$  for various skin/stiffener configurations
- These values were determined using a finite element model

## examples

- quantitative example (p. 179-180)
- qualitative notes on behavior (p. 181-182)
- **worked**

# severed stiffeners

## failure in stiffener

- Sometimes the stiffeners fail before the panel
- T. Swift conducted some parametric studies on panels with a severed stiffener
- When the crack is short (and near the severed stiffener) the residual strength is lower due to the broken stiffener
- As the crack nears the next stiffener, residual strength is very similar to a panel with all stiffeners intact

## failure in stiffener

- Swift considers the difference in stress at different points in the stiffener
- Instead of one general load factor ( $L$ ), he uses  $SCFO$  and  $SCFI$
- We can find the critical value of remote stress at the outer flange as

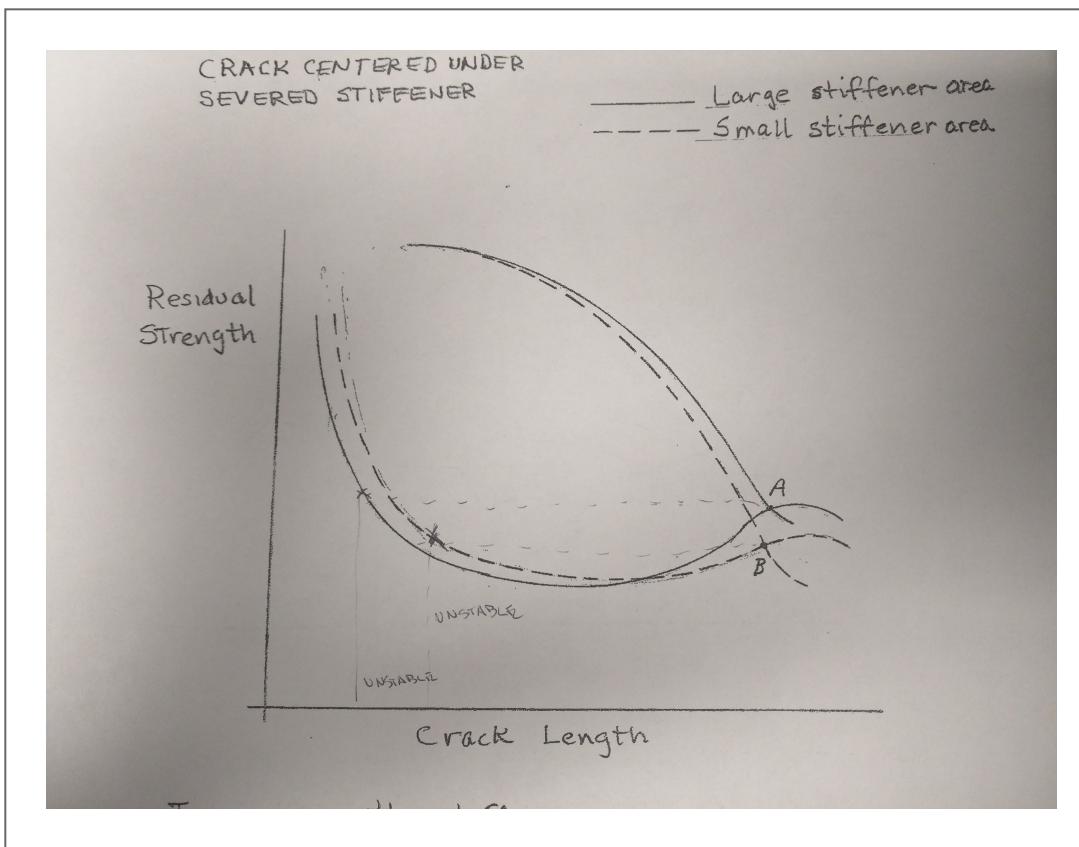
$$\sigma_C = \frac{\sigma_U}{SCFO}$$

- And similarly at the inner flange

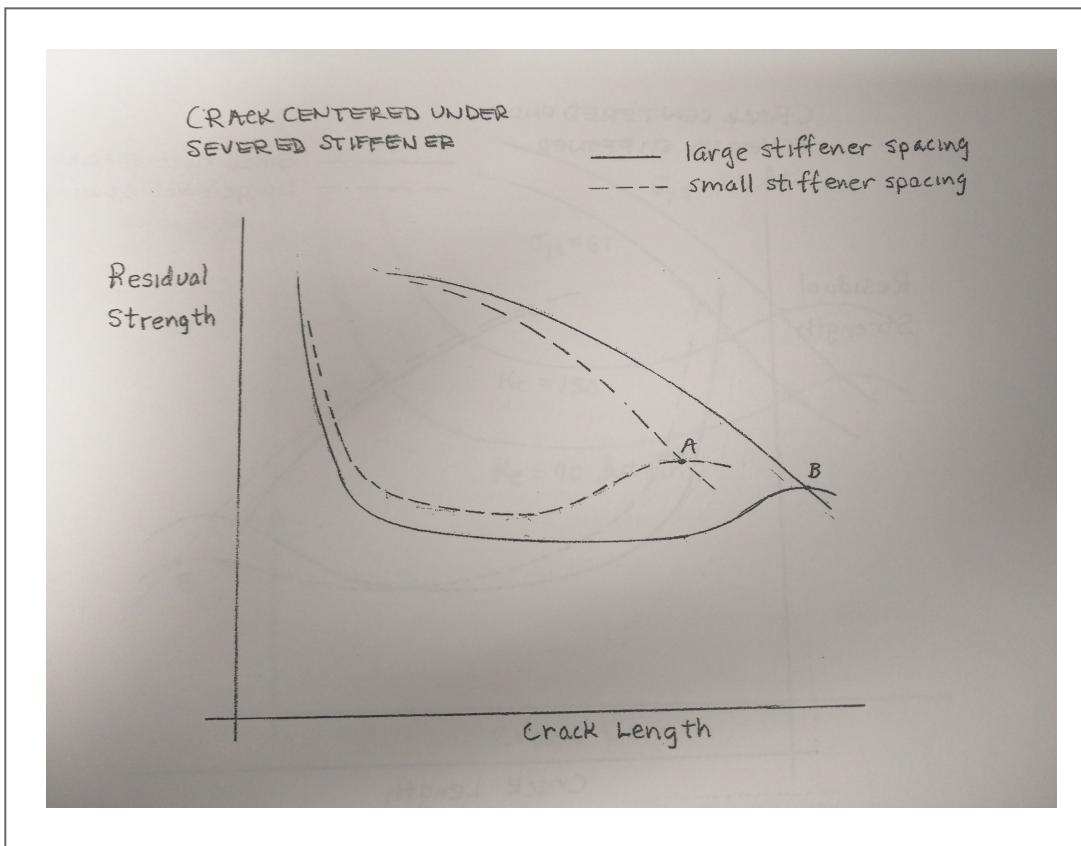
$$\sigma_C = \frac{\sigma_U}{SCFI}$$

- Swift's parametric study did not consider rivet failure

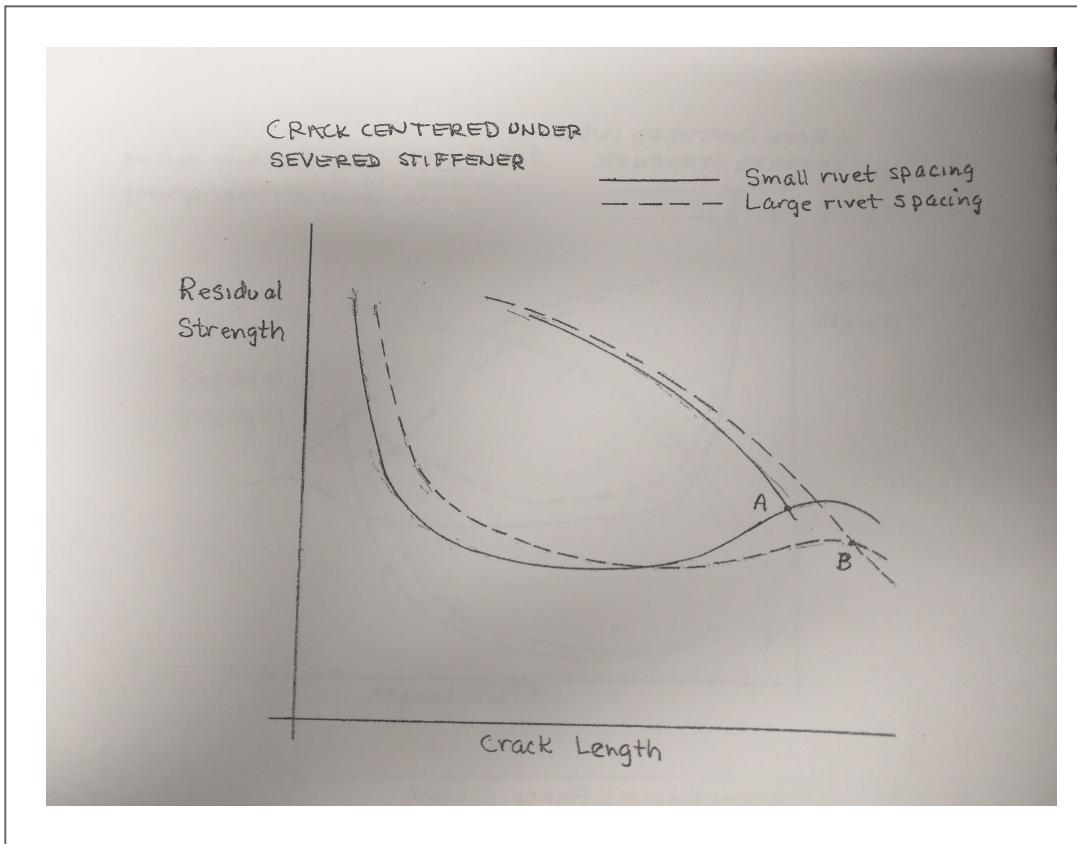
# stiffener area



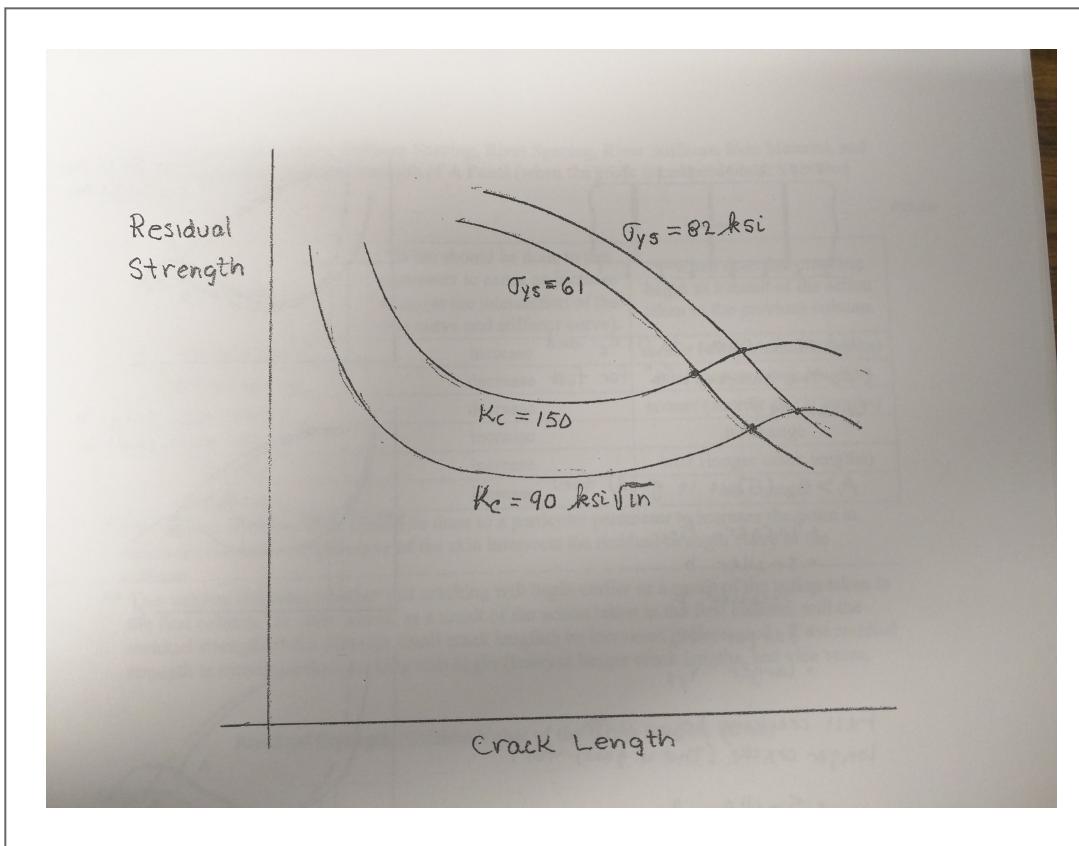
# stiffener spacing



# rivet spacing



# strength and toughness increase



## example

- If we consider the case from Swiftâ™s data most similar to our previous example:

$$P = 1.0 \text{ in}$$

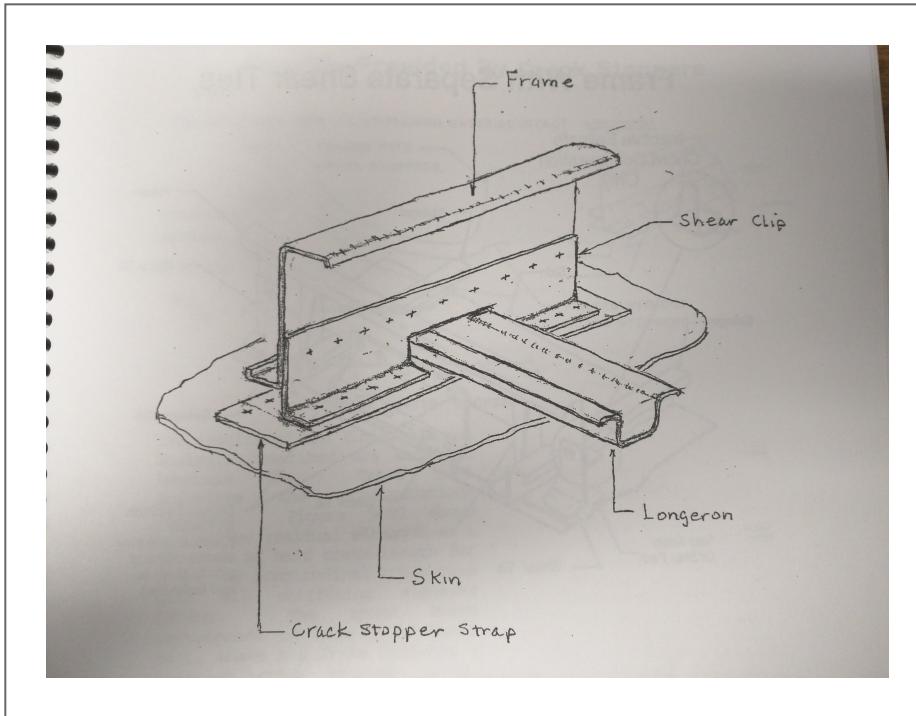
$$A_{st} = 0.2538 \text{ in}^2$$

$$b = 10.0 \text{ in}$$

- So we use the tables for Case 10

# crack stoppers

# crack stopper



## optimal crack stopper

- Swift found that the ideal crack stopper has a cross-sectional area approximately equal to  $1/4$  the stiffener area
- The ideal material was titanium (as opposed to steel or aluminum).
- Aluminum did not transfer enough load to the stiffeners, steel transferred too much

## example

- Compare cases 1, 3, and 5