SPINOFFS

Spinoffs are relatively short learning modules inspired by the LTAs. They can be easily implemented to support student learning in courses ranging from prealgebra through calculus. The Spinoffs typically give students an opportunity to use mathematics in a real world context.

LTA - SPINOFF 4A — Measuring Cracks in the Space Shuttle

LTA - SPINOFF 4B — Calculating Cracks in the Space Shuttle

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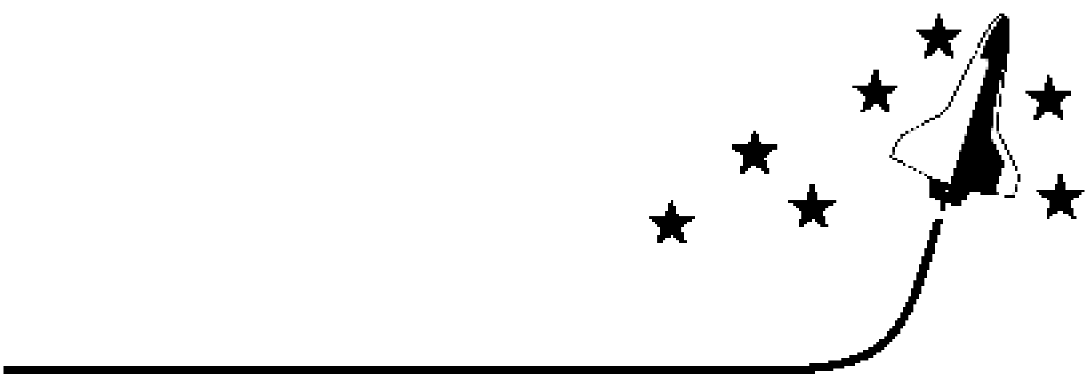

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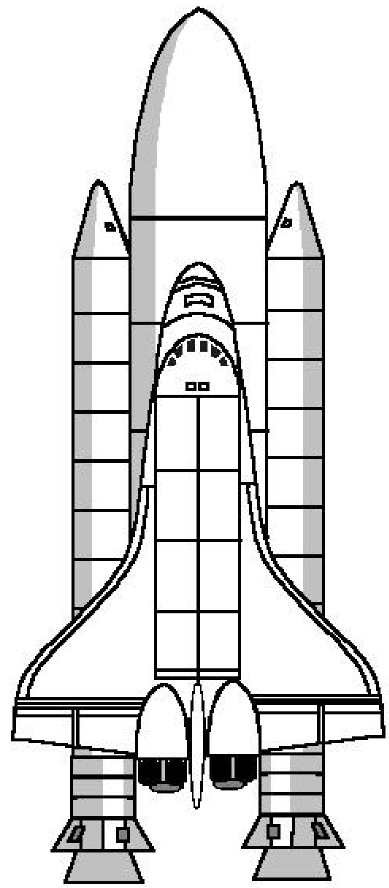
SPINOFF 4B

Calculating Cracks in the Space Shuttle

The Background



Eric Thaxton, one of the Mechanical Engineers at NASA's Kennedy Space Center, often is asked to analyze cracks that occur in various structures These cracks can be found in metallic structures such as tubes, pipes, liquid storage tanks, the Space Shuttle, or components for the space station.

If a crack reaches its critical stage, the crack will then expand at the speed of sound and the structure will most likely burst, causing possibly catastrophic consequences. Years ago, when engineers realized that the cause for ships to break in half was often a result of a critical crack, the need for experts in cracks emerged. The intensive study of cracks is a relatively new field in Mechanical Engineering called Fracture Mechanics. As a result of this intensive study, great strides have been made in detecting and analyzing cracks, especially in cracks that were previously undetected. The use of ultrasound and/or x-rays enables the engineer to detect microscopic cracks as well as cracks embedded in the metal that are not visible to the naked eye.

Environmental concerns necessitate that we reuse or extend the current use of metal structures that too often would previously have been abandoned. With pressure vessels (liquid storage tanks with the liquid under pressure) priced in the hundreds of thousands of dollars, budgetary concerns also demand they be used as long as possible. Obviously, safety must be an overriding concern of the engineers charged with the decision on continued use.

The Problem

Because many of these cracks are microscopic, sometimes it is necessary to *calculate* their lengths since *measuring* them would be impossible. To do so a grid printed on a transparent film is placed over the crack. A picture is taken, which is then 'blown-up' to a size more easily seen by the human eye. Your task will be to calculate the lengths of cracks to determine if the crack is critical or not.

Once you have measured a crack, you need to calculate the Stress Intensity Factor. Using the Stress Intensity Factor formula requires you to find ½ of the length of the crack and to know the stress value. Eric has provided us with appropriate stress values. Stress values are determined by considering the size of the tank, thickness of the tank, and the pressure exerted on the tank by its contents. Here is the formula you will use to calculate the Stress Intensity Factor.

Stress Intensity Factor, *K*

$$K = s \cdot \sqrt{p \cdot a}$$

where

a = crack half length, crack is $2a$ long (mm or inches)

s = stress (MPa or psi)

K = Stress Intensity Factor (MPa-$\sqrt{\text{mm}}$ or psi-$\sqrt{\text{in}}$)

Note: $\sqrt{\text{mm}}$ is pronounced 'root millimeters' and

$\sqrt{\text{in}}$ is pronounced 'root inches'

$p \approx 3.14$, but use the calculator value for increased accuracy

Before you begin with this problem, complete the following exercises where the length of the crack has been measured for you:

1) Find K when s = 150 psi and a = 1.1 inches.

2) Calculate K if s = 110 MPa and the length of the crack is 22 mm.

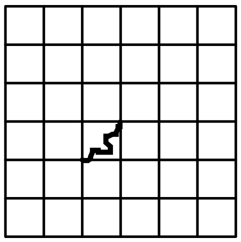
3) Determine the Stress Intensity Factor when s = 125 MPa and the length of the crack is 3.2 mm.

Once you calculate the Stress Intensity Factor (K), you can compare its value to the **allowable** Stress Intensity Factor (K_a). The allowable Stress Intensity Factor is governed by the type of metal involved as well as a safety factor which varies according to the use of the metal and any weight considerations.

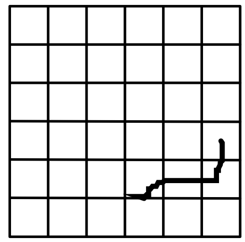
If your **calculated** value of K is greater than the given value of K_a, you would require corrective action — usually this would require cutting out a plug around the crack and welding in a new piece of metal.

4) Assume that K_a = 250 MPa-$\sqrt{\text{mm}}$ and that the grids are 1mm x 1mm. For cracks 1- 4, do the following.

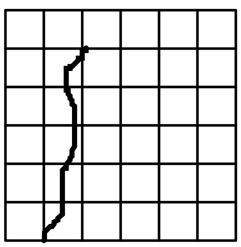
a) Estimate the length of the crack.
b) Calculate the length of the crack
c) Find ½ of the length of the crack and record this value as a = ____.
d) Calculate K.
e) Determine whether the Shuttle is still safe or if corrective action is necessary.



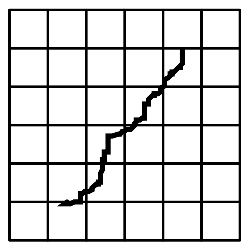
Crack 1
s = 120 MPa



Crack 2
s = 120 MPa

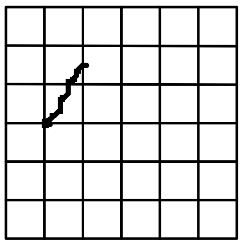


Crack 3
s = 50 MPa

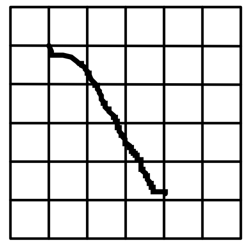


Crack 4
s = 100 MPa

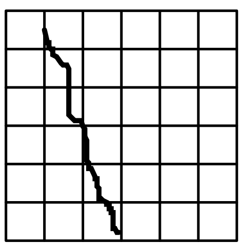
5) Assume that K_a = 70 psi-$\sqrt{\text{in}}$ and that the grids are $\left(\frac{1}{16}\text{in}\right)\times\left(\frac{1}{16}\text{in}\right)$. For cracks 5-8, do the following.
a) Estimate the length of the crack.
b) Calculate the length of the crack
c) Find ½ of the length of the crack and record this value as a = _____.
d) Calculate K.
e) Determine whether the Shuttle is still safe or if corrective action is necessary.



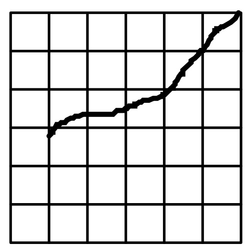
Crack 5
s = 100 psi



Crack 6
s = 100 psi



Crack 7
s = 110 psi



Crack 8
s = 20 psi

Address the following statements using your results from the preceding eight cracks:

6) Compare and contrast your observations of cracks 1 and 2.

7) Compare and contrast your observations of cracks 3 and 4.

8) Compare and contrast your results from crack 6 with other members of your class.

9) Compare and contrast your observations of cracks 7 and 8.

10) Explain why you think a long crack is sometimes safe while a comparatively small crack is sometimes critical.