Factor of Safety Packet

This packet is intended for use in a mechanical engineering Strength of Materials course. A brief overview of factors of safety is included, and a reliability standpoint is adopted. Interference between stress and strength normal curves is discussed. A homework problem involving the reliability aspect is presented, and sample exam problems are included.

Time for presentation is estimated as 30-40 minutes.

Objectives:

1. To gain an increased understanding of factors of safety.
2. To further develop knowledge pertaining to the reliability aspect of factors of safety.
3. To recognize the importance of factors of safety in design.

This packet includes the following items:

- Lecture material for the instructor
- Overheads for use during the lecture
- Handouts for the students
- Homework problems

Factor of Safety Lecture Outline

VI. Safety in Design **(OVERHEAD 1)**

A. For a portion of a structure critical to safety, structural failure must be avoided.
B. In order for failure to be avoided, possible failure modes must be identified.
C. Failure criteria must be established for each failure mode.
D. These failure criteria are then used in designing the part.
E. A factor of safety also is applied to reduce the chance of failure in a structure, thereby minimizing the risk of injury to those in contact with the structure.

II. Factor of Safety **(OVERHEAD 2)**

A. The ratio of an actual material characteristic, such as strength, to the required characteristic is called the factor of safety, F.S.:

$$\text{Factor of safety, } F.S. = \frac{actual strength}{required strength}$$

B. This definition of factor of safety is correct; however, it is a simplistic view.
C. Many complex issues are involved in the concept of the factor of safety.

III. Use of Factors of Safety **(OVERHEAD 3)**

Because failure modes differ within structural members, often several factors of safety are required in part design. An example of this is an elevator cable.

1. The cable might fail by elastically extending too far, or fail due to metal fatigue.
2. The failure criterion for extension might be related to modulus of elasticity and a factor of safety less than 2.0 might be appropriate.
3. For metal fatigue, a factor of safety of 40 might be required based on a fatigue strength failure criterion.

IV. Determination of Factor of Safety **(OVERHEAD 4)**

A. There are several points to consider when choosing a safety factor.
   1. The factor of safety must be greater than 1.0 to prevent failure.
   2. If the factor of safety is too big, performance is sacrificed.
   3. If the factor of safety is too small, safety becomes an issue.
B. **(OVERHEAD 5)** In the corporate environment, several groups have an interest in factors of safety.
   1. Engineers obviously have an interest, as they are responsible for the designs and their functionality.
   2. Management, the legal department, and insurers also have concerns, mainly for liability reasons.
   3. Management, marketing, and sales are interested because the ability to sell a product depends on its performance, which is affected by factors of safety.
   4. Because there are several groups within a corporation affected by a factor of safety, establishment of factors of safety should be a corporate decision.
C. **(OVERHEAD 6)** Minimum factors of safety are often specified by design specifications or building codes, which are written by engineers working with professional societies, industries, or federal, state, or city agencies. These factors of safety are written to provide adequate levels

of safety with reasonable costs. Some examples of design specifications and building codes are listed.

1. Steel: American Institute of Steel Construction, Specifications for the Design and Erection of Structural Steel for Buildings
2. Concrete: American Concrete Institute, Building Code Requirement for Reinforced Concrete
3. Timber: National Forest Products Association, National Design Specifications for Stress-Grade Lumber and Its Fastenings
4. Highway bridges: American Association of State Highway Officials, Standard Specifications for Highway Bridges

V. Factors to be Considered in Determining a Factor of Safety **(OVERHEAD 7)**

Defining a factor of safety must take into consideration many details, including:

A. Risk of accidental overloading of structure above actual design tolerances.
B. Type of load (static or dynamic).
C. Rate of load applications (intermittent or repeated).
D. Load size.
E. Possibility of structural fatigue failure.
F. Variability in quality of workmanship.
G. Variation in material properties.
H. Deterioration due to poor maintenance, corrosion, and other environmental factors (Time/life issues).
I. Type of failure (progressive or sudden).
J. Consequences of failure (Human safety and economics).
K. Uncertainty.
L. Importance of a certain portion or member of the structure to the integrity of the entire structure.

VI. Variability of Factors of Safety **(OVERHEAD 8)**

A. Most textbooks address the factor of safety as a ratio of deterministic (single valued) numbers.
B. However, the actual values (for example, loads and material strengths) are not single valued.
C. For the purpose of this lecture, it is assumed that loads and material strengths are normally distributed.
D. Variables that are often unknown, such as the effect of time, must be reflected in the factor of safety.

VII. Factor of Safety in Reliability **(OVERHEAD 9)**

A. For the traditional definition of a factor of safety, a load of 10 N with a strength equal to 20 N would have a factor of safety of 2.0.
B. This definition of factor of safety is based on single or “deterministic” values.
C. Actual values will not be deterministic, but will be variable.
D. **(OVERHEAD 10)** Assuming that the load (stress) and strength each have a normal distribution, there are areas of overlap in which failure might occur.
E. A structure with the average value of stress and an average value of strength would still have an appropriate factor of safety.
   1. However, you cannot predict which stress and strength values will occur for a given

situation.

2. Therefore, some values will be in the interference region of the curves.
3. When in the interference region:
    a. If strength is greater than stress, the structure will still be safe.
    b. If strength is less than stress, the structure would fail.
    c. Obviously, the deterministic factor of safety of 2.0 does not actually exist.

F. **(OVERHEAD 11)** Loading is something that probably cannot be controlled as readily as material strength. Material strength, especially for requirements such as fatigue loading, can be controlled to a great extent by better process control. As shown in the graph, the original strength curve has been modified so there are no areas of overlap. The probability of failure decreases even further as the curve becomes thinner due to process control, and consequently moves away from the stress curve.

G. **(OVERHEAD 12)** Once control of the process has been gained:
1. it may be possible to increase the loads, and
2. less material may have to be used.
3. The effects of time, the environment, and other variables may not be so easily controlled or even known, but the designer should work to characterize these effects.

VIII. Conclusion **(OVERHEAD 13)**

A. When factors of safety are applied appropriately, the chance of failure is significantly reduced while maintaining system capability.

B. The risks of human injury and economic challenges are decreased when designing for stress and strength curves with smaller variability.

Lecture adapted from:

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Factor of Safety

Safety in Design

- For a portion of a structure critical to safety, structural failure must be avoided.
- In order for failure to be avoided, possible failure modes must be identified.
- Failure criteria must be established for each failure mode.
- These failure criteria are then used in designing the part.
- A factor of safety also is applied to reduce the chance of failure in a structure, thereby minimizing the risk of injury to those in contact with the structure.

Factor of Safety

- The ratio of an actual material characteristic, such as strength, to the required characteristic is called the factor of safety, F.S.:

  Factor of safety,

$$F.S. = \frac{actual strength}{required strength}$$

- This definition of factor of safety is correct; however, it is a simplistic view.
- Many complex issues are involved in the concept of the factor of safety.

Use of Factors of Safety

Because failure modes differ within structural members, often several factors of safety are required in part design. An example of this is an elevator cable.

- The cable might fail by elastically extending too far, or fail due to metal fatigue.
- The failure criterion for extension might be related to modulus of elasticity and a factor of safety less than 2.0 might be appropriate.
- For metal fatigue, a factor of safety of 40 might be required based on a fatigue strength failure criterion.

Determination of Factor of Safety

There are several points to consider when choosing a safety factor.

- The factor of safety must be greater than 1.0 to prevent failure.
- If the factor of safety is too big, performance is sacrificed.
- If the factor of safety is too small, safety becomes an issue.

In the corporate environment, several groups have an interest in factors of safety.

- Engineers obviously have an interest, as they are responsible for the designs and their functionality.
- Management, the legal department, and insurers also have concerns, mainly for liability reasons.
- Management, marketing, and sales are interested because the ability to sell a product depends on its performance, which is affected by factors of safety.
- Because there are several groups within a corporation affected by a factor of safety, establishment of factors of safety should be a corporate decision.

Minimum factors of safety are often specified by design specifications or building codes, which are written by engineers working with professional societies, industries, or federal, state, or city agencies. These factors of safety are written to provide adequate levels of safety with reasonable costs. Some examples of design specifications and building codes are listed.

1. Steel: American Institute of Steel Construction, Specifications for the Design and Erection of Structural Steel for Buildings
2. Concrete: American Concrete Institute, Building Code Requirement for Reinforced Concrete
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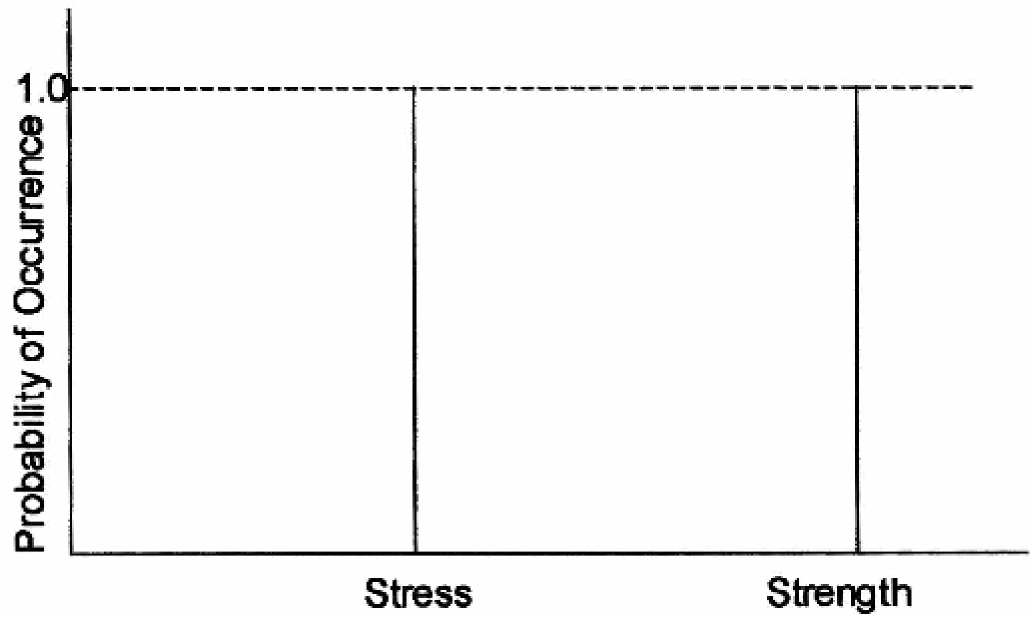
Factors to be Considered in Determining a Factor of Safety

Defining a factor of safety must take into consideration many details, including:

- Risk of accidental overloading of structure above actual design tolerances.
- Type of load (static or dynamic).
- Rate of load applications (intermittent or repeated).
- Load size.
- Possibility of structural fatigue failure.
- Variability in quality of workmanship.
- Variation in material properties.
- Deterioration due to poor maintenance, corrosion, and other environmental factors (Time/life issues).
- Type of failure (progressive or sudden).
- Consequences of failure (Human safety and economics).
- Uncertainty.
- Importance of a certain portion or member of the structure to the integrity of the entire structure.

Variability of Factors of Safety

- Most textbooks address the factor of safety as a ratio of deterministic (single valued) numbers.
- However, the actual values (for example, loads and material strengths) are not single valued.
- For the purpose of this lecture, it is assumed that loads and material strengths are normally distributed.
- Variables that are often unknown, such as the effect of time, must be reflected in the factor of safety.



Factor of Safety in Reliability

- For the traditional definition of a factor of safety, a load of 10 N with a strength equal to 20 N would have a factor of safety of 2.0.
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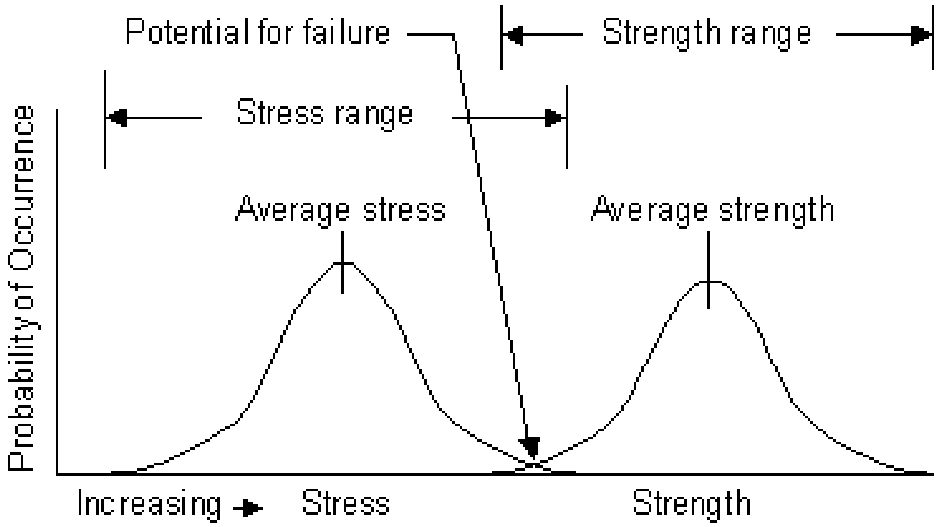

Assuming that the load (stress) and strength each have a normal distribution, there are areas of overlap in which failure might occur.

A structure with the average value of stress and an average value of strength would still have an appropriate factor of safety.

- However, you cannot predict which stress and strength values will occur for a given situation.
- Therefore, some values will be in the interference region of the curves.
- When in the interference region:
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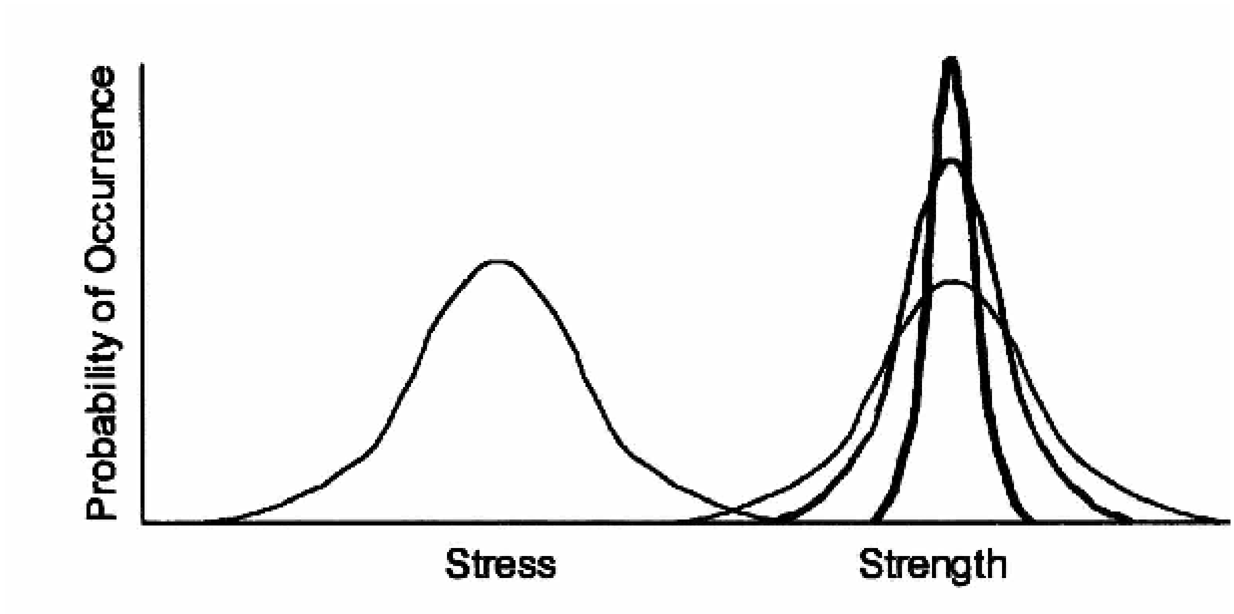
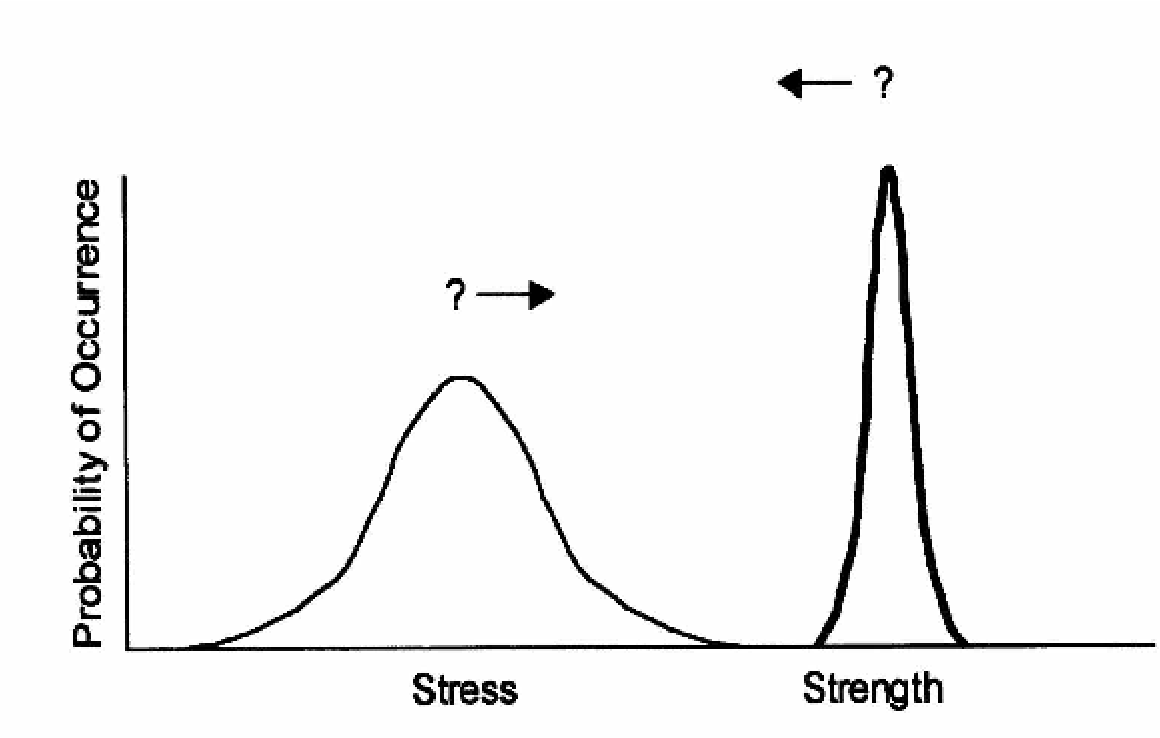


Loading is something that probably cannot be controlled as readily as material strength. Material strength, especially for requirements such as fatigue loading, can be controlled to a great extent by better process control.

As shown in the graph, the original strength curve has been modified so there are no areas of overlap. The probability of failure decreases even further as the curve becomes thinner due to process control, and consequently moves away from the stress curve.



Once control of the process has been gained, it may be possible to:

- increase the loads, and/or
- use less material.

The effects of time, the environment, and other variables may not be so easily controlled or even known, but the designer should work to characterize these effects.

Conclusion

- When factors of safety are applied appropriately, the chance of failure is significantly reduced while maintaining system capability.
- The risks of human injury and economic challenges are decreased when designing for stress and strength curves with smaller variability.

Factor of Safety Lecture Handout

I. Safety in Design
   A. For a portion of a structure critical to safety, structural failure must be avoided.
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   A. The ratio of an actual material characteristic, such as strength, to the required characteristic is called the factor of safety, F.S.:

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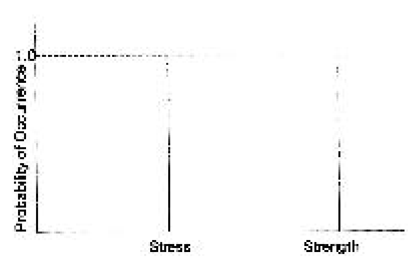

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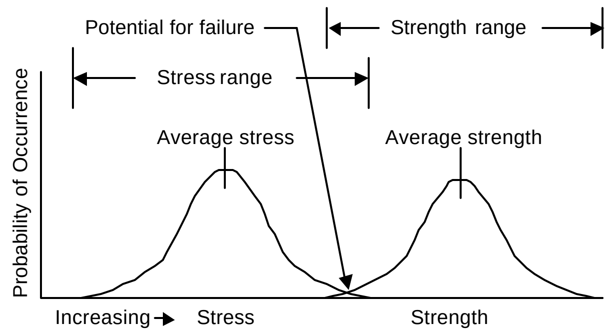

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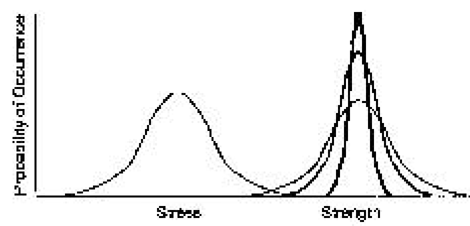

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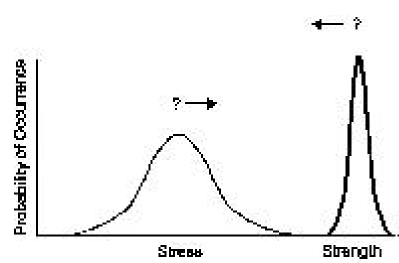

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Factor of Safety Homework Assignment

Background: In many mechanics of materials textbooks, the safety factor is introduced in terms of the ratio of safe-to-actual loads. For example, you might be given that a 2 sq. in. structural steel (yield strength 36 ksi) bar is to support an axial tensile load of 24 kip, and asked for the safety factor. In this case you would find that the actual stress was to be (24 kip)/(2 sq. in.) = 12 ksi and the safety factor was (36 ksi safe load)/(12 ksi actual load) = 3.0. For this problem all of the values are deterministic or single valued, as shown in Figure 1.

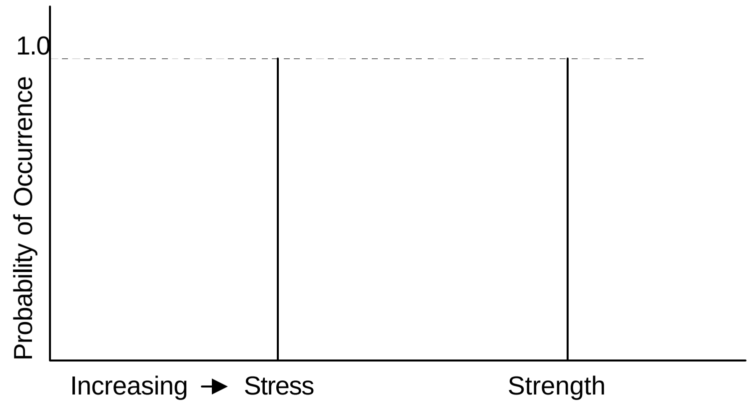

Figure 1. Deterministic values of stress and strength. A single value is given for each and it is assumed that 100% (probability = 1.0) of all stress or strength values will be these given values.

In actual practice, safety factors are applied to loads, but also often are applied to ensure safety for other requirements such as stiffness, lifetime, or number of allowable cycles. Additionally, both the requirement (12 ksi above), and the material or component capability (36 ksi above) are not deterministic, but assume some distribution of values, as shown in Figure 2. Some average value might be used to describe where the distribution is located, and some measure, such as the range of values, might be given to help describe the width of the distribution. Under conditions of variability, the concepts of the safety factor become more complicated, as the problems which follow will show.

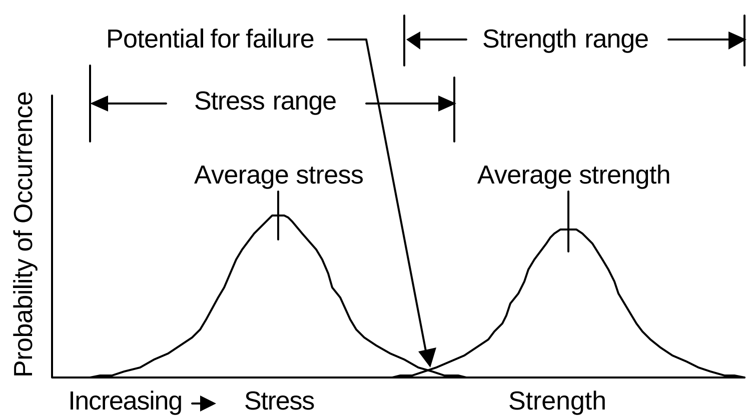

Figure 2. The required stress, and material strength have some distribution of values.

1. Your boss asks you to look into buying components that will operate safely at some maximum stress for 1000 hours. You find three manufacturers who make these components. Manufacturer "A" claims to have components that operate at that stress for 2200 hours; manufacturer "B" has components that operate at that stress for 2000 hours; and manufacturer "C" has components that operate at that stress for 1700 hours. Based on these values (deterministic), what is the lifetime-based factor of safety for each? Which manufacturer makes the safest components? Show your work.

2. However, you remember this assignment and decide to gather more information. The shop foreman tells you that the components cannot be replaced except when the systems are returned for periodic maintenance. Therefore, it would be better to plan on 1000 +/- 200 hours. Also, you question the manufacturers' representatives and find that manufacturer "A" components actually have demonstrated lives of 2200 +/- 1000; and manufacturer "B" components have demonstrated lives of 2000 +/- 600 hours. The manufacturer "C" representative states that their component lives are 2200 +/- 500 hours, but that they advertise the more conservative value of 1700 hours. Which manufacturer would you choose based on this information? Show your work.