Introduction

Engineering Design 0906333

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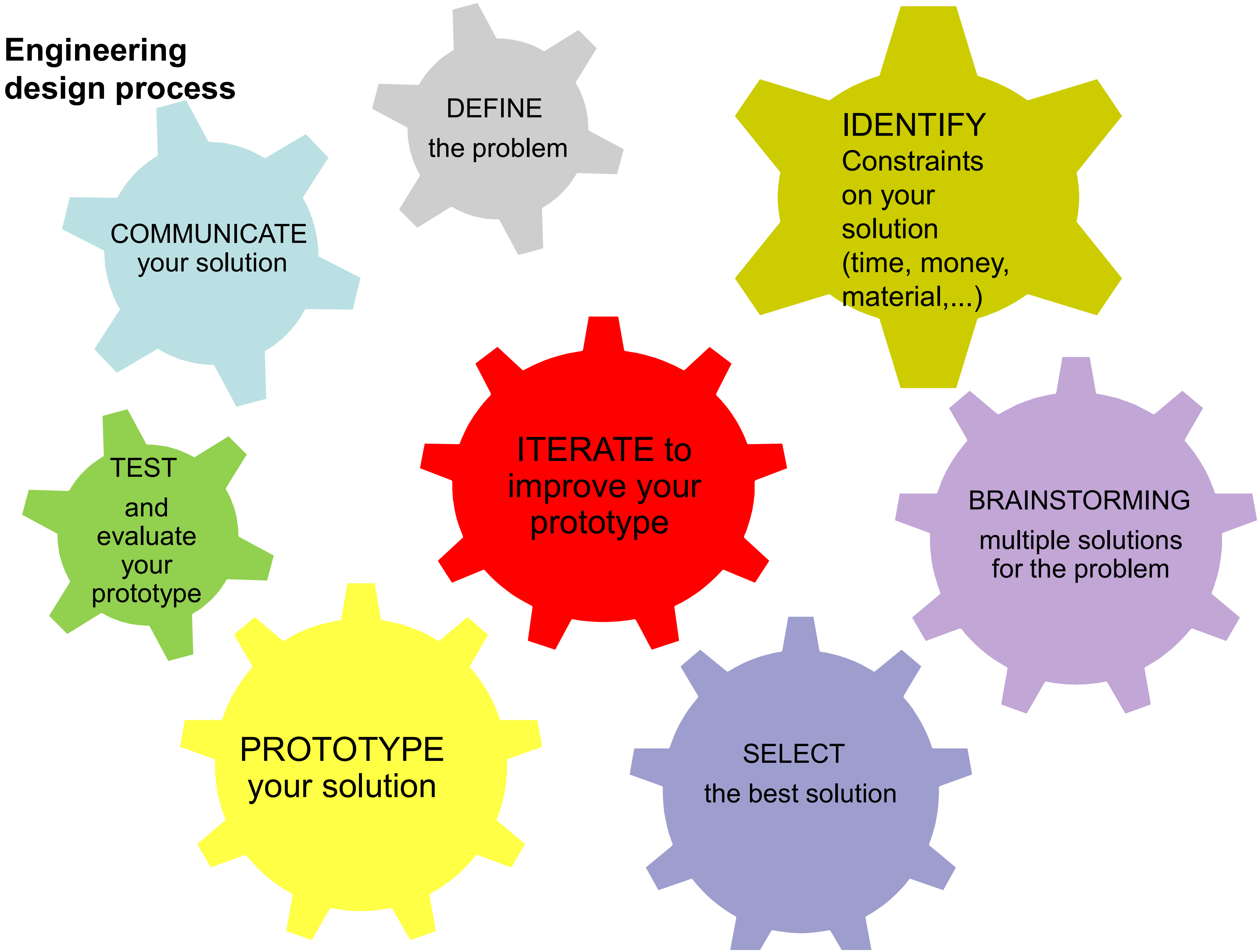
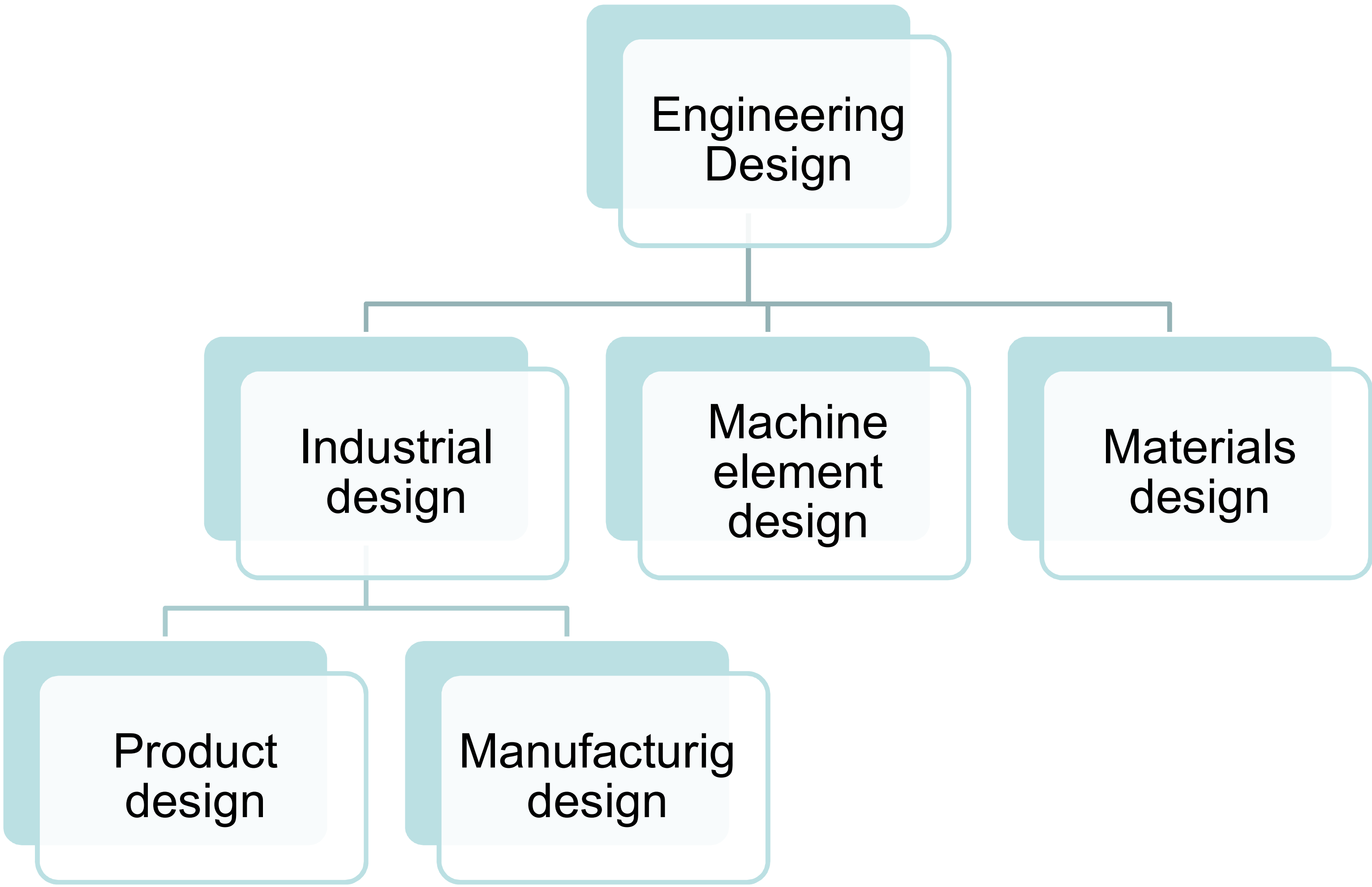
What Is Design?

- Engineering design is a systematic process by which solutions to the needs of humankind are obtained
  - Examples
  - Lightweight,compact wireless communication devices
  - High-temperature resistance material for reentry vehicle


Engineering design process
DEFINE the problem
IDENTIFY Constraints on your solution (time, money, material,...)
BRAINSTORMING multiple solutions for the problem
SELECT the best solution
PROTOTYPE your solution
TEST and evaluate your prototype
COMMUNICATE your solution
ITERATE to improve your prototype

Some Categories of Engineering Design



What Is Empathic Design

user-centered design approach that pays attention to the user's feelings toward a product.

Empathic design caters to real user needs,

Graphic design

Graphic design uses visual compositions to solve problems and communicate ideas through typography, imagery, color and form

Which 3D Design Software should you use

- Auto CAD
- ALIAS by Auto desk
- CREO PARAMETRIC
- FUSION 360 from Auto desk cloud base
- AUTODESK INVENTOR
- CATIA by Dassault Systems
- SOLID WORK by Dassault Systems
- SketchUp
- Tinkercad

Machine Design

Machine Design is a process of selecting the proper machine components for a predetermined function.

To clarify this definition, **machine** is defined as a system of **machine elements** **selected** or **designed** for a specific function.

Machine

Contains mechanism which are designed to provide significant forces and transmit power

MACHINE ELEMENTS

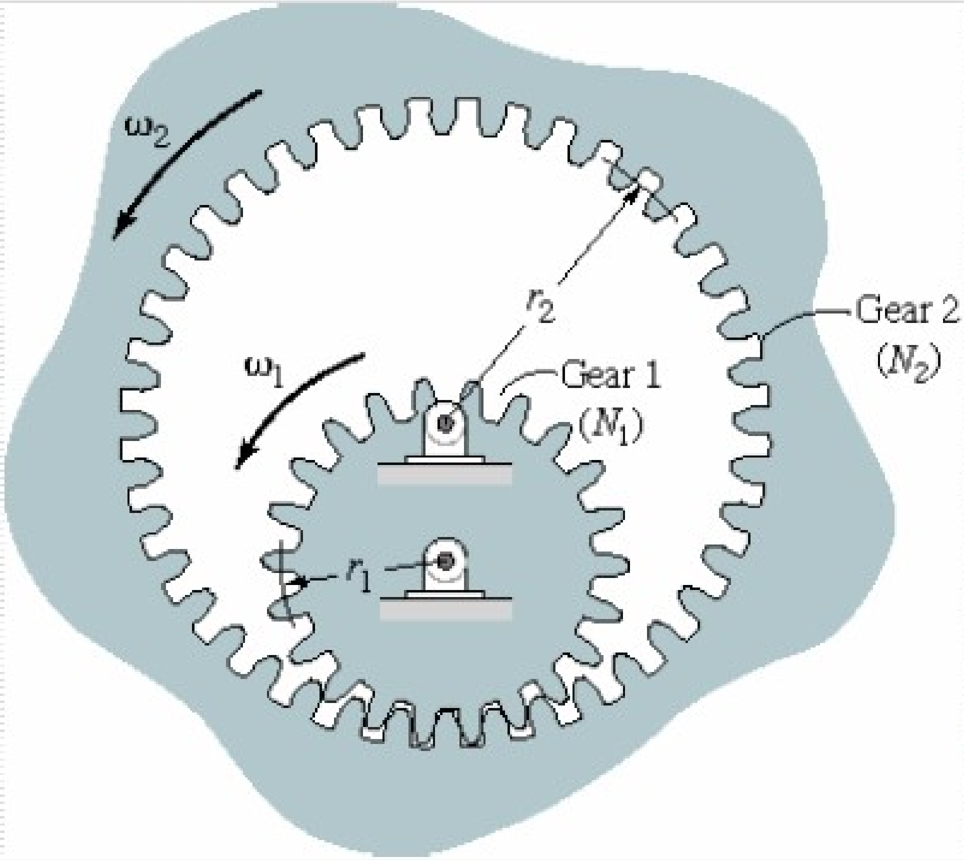
Gears, Springs, Bolts, ...

Electric motors, Electric switches, ...

Optical sensors, Sonic sensors, ...

Control circuits, ...

Microprocessors, ...



Machine Element Design: System→ Elements

Power transmission System→ Gears, Bearings, Shaft, Seals.

Yield Factor of Safety

Factor of safety, n

$$\sigma_{working} = \frac{\sigma_{yield}}{n}$$

Often is between 1.2 and 4

❖**There will always <u>be uncertainties</u> when determining exactly how a material will behaves**.

-Imperfections, stress concentrators and other flaws can be introduced during the manufacturing process

❖**Therefore when designing a part, the unexpected must be taken into account**

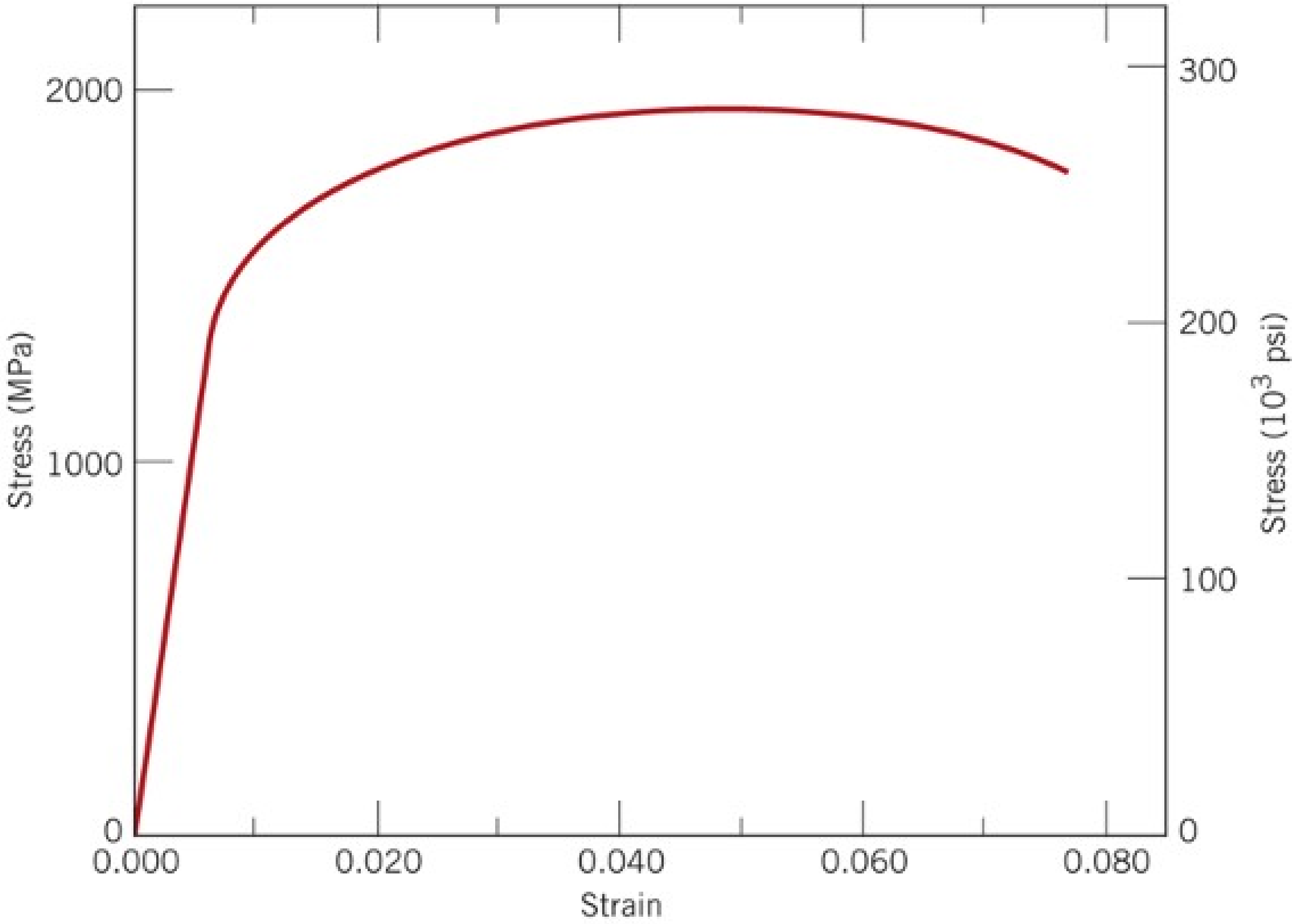
Variation in Material Strength (MPa)

Material (AISI, rolled)	Range	Mean	St. Deviation
1080	865 - 975	920	18.33
1095	865 - 1070	967.5	34.17
1030	495 - 610	522.5	19.17
1040	565 - 690	627.5	20.83
1050	650 - 800	725.0	25.00
1060	725 - 900	812.5	29.17

"Factor of Safety"

- FOS is a ratio of two quantities that have same units:
  - Strength/stress
  - Critical load/applied load
  - Load to fail part/expected service load
  - Maximum cycles/applied cycles
  - Maximum safe speed/operating speed.

NOTE: FOS is deterministic. Often data are statistical and there is a need to use Probabilistic approach.



Stress (MPa)
2000
1000
0
0.000
0.020
0.040
0.060
0.080
Strain
Stress (10^3 psi)
300
200
100
0

Factor of Safety Method

Two distinct and separate approaches

1. The deterministic, or factor-of-safety approach. In this method, the maximum stress or stresses in a part are kept below the minimum strength by a suitable design factor or margin of safety, to ensure that the part will not fail.
2. The stochastic, or reliability approach. This method involves the selection of materials, processing and dimensions such that the probability of failure is always less than a pre selected value

Stress-Strength Analysis is a tool used in Reliability engineering

-If the distributions for both the stress and the strength both follow a Normal distribution then:

Working stresses σ have a mean μ_σ and a standard deviation σ_σ

strengths S have a normal distribution with a mean μ_s and a standard deviation σ_s.

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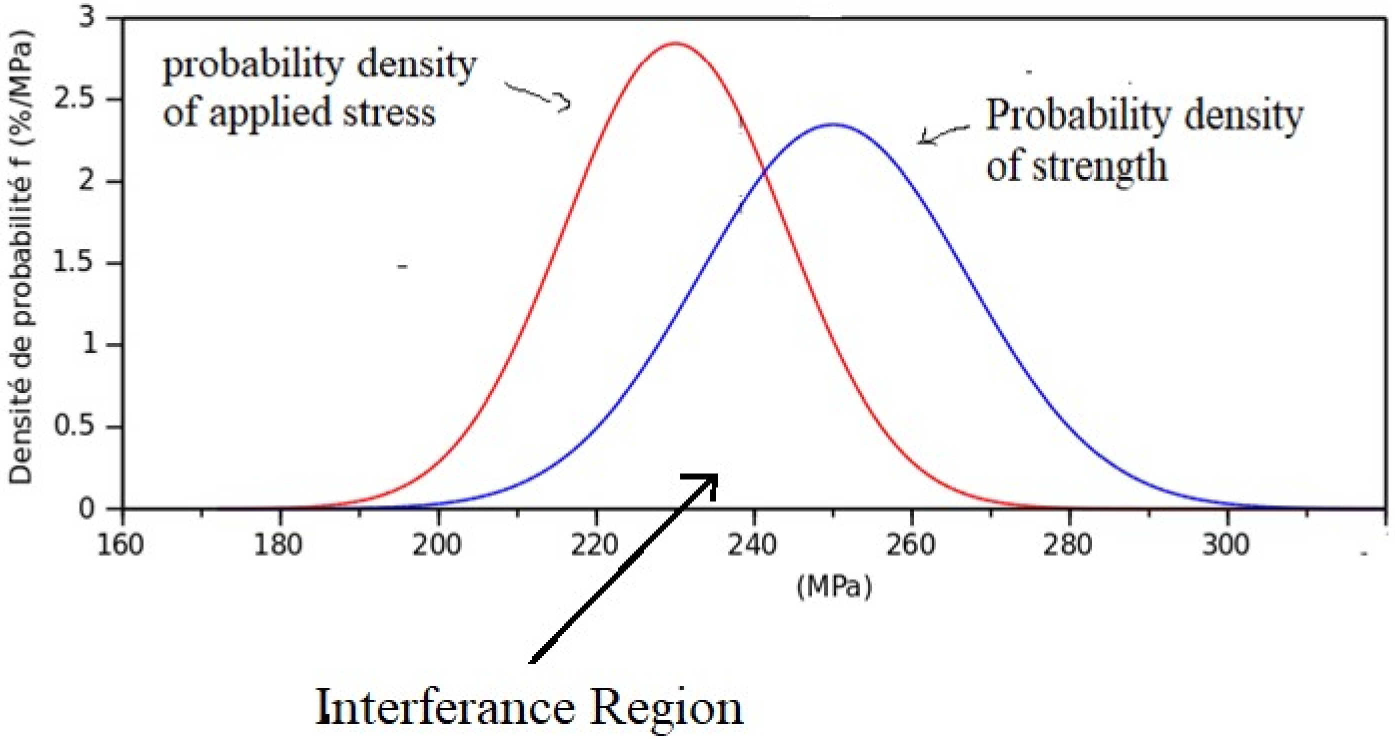
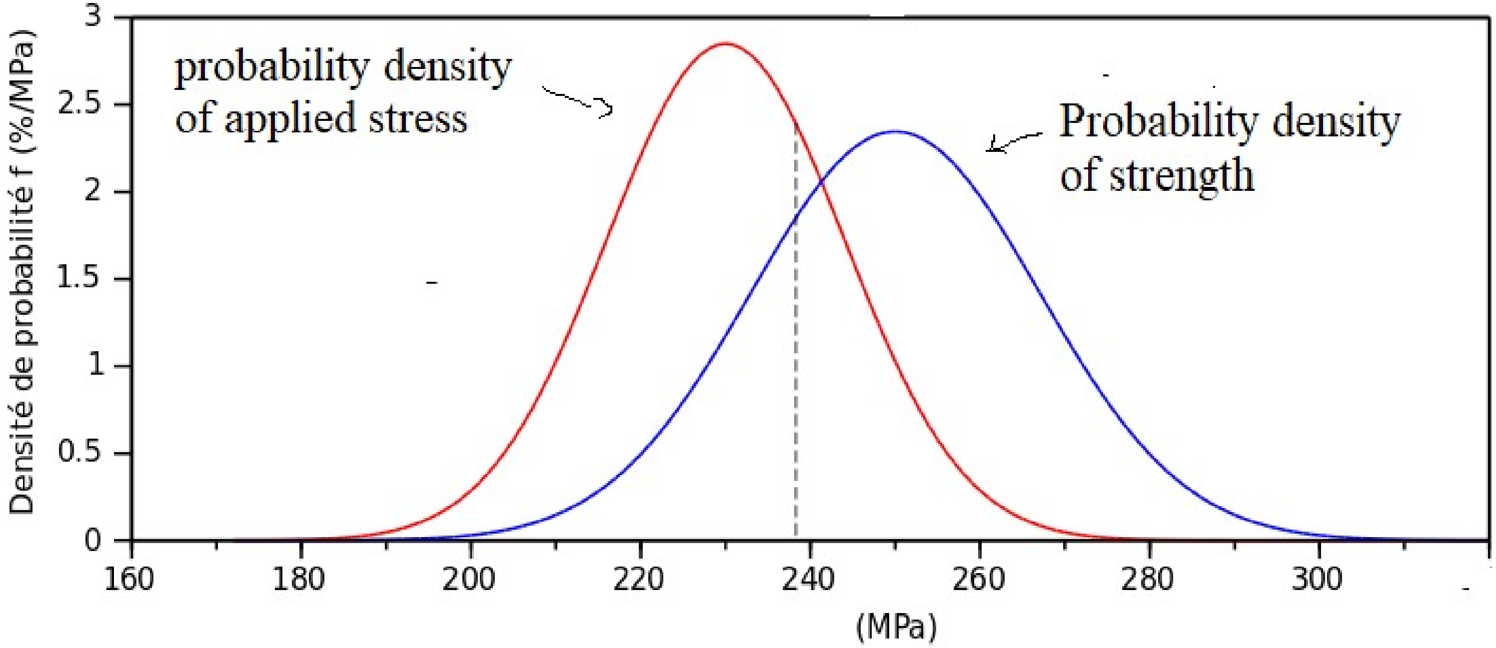


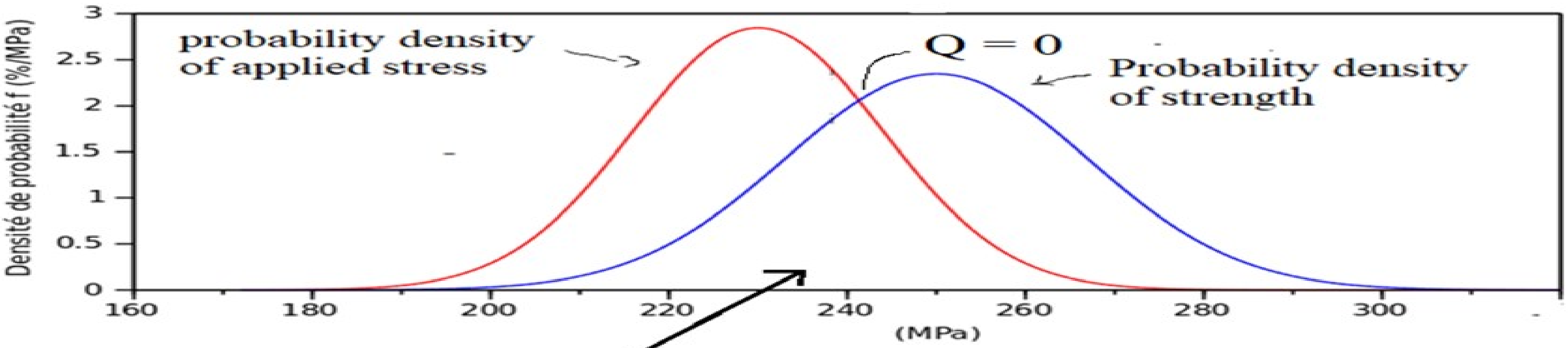
Interference Theory



It is evident that while the mean strength is greater than the mean stress, there exists a region where the distributions overlap and the stress can actually exceed the strength and lead to part or material failure.

-This region is referred to as the “Interference Region”.

- From a “qualitative perspective”, the existence of this interference region implies there is a probability of failure for the design.



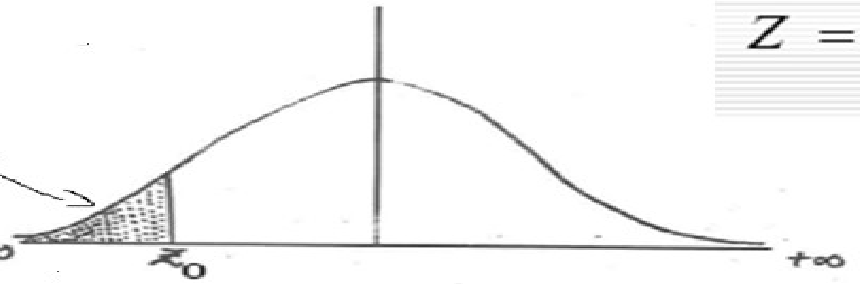
Interferance Region

$$\text{Margin } Q = S - \sigma$$

Let normal variable

$$Z = \frac{Q - \mu_Q}{\sigma_Q}$$

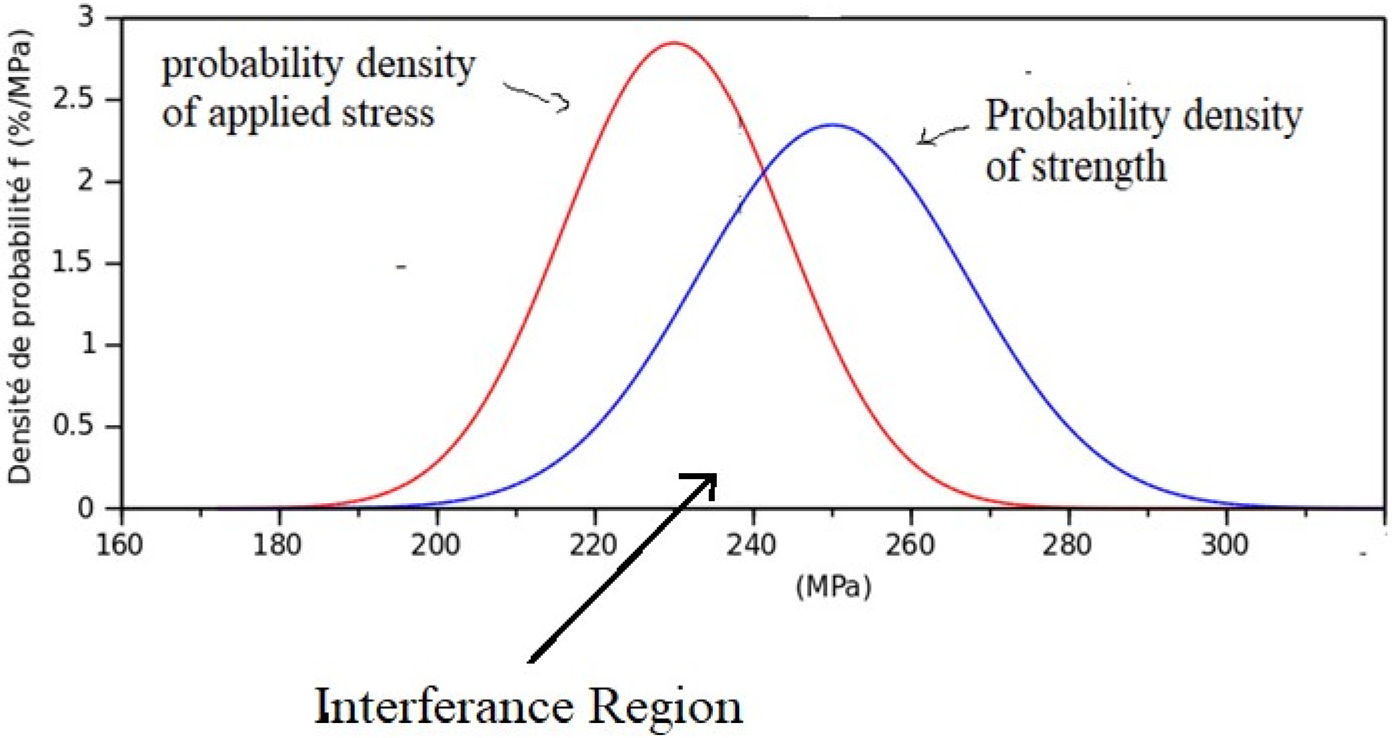
Area gives Probability



at Q= 0

$$Z_0 = \frac{0 - \mu_Q}{\sigma_Q}$$

$$Z_0 = -\frac{\mu_Q}{\sigma_Q}$$



Interference of Stress and Strength Distributions

The overlap of these distributions is the probability of failure . This overlap is also referred to **stress-strength interference**

If the distributions for both the stress and the strength both follow a Normal distribution then the reliability (R) of a component can be determined by the following equation

$$R=1-P(Z_0)$$

Where $P(Z_0)$ is the probability of interference region

$$Z_o = -\frac{\mu_s - \mu_\sigma}{\sqrt{\sigma_S^2 + \sigma_\sigma^2}}$$

$P(Z_0)$ can be determined from a Z table or a statistical software package

Probability-Based Design

- The stochastic method doesnot use a design factor at all rather attention is focused on the probability of survival –

Reliability-

Probability Density Function

$$f(x;\mu,\sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}.$$

For any Normally distributed variable:

68.3% of all values will lie between $\mu - \sigma$ and $\mu + \sigma$ (i.e. $\mu \pm \sigma$)

95.45% of all values will lie within $\mu \pm 2\sigma$

99.73% of all values will lie within $\mu \pm 3\sigma$

Reliability Method of Design

Reliability R

Reliability is probability that machine element will perform intended function satisfactorily.

$$0 \le R < 1$$

$$R = 1 - P_f$$

P_f Probability of Failure

Margin $Q = S - \sigma$

Let normal variable

$$Z = \frac{Q - \mu_Q}{\sigma_Q}$$

The area where the margin Q = S – σ is positive is the set of situation where the system is reliable (S > σ).

Example: suppose that the stress on a component is 2500psi and its strength is 4000psi.
-the stress and strength were normally distributed about the means of 2500psi and 4000psi with standard deviations of 500psi and 400psi, respectively.
Calculate the probabilistic factor of safety

The safety factor n= 4000psi/2500psi = 1.6

$$Z = -\frac{4000 - 2500}{\sqrt{(400)^2 + (500)^2}} = -\frac{1500}{\sqrt{410000}}$$

$$= -2.34$$

Using the Z-value table for a standard Normal distribution, the area above a Z value of -2.34 is 0.0096.
Therefore, the probability of failure is 0.96%.
the reliability is 1-0.0096 = 0.9904 or 99.04%.

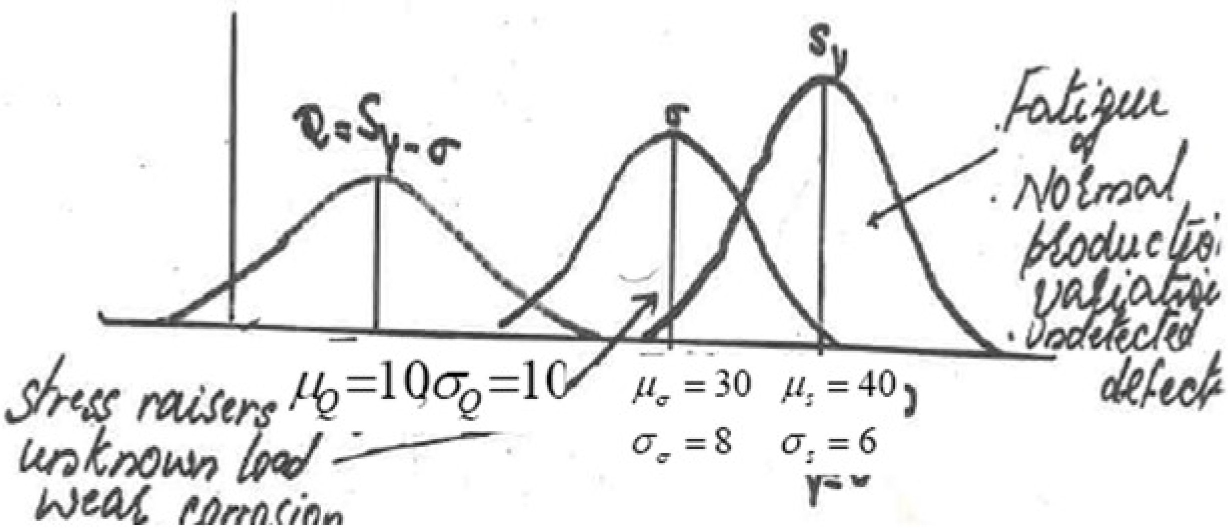
Using the Z-value table for a standard Normal distribution, the area above a Z value of -2.34 0.0096. Therefore, the probability of failure is 0.96%. Likewise, the reliability is 1-0.0096 = 0.9904 or 99.04%.

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641

Ex: Consider a structural member($\mu_s = 40$, σ_s) subjected to a static load that develops a stress σ($\mu_\sigma = 30, \sigma_\sigma$). Find the reliability of member.

NOTE: Reliability is probability that machine element will perform intended function satisfactorily 100% reliability.

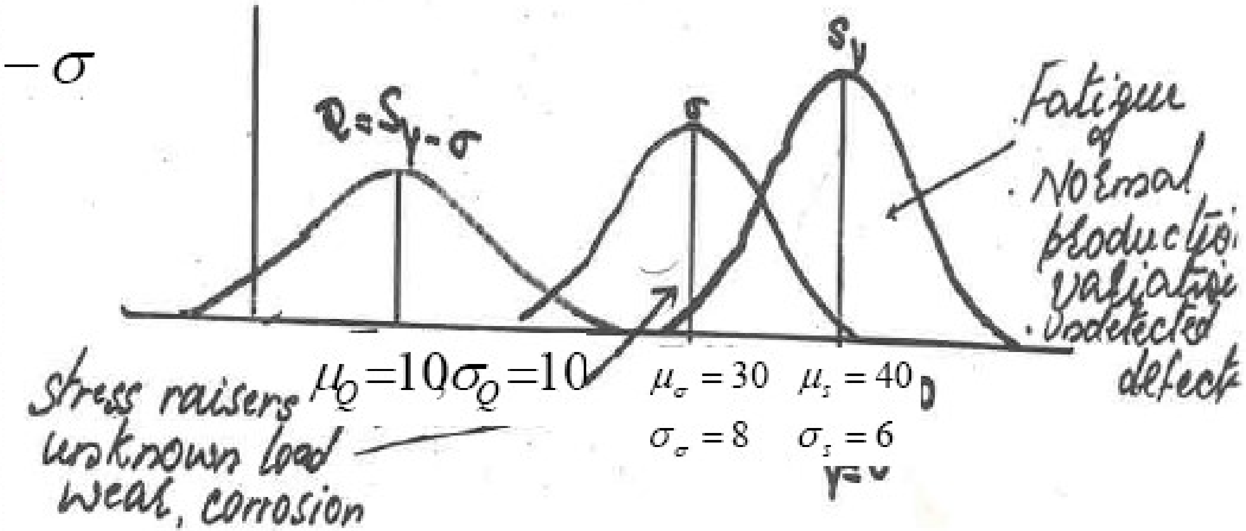
Deterministic FOS = 40/30 = 1.33



$$\mu_Q = 40 - 30 = 10$$

$$\sigma_Q = \sqrt{6^2 + 8^2} = 10$$

Margin $Q = S - \sigma$



Probability of failure $P_f = P(Q < 0)$

Reliability $R = 1 - P_f$

$$f(Q) = \frac{1}{\sigma_Q \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{Q-\mu_Q}{\sigma_Q}\right)^2}$$

Let normal variable

$$Z = \frac{Q - \mu_Q}{\sigma_Q}$$

$$Z = \frac{Q - \mu_Q}{\sigma_Q}$$

$$R = \frac{1}{\sqrt{2\pi}} \int_{Z_0}^{+\infty} e^{-\frac{1}{2}Z^2} \, dZ \qquad \boxed{F = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_0} e^{-\frac{1}{2}Z^2} \, dZ}$$

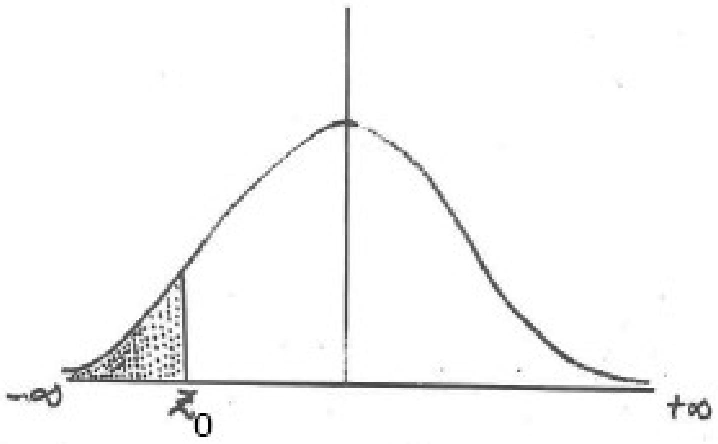
$$where \quad Z_0 = -\frac{\mu_Q}{\sigma_Q}$$

$$\mu_Q = 10$$

$$\sigma_Q = 10$$

at $Q = 0$

$$Z_0 = \frac{0 - 10}{10} = -1$$



- R(z) is the integral of the standardized normal distribution from $-\infty$ to z_0 (in other words, the area under the curve to the left of z_0)

- $P_f(z) = 1 - R$
(the area under the curve to the right of z_0)

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641

Probability of failure is 0.1587 reliability is 0.8413

Answer:

FOS is equivalent to 1.33 gives a reliability of 84.13%.

Which is lower than 100% Reliability needed so it is insufficient for the present design, therefore there is a need to increase this factor

Ex:A round 1018 steel rod having yield strength (540, 40) Mpa is subjected to tensile load (220, 18) kN. Determine the diameter of rod that results in a reliability of 0.999 (z = -3.09). Table A10 0.001

Given $\mu_s = 540\,MPa\,; \quad \sigma_s = 40\,MPa$

$$\mu_\sigma = \frac{220000}{\pi/4\,d^2}\,MPa\,;\ \sigma_\sigma = \frac{18000}{\pi/4\,d^2}\,MPa$$

$$Z = \frac{Q-\mu_Q}{\sigma_Q}\,;\ R = \frac{1}{\sqrt{2\pi}}\int_{z_0}^{+\infty} e^{-\frac{1}{2}z^2}\,dZ \qquad \mu_Q = 540 - \frac{880000}{\pi d^2}$$

$$where \quad Z_0 = -\frac{\mu_Q}{\sigma_Q} \qquad \sigma_Q = \sqrt{40^2 + \left(\frac{72000}{\pi d^2}\right)^2}$$

$$3.09\sqrt{40^2 + \left(\frac{72000}{\pi d^2}\right)^2} = 540 - \frac{880000}{\pi d^2}$$

$$\boxed{d = 26\ mm}$$

If stress and strength are not normally distributed, other techniques (such as Monte Carlo simulation) may be used to determine the probability of failure.

Readings:

1-11

1-12

2-2

20-3