ME303 Introduction to Mechanical Design

Song Chaoyang

Assistant Professor

Department of Mechanical and Energy Engineering

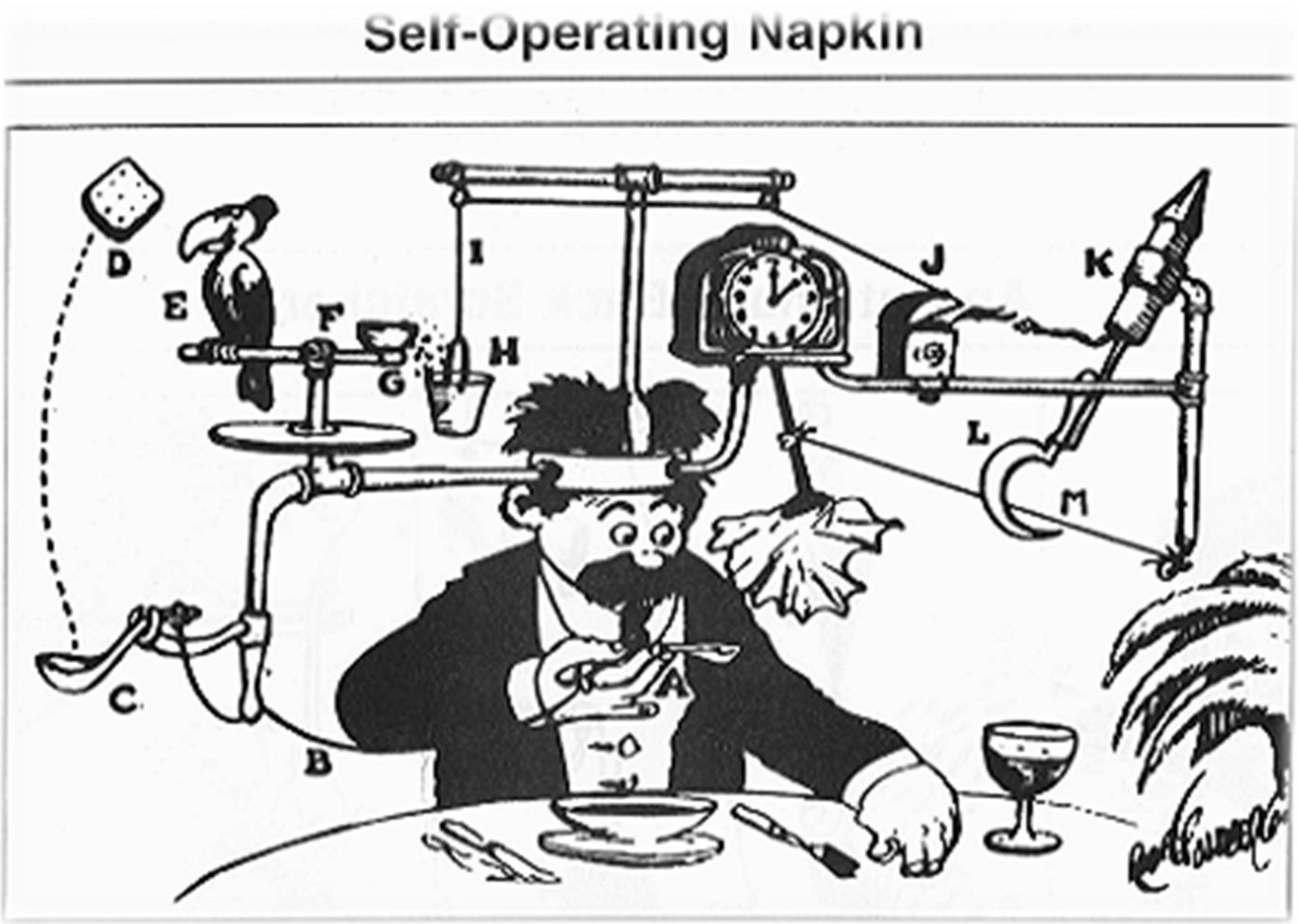
songcy@sustech.edu.cn

SUSTech

Southern University of Science and Technology

Rube Goldberg's Machine

Unnecessarily Complicated Design for a Simple Task



AncoraSIR.com

https://en.wikipedia.org/wiki/Rube_Goldberg_machine

SUSTech
Southern University of Science and Technology

Agenda

Week 01, Wednesday, Sep 04, 2019

- Course Introduction
- Mechanical Engineering Design
- Computer-Aided Design & Engineering
- Design Engineer’s Professional Responsibility
- Standards, Codes & Economics
- Safety & Product Liability
- Design Factor & Factor of Safety
- Reliability & Probability of Failure
- Relating Design Factor to Reliability
- Design Requirements vs. Design Specifications

AncoraSIR.com

Teaching Team

Design Lab website: https://designlab.ancorasir.com/

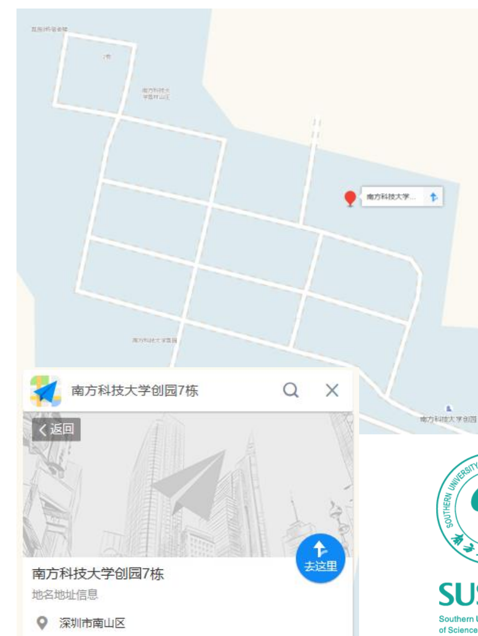
- Course Instructor
  Prof. Song Chaoyang
  (Email is preferred)
  songcy@sustech.edu.cn

- Teaching Assistants
  Xiao Xiaochuan
  xiaoxc@sustech.edu.cn

- Office
  Room 606,
  7 Innovation Park

Course Website

Design Lab



AncoraSIR.com

Course Content

Will be posted on the Instructor's website

THE BIONICDL LAB
Bionic Design + Robot Learning

HOME NEWS RESEARCH PUBLICATIONS PEOPLE LABORATORY TEACHING RESOURCES

ME303 INTRODUCTION TO MECHANICAL DESIGN, AUTUMN 2019

Student Groups

Due to the sudden increase in students, we have to split the class into two groups for the lab session, where the students in each group will take turns to do the lab experiments and group discussions.

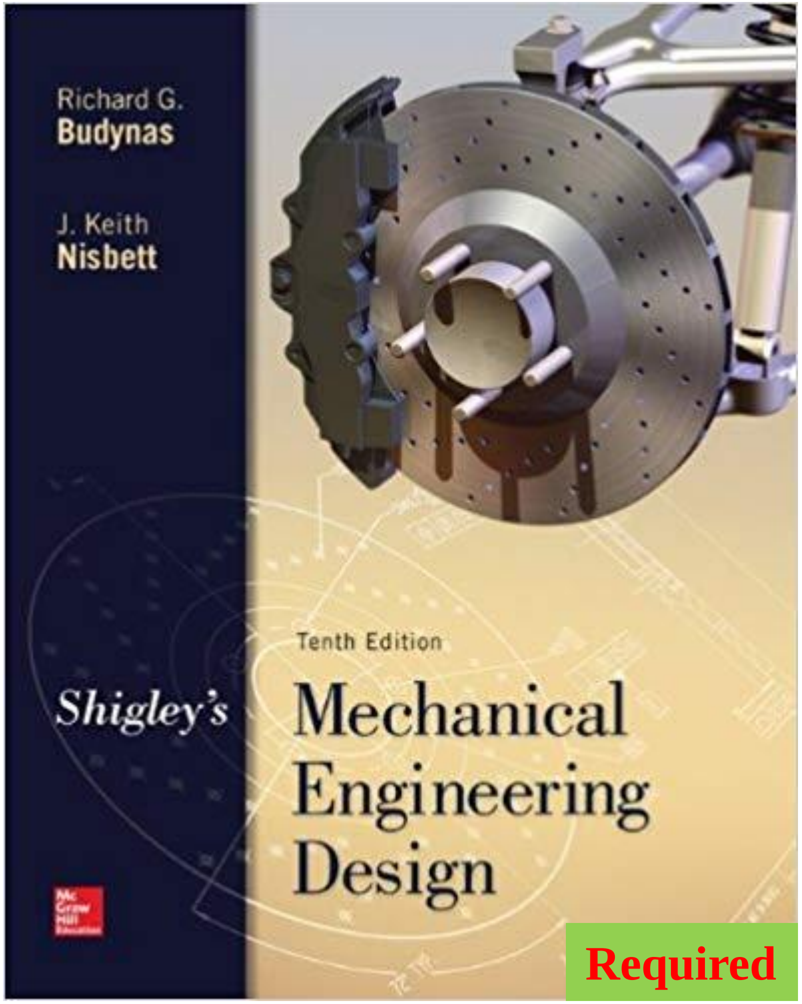
Time and Place

- Lectures (for both Group 1 and Group 2):
  - Week 1: Wednesday 1400-1600 @ Room 206, 2 Lychee Park
  - Week 1: Friday 0800-1000 @ Room 202, 1 Lychee Park
  - Week 2-14: Wednesday 1400-1600
  - Location: Room 206, 2 Lychee Park
- Discussions:
  - Group 1: Weeks 3, 5, 7, 9, 11, 13, 15
  - Group 2: Weeks 4, 6, 8, 10, 12, 14, 16
  - Friday 0800-1000 @ Room 412, 5 Wisdom Valley
- Laboratories :
  - Group 1: Weeks 4, 6, 8, 10, 12, 14, 16
  - Group 2: Weeks 3, 5, 7, 9, 11, 13, 15
  - Friday 0800-1000 @ Room 202, 1 Lychee Park

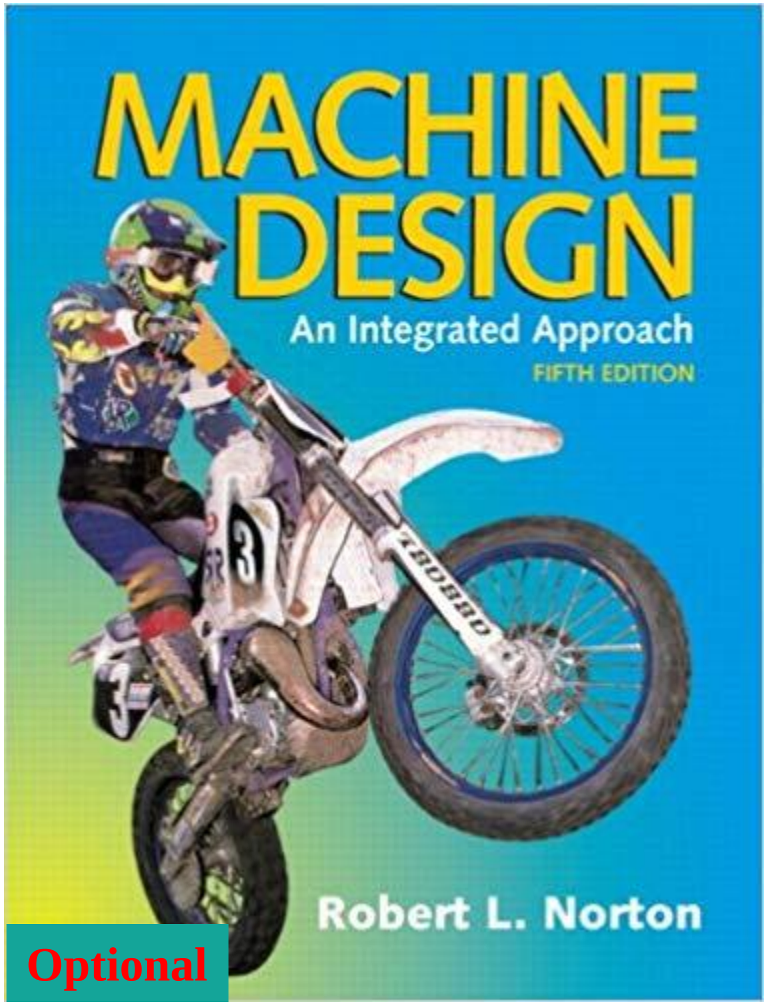
SUSTech
Southern University of Science and Technology

Textbooks

Limited copies of reprinted chapters can be borrowed from the TA.



Required



Optional

AncoraSIR.com

Student Groups, Time & Place

Lecture (Wed) + Laboratories (Fri) + Discussions (Fri)

- **Group 1 + Group 2**
  - Due to the sudden increase in students, we have to split the class into two groups for the lab session, where the students in each group will take turns to do the lab experiments and group discussions.
- **Lectures (for both Group 1 and Group 2):**
  - Week 1: Wednesday 1400-1600 @ Room 206, 2 Lychee Park
  - Week 1: Friday 0800-1000 @ Room 202, 1 Lychee Park
  - Week 2-14: Wednesday 1400-1600
  - Location: Room 206, 2 Lychee Park
- **Discussions:**
  - Group 1: Weeks 3, 5, 7, 9, 11, 13, 15
  - Group 2: Weeks 4, 6, 8, 10, 12, 14, 16
  - Friday 0800-1000 @ Room 202, 1 Lychee Park
- **Laboratories:**
  - Group 1: Weeks 4, 6, 8, 10, 12, 14, 16
  - Group 2: Weeks 3, 5, 7, 9, 11, 13, 15
  - Friday 0800-1000 @ Room 412, 5 Wisdom Valley

Please refer to the course webpage for any change of details (bottom of the page)

Lecture Schedule

Wednesday 1400-1600 @ Room 206, 2 Lychee Park

- **Engineering Basics**
  - Introduction to Mechanical Design
  - Material & Process
  - Kinematics & Load Determination
  - Stress, Strain, Deflection & Stiffness
- **Failure Prevention**
  - Failures from Static Loading
  - Failures from Variable Loading
- **Gear Components**
  - Gears in General
  - Spur, Helical, Bevel & Worm Gears
- **Joint Components**
  - Non-permanent Joints (Screws, Fasteners)
  - Permanent Joints (Welding, Bonding)
- **Various Components**
  - Shafts, Keys, Couplings & Clutches
  - Brakes, Flywheels, Bearings & Lubrications
- **Flexible Components**
  - Mechanical Springs
  - Flexible Mechanical Components
- **Special Topics**
  - Power Transmission Case Study
  - Mechanical Design for Advanced Robotics

Lab & Discussion Schedules

Friday 0800-1000 @ Room 412, 5 Wisdom Valley / Room 202, 1 Lychee Park

- **Common Mechanism**
  - Planar Mechanisms I & II
  - Planar Mechanisms III & IV
  - Gear Transmission
- **Dual-output Robotic Joint**
  - Design & Consultation @ Room 202, 1 Lychee Park
  - Fabrication & Testing @ Room 412, 5 Wisdom Valley
  - Mid-term report & presentation in Weeks 8 & 9
  - Final report & presentation in Week 16

- **Week 16 Presentation**
  - 5 min video presentation
  - A 20-page engineering report
  - Design Competition
  - Live Q&A

To design and build a robotic joint that has

- ***Two rotary outputs***
- ***Highest torque density against weight***
- ***Highest torque density against volume***
- ***Least BOM cost under 5K RMB***

<u>Please contact Mr. Xiao Xiaochuan for safety, training, purchasing & fabrication details</u>

SUSTech
Southern University of Science and Technology

AncoraSIR.com

Other Things

You should always keep in mind.

- **Grading**
  - 20% Lab + 20% Assignments + 30% Final Exam + 30% Final Presentation

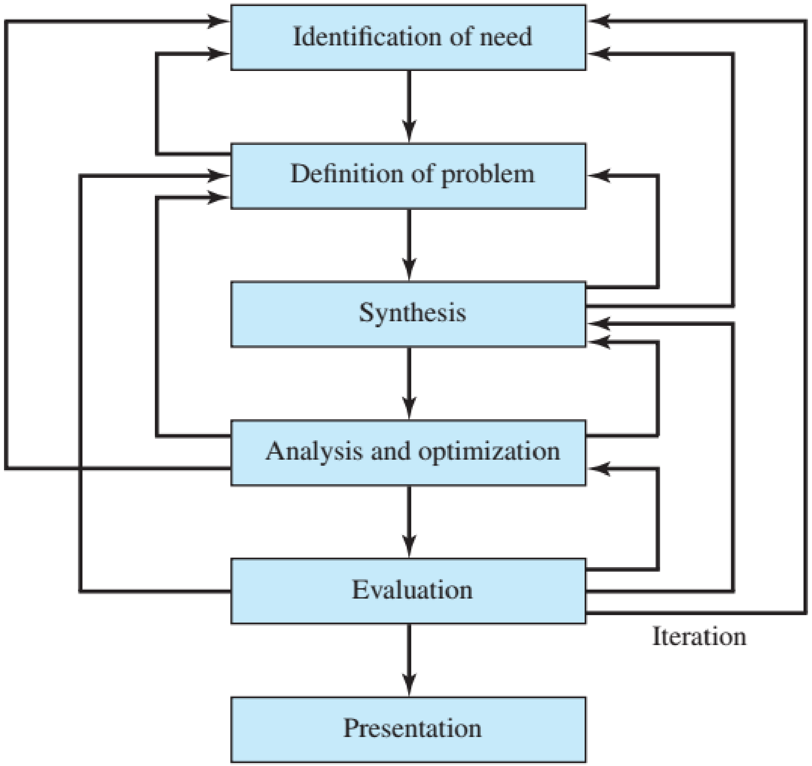
- **Late Assignment Policy**
  - Each student is granted four unpenalized late days for the semester. Assignments can be submitted in no more than four days late and will receive a 25% penalty for each day late (excluding unpenalized late days used). Homework are due at 3 PM on the due date, and each late day extends the deadline by exactly 24 hours. All assignments, labs and presentations must be done to pass the course.

- **Academic Integrity**
  - This course follows the SUSTech Code of Academic Integrity. Each student in this course is expected to abide by the SUSTech Code of Academic Integrity. Any work submitted by a student in this course for academic credit will be the student's own work. Violations of the rules (e.g., cheating, copying, non-approved collaborations) will not be tolerated.

Mechanical Engineering Design

Design | Engineering Design | Mechanical Engineering Design

- A plan to make a machine:
  - A system of elements
  - Specifically arranged
  - For motion/energy transmission



Design Considerations:

1	Functionality	14	Noise
2	Strength/stress	15	Styling
3	Distortion/deflection/stiffness	16	Shape
4	Wear	17	Size
5	Corrosion	18	Control
6	Safety	19	Thermal properties
7	Reliability	20	Surface
8	Manufacturability	21	Lubrication
9	Utility	22	Marketability
10	Cost	23	Maintenance
11	Friction	24	Volume
12	Weight	25	Liability
13	Life	26	Remanufacturing/resource recovery

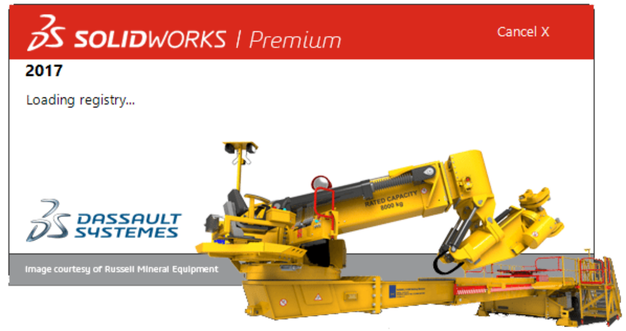
Feedbacks & Iterations

SUSTech
Southern University of Science and Technology

AncoraSIR.com

Computer-Aided Design & Engineering

The increasingly important role of the computer and internet



AncoraSIR.com

SUSTech
Southern University of Science and Technology

Design Engineer's Professional Responsibility

Communication is more important than you thought

- Understand the problem
- Identify the knowns
- Identify the unknowns and formulate the solution strategy
- State all assumptions and decisions
- Analyze the problem
- Evaluate your solution
- Present your solution

Engineers' Creed from the National Society of Professional Engineers (NSPE)

As a Professional Engineer I dedicate my professional knowledge and skill to the advancement and betterment of human welfare.

I pledge:

To give the utmost of performance;

To participate in none but honest enterprise;

To live and work according to the laws of man and the highest standards of professional conduct;

To place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above all other considerations.

In humility and with need for Divine Guidance, I make this pledge.

AncoraSIR.com

Standards and Codes

Just another way of professional communication

- Standard
  - To achieve uniformity, efficiency, and specific quality
  - To limit the multitude of variations
- Code
  - Purposely developed process, i.e. analysis, design, manufacture
  - To achieve certain safety, efficiency, performance, or quality
- Organizations
  - Chinese Mechanical Engineering Society (CMES)
  - China General Machine Components Industry Association (CMCA)
  - International Standards Organization (ISO)
  - American Society of Mechanical Engineers (ASME)
  - American National Standards Institute (ANSI)
  - Institute of Mechanical Engineers (IMechE)
  - National Institute for Standards and Technology (NIST)
  - Society of Automotive Engineers (SAE)

AncoraSIR.com

SUSTech
Southern University of Science and Technology

Economics

Love & Hate

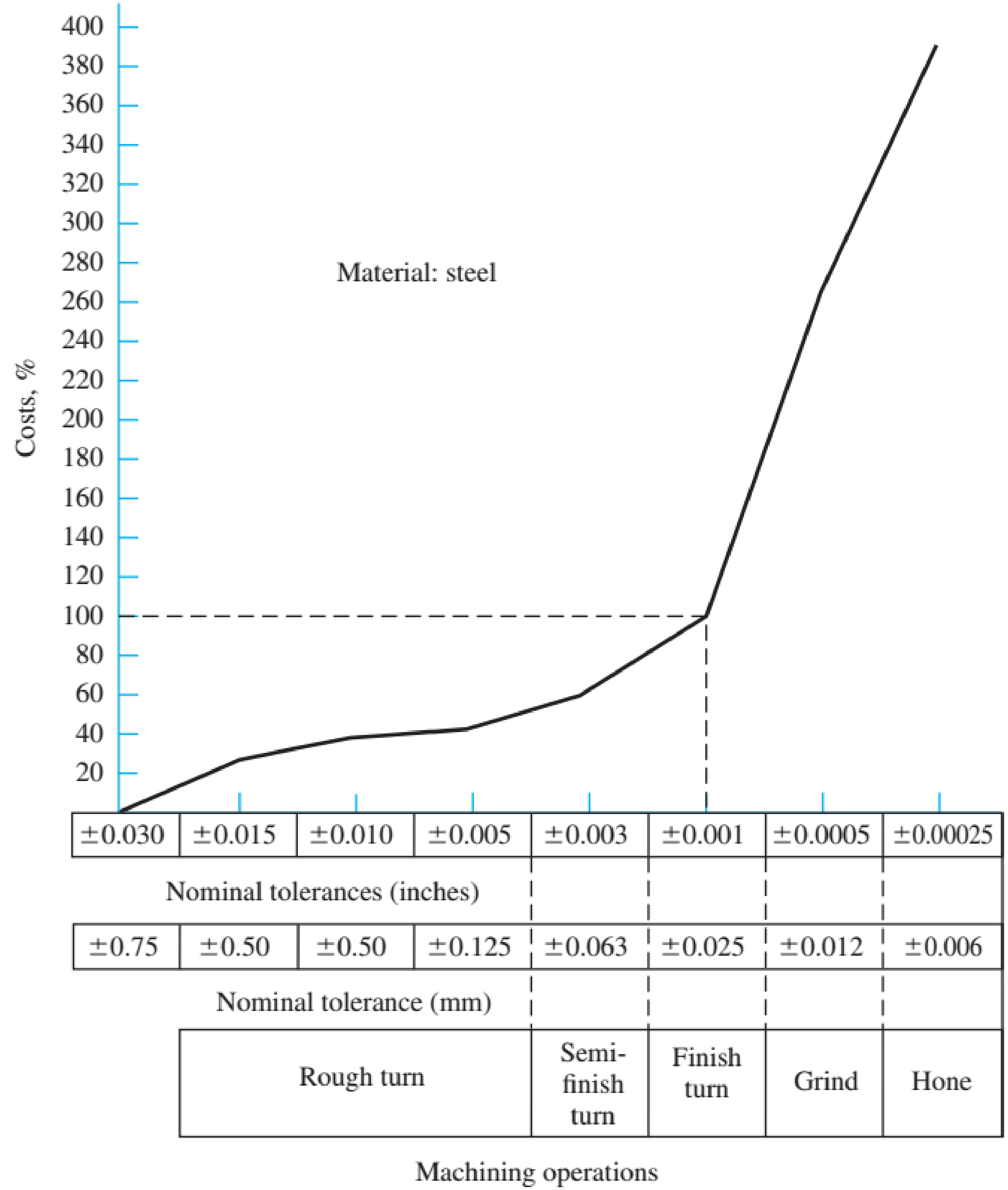
Tolerances

- Perhaps the most significant effects on cost among design specifications
- **Close tolerances** => additional steps in processing and inspection, or impractical to produce
- **Large tolerances** => higher production rates with significantly lower cost, less rejection rates and easier assembly

But why iPhone is still so expensive?

- *The changing roles of tolerances, manufacturing process, surface finish for consumer electronics.*

AncoraSIR.com



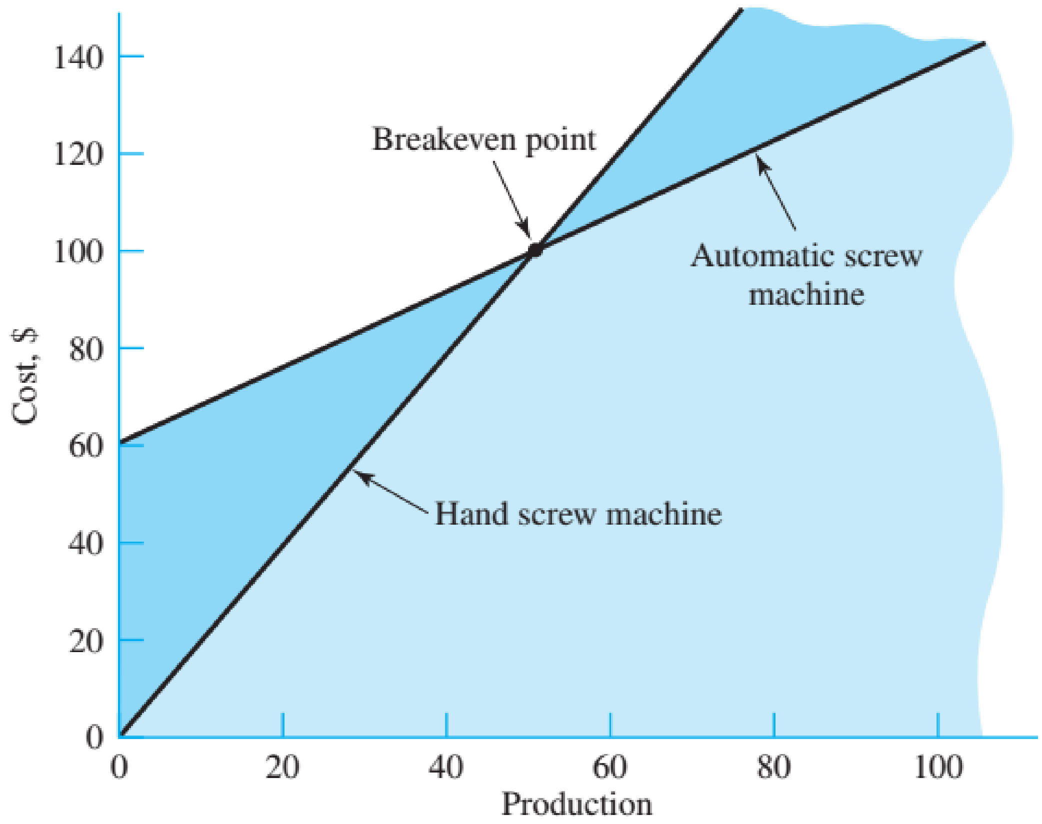
When reality meets your design …

Breakeven point & Cost estimates

i.e. when machines replace manual labor

But how would I know the actual cost of a specific design?

- Scenario specific comparison is more useful
  - Moore's law
  - # of parts
  - Cost by weight, area, volume, horsepower, toque, speed, etc.
- Various metrics can be used to establish a comparison
- Product Design and Development

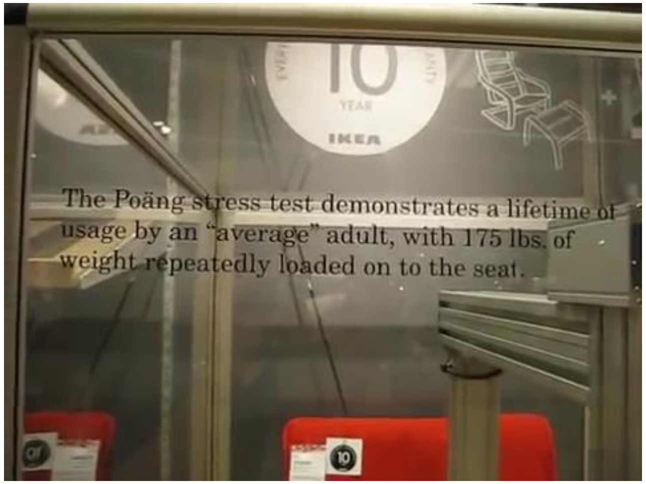


AncoraSIR.com

Safety & Product Liability

Careful review to eliminate excessive promises with adequate warnings and instruction of use

- Strict Liability (applicable for US engineers)
  - The manufacturer of an article is liable for any damage or harm that results because of a defect.
  - No mater if the manufacturer knew about the defect
  - Or could have known about it
- Best approach to prevention
  - Good engineering in **analysis and design**, **quality control**, and **comprehensive testing**



https://www.youtube.com/watch?v=FVAOl334s5k

https://www.youtube.com/watch?v=kP9PZYjVwUo

AncoraSIR.com

http://www.scmp.com/news/world/united-states-canada/article/1982934/ikea-recalls-millions-malm-dressers-us-and-canada

IKEA Chests of Drawers/Dressers

IKEA chests and dressers in the chart below, in addition to the MALM 3-, 4-, 5- and 6-drawer units, that were manufactured before June 2016 are subject to recall. To determine whether your unit was manufactured before June 2016, check the product label on the inside of the top or side frame of the unit for a date code lower than "1622":

Product Label:

https://www.ikea.com/ms/en_US/pdf/non_malm_CoD_list.pdf

FAMILY NAME	MODEL
ALESUND	4-drawers
ALVESTA	5-drawers
ANEBODA	3-drawers, 5-drawers
ANGUS	chest of drawers
ÅNES	4-drawers
ARUP	4-drawers, 6-drawers
ASKEDAL	4-drawers, 6-drawers
ASKVOLL	5-drawers
ASPELUND	2-drawers, 3-drawers, 4-drawers
BALSTAR	6-drawers, 10-drawers
BANKERYD	3-drawers, 5-drawers
BERGSMO	8-drawers
BIALITT	3-drawers, 6-drawers
BIRKELAND	3-drawers, 6-drawers
BJÖRKVALLA	5-drawers, 6-drawers
BJÖRN	4-drawers, 6-drawers, 8-drawers
BLIMP	chest of drawers
BOJ	chest of drawers
BOKSTA	6-drawers

FAMILY NAME	MODEL
BRETT	3-drawers
BRIMNES	2-drawers, 3-drawers, 4-drawers
BRUSALI	3-drawers, 4-drawers
BUSUNGE	2-drawers
DIKTAD	changing table/chest of drawers
EDLAND	2-drawers, 3-drawers, 5-drawers, 6-drawers
ELIS	chest of drawers
ENGAN	2-drawers/2-door, 4-drawers
ESKIL	5-drawers
FJELL	4-drawers
FJORD	3-drawers, 5-drawers, 6-drawers, 7-drawers, 8-drawers
FLATEN	3-drawers, 5-drawers, 6-drawers, 7-drawers
FRIDOLIN	7-drawers, 11-drawers
GUTE	4-drawers, 6-drawers, 8-drawers, 10-drawers
GRANAS	4-drawers, 6-drawers
HADDAL	3-drawers, 4 drawers
HAJDEBY	chest of drawers
HEMNES	2-drawers/1 shelf, 3-drawers, 5-drawers, 6-drawers stained pine, mirror chest
HENSVIK	3-drawers
HERRESTAD	4 drawers
HOPEN	4-drawers, 6-drawers, 8-drawers
HOSTELAND	4-drawers, 6-drawers
HOLLEBY	chest of drawers
HOVDA	double chest
HURDAL	3-drawers, 5-drawers (22 inches wide)
KABIN	4 drawers, 6 drawers, 8 drawers
KIRKENES	5 drawers
KNOT	3-drawers
KOPPANG	3-drawers
KUSK	3-drawers
KULLEN	5-drawers
KURS	3-drawers, 4-drawers, 6 drawers
KVIBY	4-drawers
LEKSVIK	2-drawers, 4-drawers, 5-drawers, 6-drawers, 7-drawers
LO	3-drawers
LOMEN	3-drawers, 2 drawers/2 door chest
MAC	5-drawers 6-drawers 8-drawers
MAST	6-drawers
MAMMUT	3-drawers, 4-drawers, chest of drawers
MANDAL	3-drawers, 4-drawers, 6-drawers
MERÅKER	4-drawers, 7-drawers
MIDSUND	5-drawers

FAMILY NAME	MODEL
NATURA	4-drawers, 5-drawers
NARVIK	3-drawers chest, changing table/chest of drawers, 5 drawers, 6-drawers
NORDLI	3-drawers, 4-drawers (15,7 inches wide)
NORDNES	10-drawers
NORNÅS	4-drawers/2-compartments
NYVOLL	3-drawers, 6-drawers
OTTENBY	5-drawers
RANVIK	5-drawers
RAKKE	5-drawers
RAMBERG	3-drawers
RODD	3-drawers, 5-drawers
ROBIN	3-drawers, 8-drawers
RUSTIK	chest of drawers
SALA	3-drawers
SANDEFJORD	5-drawers
STOCKHOLM	4-drawers
STRANDA	4-drawers
STUVA	chest of drawers
SUNDVIK	changing table/chest of drawers
SVEIO	5-drawers
STAVANGER	5-drawers
SYDVAST	3-drawers, 6-drawers, 7-drawers
TARVA	3-drawers, 5-drawers, 6-drawers
TASSA	3-drawers
TRANDUM	3-drawers
TORE	chest of drawers
TOVIK	3-drawers
TRANDUM	6-drawers
TROGEN	3-drawers, chest of drawers
TROFAST	chest of drawers
TRONDHEIM	3-drawers, 4-drawers, 6-drawers
TRYSIL	3-drawers
TYSSEDAL	4-drawers, 6-drawers
UNDREDAL	4-drawers
VARDE	6-drawers
VALLVIK	3-drawers, 6-drawers
VAJER	4-drawers, 6-drawers
VESTBY	chest of drawers
VINSTRA	3-drawers, 6-drawers
VISDALEN	7-drawers, 6-drawers
VOLLEN	3-drawers

AncoraSIR.com

Design Factor & Factor of Safety

The Classical Method of Design

- The Design Factor
  - All loss-of-function modes must be analyzed
  - The mode leading to the smallest design factor governs
  - The Design Factor may change after a design is completed
    - Rounding up to a standard size for a cross section
    - Using off-the-shelf components with higher ratings instead of calculated

$$n_d = \frac{\text{loss-of-function parameter}}{\text{maximum allowable parameter}}$$

- The Factor of Design, *n*
  - Same definitions but generally differ numerically

How to know better?
Test, test, test, …

- More practical expression of design factor
  - Stress may not vary linearly with load, making it a better choice

$$n_d = \frac{\text{loss-of-function strength}}{\text{allowable stress}} = \frac{S}{\sigma\,(\text{or } \tau)}$$

AncoraSIR.com

Reliability & Probability of Failure

The Reliability Method of Design

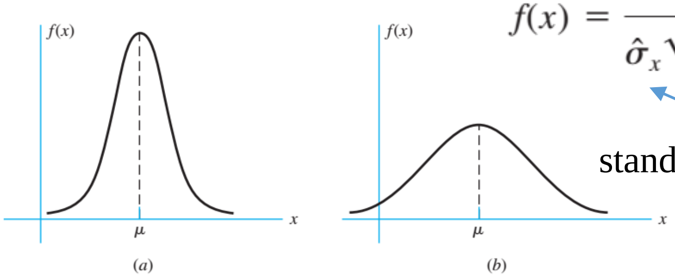
- **Designer's Task**: To make a judicious selection of materials, processes, geometry so as to achieve a specific reliability goal, i.e. $R = 0.99$

R=0.99 means that there is a 99% chance that the part will perform its proper function without failure.

- **Reliability**: $R = 1 - p_f$
  - The statistical measure of the probability that a mechanical element will not fail in use
- **Probability of Failure**: p_f
  - Probability Density Function: the distribution of events within a given range of values.
    - Gaussian (normal) distribution: generally applicable
    - Weibull distribution: widely used in rolling-contact bearing design

Design Engineers usually look up the table for quick calculations

Small SD vs. Large SD



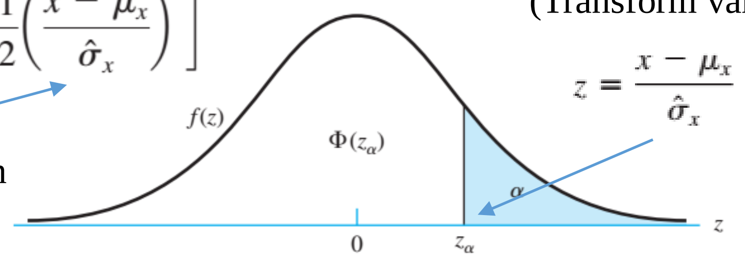
$$f(x) = \frac{1}{\hat{\sigma}_x\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu_x}{\hat{\sigma}_x}\right)^2\right]$$

mean

standard deviation

(Transform variant)

$$z = \frac{x-\mu_x}{\hat{\sigma}_x}$$



Transformed normal distribution (mean = 0, SD = 1)

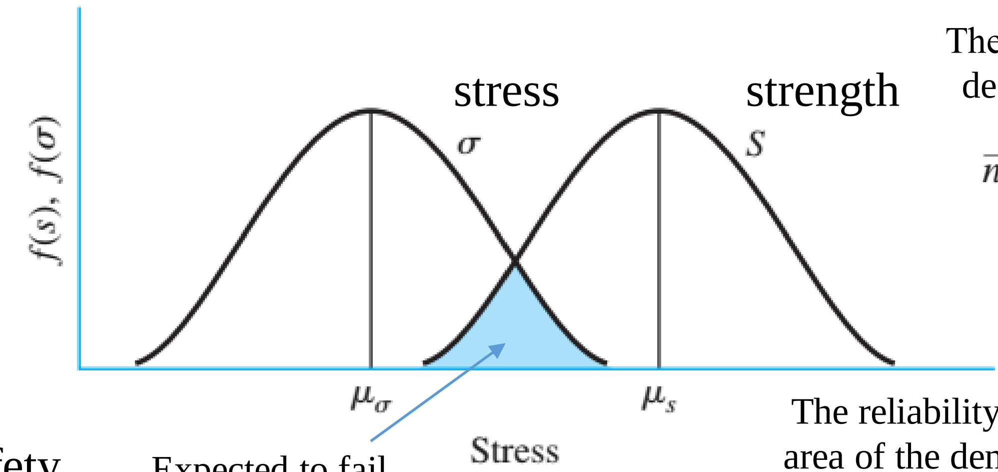
AncoraSIR.com

SUSTech Southern University of Science and Technology

Relating Design Factor to Reliability

Design Factor (S) => Reliability (R)

Distribution of stress and strength



The "average" design factor

$$\bar{n}_d = \frac{\mu_S}{\mu_\sigma}$$

Margin of safety

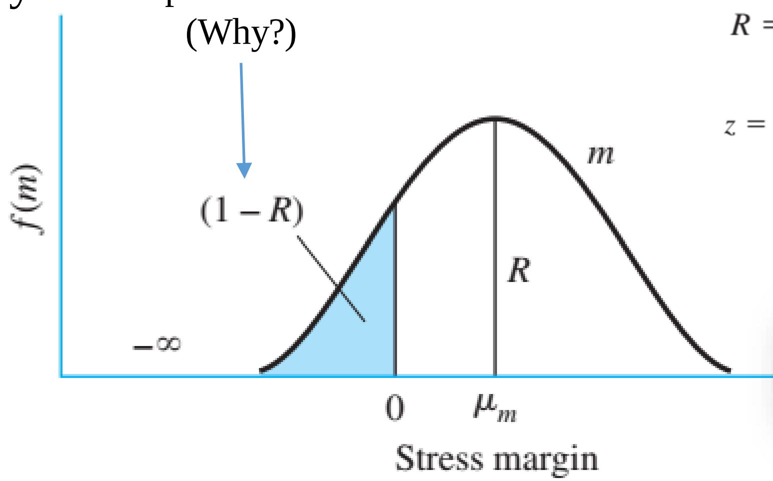
$$m = S - \sigma$$

Average margin of safety

$$\bar{m} = \mu_S - \mu_\sigma$$

Expected to fail (Why?)

Distribution of interference



The reliability R (will not fail) is the area of the density function for $m > 0$

$$R = p(S > \sigma) = p(S - \sigma > 0) = p(m > 0)$$

$$z = \frac{m - \mu_m}{\hat{\sigma}_m} = \frac{0 - \mu_m}{\hat{\sigma}_m} = -\frac{\mu_m}{\hat{\sigma}_m} = -\frac{\mu_S - \mu_\sigma}{(\hat{\sigma}_S^2 + \hat{\sigma}_\sigma^2)^{1/2}}$$

Some derivations and table loop-up (no need to memorize)

$$\bar{n}_d = \frac{1 \pm \sqrt{1 - (1 - z^2C_S^2)(1 - z^2C_\sigma^2)}}{1 - z^2C_S^2}$$

+: $R > 0.5$ -: $R < 0.5$

AncoraSIR.com

SUSTech Southern University of Science and Technology

Design Requirements vs. Design Specifications

Customer Needs vs. Engineering Designs

Design Requirements

Power to be delivered: 20 hp
Input speed: 1750 rev/min
Output speed: 85 rev/min
Targeted for uniformly loaded applications, such as conveyor belts, blowers, and generators
Output shaft and input shaft in-line
Base mounted with 4 bolts
Continuous operation
6-year life, with 8 hours/day, 5 days/wk
Low maintenance
Competitive cost
Nominal operating conditions of industrialized locations
Input and output shafts standard size for typical couplings

Design Specifications

Power to be delivered: 20 hp
Power efficiency: >95%
Steady state input speed: 1750 rev/min
Maximum input speed: 2400 rev/min
Steady-state output speed: 82–88 rev/min
Usually low shock levels, occasional moderate shock
Input and output shafts extend 4 in outside gearbox
Input and output shaft diameter tolerance: ±0.001 in
Input and output shafts in-line: concentricity ±0.005 in, alignment ±0.001 rad
Maximum allowable loads on input shaft: axial, 50 lbf; transverse, 100 lbf
Maximum allowable loads on output shaft: axial, 50 lbf; transverse, 500 lbf
Maximum gearbox size: 14-in × 14-in base, 22-in height
Base mounted with 4 bolts
Mounting orientation only with base on bottom
100% duty cycle

What "they" want …

- Some are very specific
- Some, maybe …
- Some are a bit vague

What "we" provide …

- Engineering limitations
- Design solutions
- Measurable performances

AncoraSIR.com

SUSTech
Southern University of Science and Technology

Next class

- **Lecture Topic**: Material & Process
- Friday 0800-1000
- Room 202, 1 Lychee Park

The Dear Customer made a request: *I want the "Sky Blue."*
A Design Engineer replied: *#00008B?*

Thank you!

Prof. Song Chaoyang

- Xiao Xiaochuan (xiaoxc@sustech.edu.cn)

SUSTech Southern University of Science and Technology

AncoraSIR.com