Chapter 1

Overview of Engineering Analysis
What is Engineering Analysis?

It is a vital TOOL for practicing engineering professionals in performing their duties:

- Creations
- Decision making
- Problem solving
Engineers create:

“Scientists DISCOVER what it was,
Engineers CREATE what it was not”

Engineers create “what it was not” in DESIGN to satisfy human needs:

Greatest Engineering Achievements of the 20th Century
as selected by the US Academy of Engineering

1. Electrification*
2. Automobile*
3. Airplane*
4. Water supply and distribution
5. Electronics
6. Radio and television
7. Agriculture mechanization*
   petrochemical
8. Computers
9. Telephone
10. Air conditioning and refrigeration*
11. Highways
12. Spacecraft*
13. Internet
14. Imaging
15. Household appliances*
16. Health technologies
17. Petroleum and
   petrochemical technologies
18. Laser and fiber optics
19. Nuclear technology*
20. High performance materials

* With significant mechanical engineering involvements
Engineers make **DECISIONS** – often crucial ones:

**Decisions are required in:**

- **Design** – Configurations
  - Selection of design methodology, materials and fabrication methods
  - Assembly, packaging and shipping

- **Manufacturing** – Tools and machine tools
  - Fabrication processes
  - Quality control and assurance

- **Maintenance** – Routine inspections and Procedures

- **Unexpected cases with potential grave consequences** –
  - Change of customer requirements
  - Malfunctioning of machines and equipment
  - Defects in products

**Critical Decisions by Engineers** on what to do if **flaws** or **cracks** appear on the surfaces of:

- **Pressurized pipelines**
- **A jumbo jet airplane?**
Engineers solve **Problems** – often in ways like fire-fighting:

**Problems relating to:**

- Design ambiguity
- Manufacturing in disorder
- Malfunction of equipment
- Inferior quality in production
- Run-away cost control
- Resolving customer complaints and grievances
- Public grievances and mistrust
All **TASKS** relating to:

- Creation
- Decision making
- Problems solving

are of **PHYSICAL nature**

The required **ANSWERS**
are of **PHYSICAL nature** too
Engineering Problems (Physical)

Engineering Analysis

Mathematical Formulation

Mathematical Analysis

Mathematical Solutions

Translation Math to Physical Situation

Solution to Engineering Problems (Physical)

Desirable direct approach

Not Possible!

Unavoidable Approach

Math plays a principal role as a servant to Engineering (the Master) in engineering practices

Conclusion: Math plays a principal role as a servant to Engineering (the Master) in engineering practices

Translate engineering problems into math form by:
1) Idealizing physical situations.
2) Identifying idealized physical situation with available math representations
3) Formulate math models, e.g., expressions, equations.
Mathematical Modeling

It is a practice involving the translation of physical (engineering) situations into mathematical forms with:

- Empirical formulas
- Algebraic equations and formulas from textbooks and handbooks
- Differential and integral equations with appropriate conditions fit to the specific problems
- Numerical solutions, e.g., by finite element method (FEM) or finite difference method (FDM).

Many mathematical formulas and expressions are available in handbooks, e.g.:

The Four Stages in General Engineering Analysis

Stage 1: Identification of the physical problem – specification of the problem:
- Intended application
- Possible geometry and size (dimensions)
- Materials for all components
- Loading: range in normal and overloading; nature of loading
- Other constraints and conditions, e.g., space, cost, government regulations

Example: Design a coat hanger for hanging an overcoat up to 6 pounds
  - Given assumed geometry and dimensions:
  - Selected material: plastic with allowable tensile strength @ 500 psi from handbooks

Stage 2: Idealization of actual physical situations for subsequent mathematical analysis:
- On geometry
- On loading condition:
- P – uniform distributed load of the coat = 0.649 lb/in
- Rigidly held ends
The Four Stages in General Engineering Analysis-cont’d

Stage 3: Mathematical modeling and analysis:

Derive or search for suitable mathematical formulations to obtain solution on the specific engineering problem.

- In the case of coat hanger design, the solution required is:

  “Will the assumed geometry and size of the hanger withstand the specified maximum weight of the coat?” – a physical statement

- The required solution is to keep the maximum stress in coat hanger induced by the expected maximum load (the weight of the coat) **below** the allowable limit (the maximum tensile strength) of the hanger material (500 psi), as given

- With the “idealization” in Stage 2, the maximum stress in the hanger can be computed from the formula on “simple beam theory” available from “strength of materials” textbooks or a handbook for mechanical engineers

\[
\sigma_m = \frac{M_m C}{I}
\]

where \( M_m \)=max. bending moment, \( C \)=radius of frame rod, \( I \)=moment of inertia of the frame rod X-section=0.0001916 in\(^4\)

\[\sigma_m = 302 \text{ psi} \] (top surf. at ends)
The Four Stages in General Engineering Analysis- cont’d

Stage 4: Interpretation of results – a tricky task:

- Result from analysis in Stage 3 normally is in the form of NUMBERS
- Require ways to interpret these numbers into physical senses, e.g.
  “Can the coat hanger with the assumed geometry and dimensions carry a 15-lb coat?”
- Various ways available for such translation

For the case of structure-related design problems, one would use the following criterion:

\[
\text{The max. stress, } \sigma_m < \sigma_a
\]

where \( \sigma_a \) = allowable stress = Maximum tensile strength/Safety Factor (SF)

- The SF in an analysis relates to “the extent engineers can make use of the strength of the material”
- There are a number of factors determining the SF in a structure design;
  - The degree of sophistication of the analysis – the less “idealization” made in Stage 2 → the low the value of SF, i.e., less material is needed
- The potential consequence of the

For the case of coat hanger design, the \( \sigma_m = 302 \text{ psi} < \sigma_a = 500 \text{ psi} \) with SF = 1. Physically, it means the coat hanger with the assumed geometry and dimensions CAN carry a 6-pound coat. If not, Engineer will either adjust the assumed dimensions of the hanger, or reduce the weight of garment for the hanger to carry.
1. Read the Example on Application of Engineering Analysis on a bridge on P. 7.

2. Conduct an engineering analysis on the above example but include the weights of the steel structure and the required concrete road surface for the bridge. Remind you that you do not always have the information and conditions given in your design analyses. You, as an engineer, needs to make reasonable and logical assumptions on these missing information based on available reference “tools” available to you.

3. Be prepared to answer the question on the significance of “Safety Factor” used in a design analysis of a structure or machine component. What are the fundamental principles for determining the numerical value of this factor? Explain why a SF = 4 is used in pressure vessel design by ASME design code, yet SF = 1.2 is used in aircraft structure design.

4. Be prepared to offer example of engineers making decisions and solve problems based on your personal experience.