San Jose State University
Department of Mechanical and Aerospace Engineering

ME 130 Applied Engineering Analysis

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Chapter 1

Overview of Engineering Analysis
What is Engineering Analysis?

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

**Creations**

**Decision making**

**Problem solving**
Engineers **create:**

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

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

<table>
<thead>
<tr>
<th>Greatest Engineering Achievements of the 20th Century</th>
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<tr>
<td>as selected by the US Academy of Engineering</td>
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<tr>
<td>1. Electrification*</td>
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<td>2. Automobile*</td>
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<td>3. Airplane*</td>
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<tr>
<td>4. Water supply and distribution</td>
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<tr>
<td>5. Electronics</td>
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<tr>
<td>6. Radio and television</td>
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<td>7. Agriculture mechanization*</td>
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<td>8. Computers</td>
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<td>9. Telephone</td>
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<td>10. Air conditioning and refrigeration*</td>
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<td>11. Highways</td>
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<td>12. Spacecraft*</td>
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<td>13. Internet</td>
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<tr>
<td>14. Imaging</td>
</tr>
<tr>
<td>15. Household appliances*</td>
</tr>
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<td>16. Health technologies</td>
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<td>17. Petroleum and petrochemical technologies</td>
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<tr>
<td>18. Laser and fiber optics</td>
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<tr>
<td>19. Nuclear technology*</td>
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<tr>
<td>20. High performance materials</td>
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* With significant mechanical engineering involvements
Engineers make **DECISIONS** – at all times, and 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 fault and ambiguity
- Manufacturing 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
Translate engineering problems into \textit{math form} by:

1) Idealizing physical situations.
2) Identifying idealized physical situation with available math representations
3) Formulate math models, e.g., expressions, equations.

\textbf{Conclusion:} Math plays a principal role as a servant to Engineering (the Master) in engineering practices.
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

Engineers are expected to perform “Engineering analysis” on a variety of different cases in their careers. There is no set rules or procedure to follow for such analyses.

Below are the 4 stages that one may follow in his (her) engineering analysis.

**Stage 1: Identification of the physical problem** – specification of the problem:
- To ensure knowing what the analysis is for on:
  - Intended application(s)
  - 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

**Stage 2: Idealization of actual physical situations for subsequent mathematical analysis:**
- Often, the engineer needs to make assumptions and hypotheses on the physical conditions of the problem, so that he (she) can handle the analysis by his (her) capability with the “tools” available to him or her.

**Stage 3: Mathematical modeling and analysis:** by whatever means he (she) believes applicable, e.g., solution methods from handbooks, computer software, company handbooks or own derived formula and equations, including differential equations, etc..

**Stage 4: Interpretation of results** – a tricky but important task.
- To translate the results of math modeling with numbers, charts, graphs to physical sense applicable to the problem on hands.
Example on a Simple Engineering Analysis Involving the Four Stages in General Engineering Analysis

Stage 1: The problem:
To design a coat hanger that will have sufficient strength to hang up to 6 pounds for an overcoat.
A design synthesis resulted in the following conditions:
- Geometry and dimensions as shown:
- Material: plastic with allowable tensile strength @ 500 psi from a materials handbook

Stage 2: Idealization of actual physical situations for subsequent mathematical modeling and analysis:
This is a “beam bending” problem. The solution on the strength of the hanger appears available in “mechanics of materials.” But the required geometry shown above is too complicated to be handled by available formula in textbooks or design handbooks.
Need to make the following idealizations in order to use available formula in the analysis:

- On geometry:
- On loading condition:
- On boundary (end) conditions: $P$ - uniform distributed load of the coat = 0.3243 lb/in

$\frac{1}{4}$" dia rods

Rigidly held ends (how realistic is this?)
**Stage 3:** Mathematical modeling and analysis:
Derive or search for suitable mathematical formulations to obtain solution on the specific engineering problem.

- In this 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 up to 6 lbs?” – 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) **BETWEEN** the allowable limit (the maximum tensile strength) of the hanger material (500 psi), as given (another physical statement)

- With the “idealization” in Stage 2, the maximum stress in the hanger can be computed from the formula on “simple beam theory” available from “mechanics of materials” (e.g., CE 112) textbook or a handbook for mechanical engineers

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

where \( M_m = \text{max. bending moment} \), \( C = \text{radius of frame rod} \), \( I = \text{area moment of inertia of the frame rod} \)

**Case of coat hanger**

Distributed load, \( P \)

23.23°

**Available case in textbook**

Distributed load, \( PCos(23.23^\circ) = 0.298 \text{ lb/in} \)

Maximum stress, \( \sigma_m = \frac{M_m C}{I} \)

9.25”
Results of Stage 3 analysis:

We may compute the following:

The area moment of inertia of the frame rod, \( I = \frac{\pi d^4}{64} = 1.9165 \times 10^{-4}\ \text{in}^4 \)

The maximum bending moment, \( M_m = \frac{p\ell^2}{8} = \frac{0.298x(9.25)^2}{8} = 3.1872\ \text{lb} - \text{in} \)

The radius of the frame rod, \( C = 0.125'' \)

The maximum bending stress, \( \sigma_m = \frac{3.1872 \times 0.125}{1.9165 \times 10^{-4}} = 2078.8\ \text{psi} \)

occurs at both ends of the frame rod.
Stage 4: Interpretation of results – a tricky but very important task:

- Result from analysis in Stage 3 normally is in the form of NUMBERS, such as $\sigma_m = 2078.8$ psi as in the present case of a coat hanger design.
- Require ways to interpret these numbers into physical senses, e.g. in the current case: “Can the coat hanger with the assumed geometry and dimensions carry a 6-lb coat?”

- There are VARIOUS ways available for such translation:

  A) For the case of structure-related design ONLY, one would use the following criterion:

      The max. stress, $\sigma_m < \sigma_a$

      where $\sigma_a =$ allowable stress = Maximum tensile strength from handbooks/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 value of SF is set by designers based on the degree of sophistication of the analysis – the less “idealization” made in Stage 2: e.g., low value of SF for more sophisticated analyses with fewer idealization and assumptions made in the analysis. Physically it means less material is needed
- The value of SF also relates to possible potential consequence of the case in the analysis

For the case of coat hanger design, the $\sigma_m = 2078$ psi $> \sigma_a = 500$ psi with SF = 1. Physically, it means the coat hanger with the set geometry and dimensions CANNOT carry a 6-pound coat. The engineer will either adjust the assumed dimensions of the hanger, or reduce the weight of garment for the hanger to carry, following the following general design procedure.
B) Stage 4 Interpretation of Results in **GENERAL** – General procedure in engineering design

**Stage 1:** Understand the physical problem

**Stage 2:** Idealization for math modeling

**Stage 3:** Math modeling & analysis

**Stage 4:** Interpretation of results
No safety factors are involved
Chapter-End Assignment

1. Read the Example on Application of Engineering Analysis on a bridge on P. 9.

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.