PHY 115

Professionalism in Science

Analysis Methodology
Engineering Analysis is the process of acquiring an analytical solution to an engineering problem using mathematics and principles from science. Newton's laws of motion or Kepler's laws of planetary motion are examples of well established scientific principles used to solve engineering problems.

The process may involve both hand and computer computations. The process can be regarded as a type of modeling or simulation. It is very important that the process be very systematic.

The engineering method can be thought of as a systematic process by which problems are solved for the betterment of society.

Just as dimensions and units play an important role in the calculations for an analysis, so to does the way in which the calculations are done.

### Numerical Calculations

Approximations or "back of the envelope" calculations are performed with an order of magnitude. This means with powers of 10.

- order 1 $\equiv 10^1$
- order 2 $\equiv 10^2$
- order 3 $\equiv 10^3$
  
Example

Approximate the air exchange flow rate for each of twelve ventilation fans in a 200’ × 150’ × 20’ warehouse. There is to be a complete air exchange twice an hour.

$$Q_T \approx (10^2 \text{ ft})(10^2 \text{ ft})(10 \text{ ft}) \left( \frac{2 \text{ changes}}{\text{hr}} \right)$$

$$Q_T \approx 2(10^5) \frac{\text{ft}^3}{\text{hr}}$$

$$Q = \frac{Q_T}{N} \Rightarrow$$
When performing calculations, there are two closely related concepts that must be considered; precision and accuracy.

Precision refers to the number of decimal places carried out in a calculation or measurement. It is usually given in fractions of a unit, i.e. it is precise to $\frac{1}{1000}$ of a unit.

Accuracy is determined by the number of digits used in measurements and calculations. A calculation can only be considered as accurate as the value with the fewest digits.

The common rule in engineering is to report answers back with three to four significant digits.

Numbers reported to four significant digits.

- 8.936
- 456.0
- 0.2575
- 14.06
- 5.007

2500.0 ← the extra 0
is used to keep track of the decimal point

Scientific notation is often used for very large and very small numbers. The 2500.0 from above would be better represented as $2.500 \times 10^3$. 

$$Q \approx \frac{2(10^5)}{10} \frac{ft^3}{hr} = 2(10^4) \frac{ft^3}{hr}$$

Actual answer

$$\frac{200(150)(20)(2)}{12} = 1(10^5) \frac{ft^3}{hr}$$
Numbers reported to four significant digits using scientific notation.

\begin{align*}
8640000 &= 8.640 \times 10^6 \\
36352000000 &= 3.635 \times 10^{10} \\
0.00000023456 &= 2.346 \times 10^{-7}
\end{align*}

Engineering notation is a variation on scientific notation where the power of tens are multiples of three.

Numbers reported to four significant digits using engineering notation.

\begin{align*}
8640000 &= 8.640 \times 10^6 \\
36352000000 &= 36.35 \times 10^9 \\
0.00000023456 &= 234.6 \times 10^{-9}
\end{align*}

**Example**

Calculate the weight of a 25 kg mass.

\[
W = m \times g \\
W = 25(9.81) = 245.25 = 245
\]

The above calculation assumes that the 25 is an exact value. If the 25 is not exact the calculation would be:

\[
W = 25(9.81) = 245.25 = 250
\]

**Example**

Add the two forces, 875.4 N and 9.386 N.

\[
\begin{array}{c}
875.4 \ N \\
+ 9.386 \ N \\
884.8 \ N
\end{array}
\]

You can set your calculator display to scientific or engineering notation.
Analysis Procedure

Problem analysis can be organized into seven steps.

1) Problem statement
2) Diagram(s)
3) Assumptions
4) Equations
5) Calculations
6) Check of solution
7) Discussion

Typical student analyses consist of five steps.

1) Problem statement
2) Diagram(s)
3) Given/Find statements
4) Work
5) Check of solution

Example of an analysis

A 200-kg crate is suspended by ropes as shown.
Find the tension in ropes AB and AC.

Assumptions
1. Forces in ropes AB, AC and AD are concurrent at A.
2. Neglect mass of ropes.

Governing Equations (Equations of Equilibrium)
ΣFx = 0 = Tb cos(30°) - Tc  \hspace{1cm} (1)
ΣFy = 0 = Tb sin(30°) - W  \hspace{1cm} (2)

Calculations
W = mg = (200kg)(9.81 m/s²) = 1962 N
Solving Eq. (2) for Tb and substituting into Eq. (1) to obtain Tc gives:
Tb = 3924 N = 3.92 kN, Tc = 3398 N = 3.40 kN

Solution Check (no errors found)

Discussion
As \theta increases, Tb increases and Tc decreases. When \theta = 90°, Tc = 0 (rope AC is slack) and Tb = W = 1962 N.
Computer as a Tool

To today's engineer, a personal computer (PC) is indispensable. The advantages of a PC includes:

- A PC is more accurate and efficient in performing calculations.
- A PC is quick.
- A PC provides more accurate number representation.

These same qualities are also true of mainframes (servers).

A PC (or mainframe) is used for:

- Computer Aided Design (CAD)
- Word Processing
- Communication
- Accessing Information
- Graphing
- Process Control
- Simulations
- Data Acquisition
- Analysis

Commonly used software includes:

- Spreadsheets (Excel)
- CAS/Solvers (MATLAB, Octave, MuPad, Maxima)
- Programming Languages (Fortran, VBA, C/C++)
- Specialty Software
- Finite Element Method (FEM) Solvers
Assignment 4

Engineering Methodology

1. Perform the following calculations, reporting the answers to the correct number of significant digits.

   a. \((8.14)(260)\)
   
   b. \(456/4.9\)
   
   c. \((6.74)(41.07)/(8.72)\)
   
   d. \((10.78 - 4.5)/(300)\)
   
   e. \((10.78 - 4.50)/(300.0)\)
   
   f. \((1.2 \times 10^6)/(4.52 \times 10^3 + 988)\)
   
   g. \(1000/(1.003 \times 10^9)\)
   
   h. \((8.4 \times 10^{-3})/(5000)\)

2. A 250-kg mass hangs by a cable from the ceiling. Using the standard value of gravity acceleration, \(g = 9.81 \text{ m/s}^2\), what is the tension in the cable? Express your answer to the correct number of significant digits.

3. A 9-slug mass hangs by a rope from the ceiling. Using the standard value of gravity acceleration, \(g = 32.2 \text{ ft/s}^2\), what is the tension in the rope? Express your answer to the correct number of significant digits.

4. A rectangular building lot is reported to have dimensions of \(250 \text{ ft} \times 320 \text{ ft}\). Using "back of the envelope" calculations, approximate the area of the lot. What is the actual area? Use the correct number of significant digits.

5. An excavation crew digs a hole in the ground measuring \(20 \text{ yd} \times 30 \text{ yd} \times 6 \text{ yd}\) to facilitate a basement for a small office building. Five dump trucks, each with a 20 yard \((20 \text{ yd}^3)\) capacity are available. Using "back of the envelope" calculations, approximate the number of loads each truck will haul. What will be the actual number of loads per truck?

6. Find the current in each resistor and the total current for the circuit shown. Refer to the example 4.2 for help.
Problem Statement
Two resistors with resistances of 5 kΩ and 50 Ω are connected in parallel across a 10 V battery. Find the current in each resistor.

Diagram (Electrical Schematic)

Assumptions
1. Neglect resistance of wires

Governing Equations (Ohm's Law)
\[ V = IR \]
\[ V = \text{Voltage (V)} \]
\[ I = \text{Current (A)} \]
\[ R = \text{Resistance (Ω)} \]

Calculations
Rearranging Ohm's Law: \[ I = \frac{V}{R} \]

Define \[ R_1 = 5 \, \Omega, \quad R_2 = 50 \, \Omega \]
Because resistors are connected in parallel with battery, \[ V = V_1 = V_2 = 10 \, V. \]

\[ \therefore \quad I_1 = \frac{V_1}{R_1} = \frac{10 \, V}{5 \, \Omega} = 2 \, A, \quad I_2 = \frac{V_2}{R_2} = \frac{10 \, V}{50 \, \Omega} = 0.2 \, A \]

Solution Check (no errors found)

Discussion
Current flow in a resistor is inversely proportional to the resistance.
Total current is split according to the ratio of resistances:

\[ \frac{I_1}{I_2} = \frac{R_2}{R_1} = \frac{50 \, \Omega}{5 \, \Omega} = 10 \]

Total current:
\[ I_T = I_1 + I_2 = 2 \, A + 0.2 \, A = 2.2 \, A \]
7. Long sheets of steel for manufacturing automobile body panels are tightly rolled up into a cylindrical package for easy handling. Consider a roll of steel with an inside and outside diameter of 45 cm and 1.6 m respectively, that is suspended by a single cable. If the length of the roll is 2.25 m and the density of the steel is \( \rho = 7850 \text{ kg/m}^3 \), what is the tension in the cable?

8. A portable classroom is heated with small propane heaters whose capacities are 3 kW each. The classroom is occupied by 24 students, each dissipating 120 W, and is lighted by 10 lights that dissipate 100 W each. If the heat loss from the classroom is 15 kW, how many heaters are needed to heat the portable classroom to 20° C? Refer to example 4.3.
Problem Statement

A classroom occupied by 50 students is to be air conditioned with window-mounted air conditioning units with a 4-kW rating. There are 20 fluorescent lights in the room, each rated at 60 W. While sitting at their desks, each student dissipates 100 W. If the heat transfer to the classroom through the roof, walls and windows is 5 kW, how many air conditioning units are required to maintain the classroom at a constant temperature of 22°C?

Diagram (Thermodynamic System)

Assumptions
1. Classroom is a closed system, i.e., no mass flows.
2. All heat flows are steady.
3. No other heat sources in classroom such as computers, TVs, etc.
Example 4.3

9. A man pushes a barrel with a force of $P = 80\text{ lb}$ as shown. Assuming the barrel does not move, what is the friction force between the barrel and floor? (Hint: the friction force acts parallel to the floor toward the man. Use trigonometry to find the force.)
10. The pressure exerted by a static liquid on a vertical submerged surface is calculated using the relation

\[ P = \rho g h \]

where,

- \( P \) = pressure (\( \text{Pa} \))
- \( \rho \) = density of the liquid (\( \text{kg/m}^3 \))
- \( g \) = gravitational acceleration = 9.81 \( \text{m/s}^2 \)
- \( h \) = height of the submerged vertical surface (depth of water)

Refer to the drawing and find the pressure at a depth of 2 m, 6 m, and 20 m.