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SEMM 1921
INTRODUCTION TO MECHANICAL ENGINEERING

PROBLEM SOLVING SKILLS

1.3 Problem Solving Skills

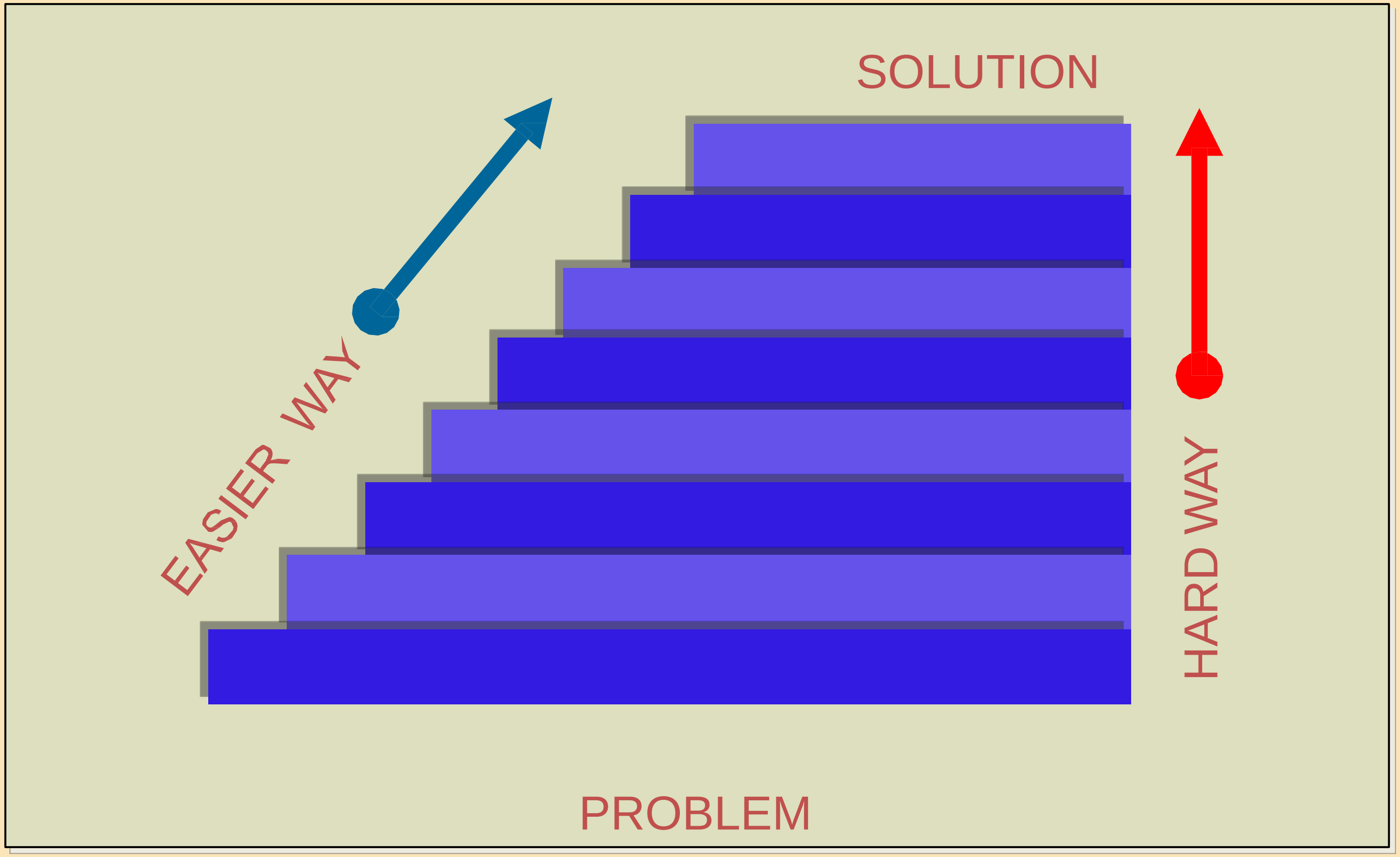
- 1.3.1 Why Problem Solving is Important?
  - Engineers by definition are problem solvers
  - Whether they are involved in analytical, experimental, computational or design work, engineers solve problems
  - In professional practice, engineers commonly solve problems that are highly complex and open-ended
  - Good engineering requires high-level thinking

1.3 Problem Solving Skills

- 1.3.1 Why Problem Solving is Important?
  - Professor Woods and his colleagues at McMaster University define problem solving as:
    - "Problem solving is the process of obtaining a satisfactory solution to a novel problem, or at least a problem which the problem solver has not seen before.“
  - Real world problems tend to be quite different than most exercises found in engineering textbooks
  - Many studies have found that engineering graduates, even though they solve more than 2,500 exercises in their undergraduate work, lack the essential problem solving skills needed to tackle real world problems

1.3 Problem Solving Skills

- 1.3.2 Problem Approach



1.3 Problem Solving Skills

- 1.3.2 Problem Solving Approach
  - Wood's Method [2,3]

STEPS	DESCRIPTION
0. Engage/Motivation	I can do it! I want to do it!
1. Define the Problem	✓ Define what the problem states ✓ Sketch the problem (if appropriate) ✓ Determine the given information ✓ Determine constraints ✓ Define criterion for judging final product
2. Explore the problem	✓ Determine the real objective of the problem ✓ Examine issues involved ✓ Make reasonable assumptions ✓ Guess/estimate the answer

1.3 Problem Solving Skills

- 1.3.2 Problem Solving Approach
  - Wood's Method

STEPS	DESCRIPTION
3. Plan the solution	✓ Develop a plan to solve the problem ✓ Map out sub-problems ✓ Select appropriate theory, principles, approach ✓ Determine info that needs to be found
4. Implement the plan	✓ Take actions ✓ Do calculations and analysis
5. Check the solution	✓ Units and accuracy
6. Evaluate/Reflect	✓ Is it reasonable? Does it make sense? ✓ Were the assumptions appropriate? ✓ How does it compare to initial guess/estimate? ✓ If appropriate, ask the question: is it socially / ethically acceptable?

1.3 Problem Solving Skills

- 1.3.2 Problem Solving Approach
  - Wales's Method – Professional Decision Making Process [4,5]

STEPS	DESCRIPTION
1. Affirmation	✓ Make statement(s) that promote effective psychological management
2. Define the situation	✓ Ask questions and gather appropriate information with an intent of clarifying, interpreting, and understanding the situation
3. State the goal	✓ Determine the appropriate or best goal or combination of goals. ✓ The goal should be concrete ✓ The goal should be presented with enough specificity so different people would agree when the goal is reached

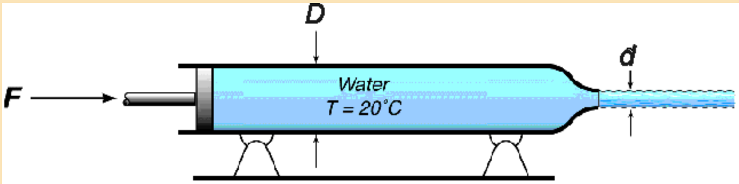
1.3 Problem Solving Skills

- 1.3.2 Problem Solving Approach
  - Wales's Method – Professional Decision Making Process

STEPS	DESCRIPTION
4. Generate Ideas	✓ Generate many possible ways to reach the goal ✓ Analyze these ideas, and then select the best idea or combination of ideas
5. Prepare a plan	✓ Carefully plan the steps needed to make the best idea a reality
6. Take action	✓ Implement the plan
7. Review & Reflect	✓ Check the solution to assess quality. ✓ Analyze the problem solving approach in order to identify what worked and what did not work ✓ Seek ways to refine or improve one's problem solving approach ✓ Clarify what was learned during the complete experience.

1.3 Problem Solving Skills

- 1.3.2 Problem Solving Approach
  - Professional Decision Making Process : An Example [4]
    - ***5.52 Water is forced out of this nozzle by a piston moving at a speed of 5*** *m/s. Determine the force F required to move the piston and the speed of efflux of water from the nozzle. Neglect friction on the piston and assume irrotational flow. The exit pressure is atmospheric; D = 6 cm and d = 2 cm.*



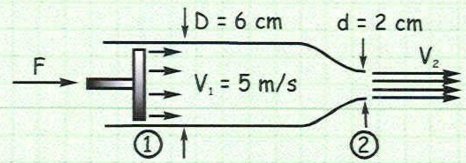
Problem 5.52; from Crowe et al. (2001)

CROWE: 5.52 | JJS 11/15/00 | 1/1

AFFIRM

I will practice skills that lead to excellence in professional practice!

DEFINE THE SITUATION



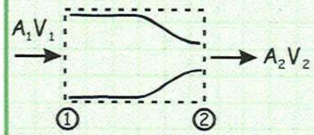
Piston forces H_2O out of nozzle
* Bernoulli eqn. applies
* p_2 = 0 kPa-gage
* T = 20 °C
* Assume steady flow
* Neglect friction on piston

GOAL

F (N) <== Force to move piston
V_2 (m/s) <== Speed of jet

GENERATE IDEAS

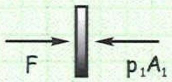
1. Conservation of Mass



2. Bernoulli Eqn.

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} = \frac{p_2}{\rho}$$

3. Equilibrium



PLAN

G	E	N	I
F	$F = p_1A_1$	~~p_1~~	$A_1 = \pi \bullet 0.03^2$ m
p_1	$\frac{p_1}{\rho} + \frac{V_1^2}{2} = \frac{p_2}{\rho} + \frac{V_2^2}{2}$	~~V_2~~	$\rho = 1000$ kg/m^3, $V_1 = 5$ m/s, $p_2 = 0$
V_2	$V_2 = V_1 \left(D/d\right)^2$	none	$D/d = 3$

ACTION

1. $V_2 = \left(\frac{5\text{m}}{\text{s}}\right)(9) = \underline{\underline{45\text{ m/s}}}$

2. $p_1 = \rho\frac{(V_1^2 - V_2^2)}{2} = \left(\frac{1000\text{kg}}{\text{m}^3}\right)\left(\frac{45^2 - 5^2\ \text{m}^2}{\text{s}^2}\right)\left(\frac{\text{Pa} \bullet \text{m} \bullet \text{s}^2}{\text{kg}}\right) = 998\text{ kPa}$

3. $F = p_1A_1 = \left(\frac{998\text{ kN}}{\text{m}^2}\right)\left(\frac{\pi \bullet 0.06^2\text{ m}^2}{4}\right) = \underline{\underline{2.82\text{ kN}}}$

REVIEW

1. p_1 is about 10 atm; make sure pipe material is strong
   Force on piston is about 600 lbf
2. GENI worked well; next time double check problem statement
3. Jet speed about 90 mph--is this a safety issue ??
4. REMEMEBER--Contracting flow ==> good use of Bernoulli eqn.

UNIT SYSTEMS AND CONVERSIONS

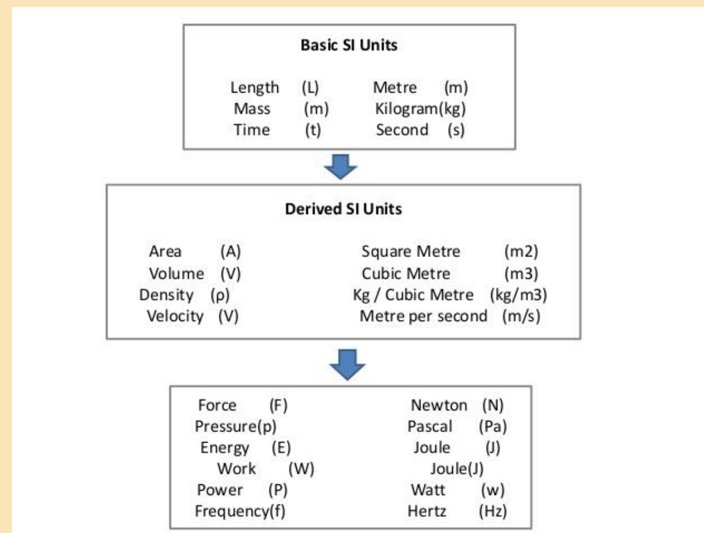
Engineers specify physical quantities in two different—but conventional—systems of units:

1) United States Customary System (USCS)
2) International System of Units (Systeme International d'Unites or SI).

Practicing mechanical engineers must be conversant with both systems. They need to convert quantities from one system to the other, and they must be able to perform calculations equally well in either system.

Typical Mechanical Properties of Carbon–Carbon Matrix Composites

Property	Units	C–C	Steel	Aluminum
System of units: USCS				
Specific gravity	—	1.68	7.8	2.6
Young's modulus	Msi	1.95	30	10
Ultimate tensile strength	ksi	5.180	94	40
Coefficient of thermal expansion	μin./in./°F	1.11	6.5	12.8
System of units: SI				
Specific gravity	—	1.68	7.8	2.6
Young's modulus	GPa	13.5	206.8	68.95
Ultimate strength	MPa	35.7	648.1	234.4
Coefficient of thermal expansion	μm/m/°C	2.0	11.7	23



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To Convert from U.S. Units, to SI Units, Multiply by	U.S. Unit	SI Unit	To Convert from SI Units to U.S. Units, Multiply by
25.4	in.	mm	0.03937
0.3048	ft	m	3.281
645.2	$in.^2$	mm^2	1.550×10^{-3}
16.39×10^3	in^3	mm^3	61.02×10^{-6}
416.2×10^3	$in.^4$	mm^4	2.403×10^{-6}
0.09290	ft^2	m^2	10.76
0.02832	ft^3	m^3	35.31
0.4536	lb (mass)	kg	2.205
4.448	lb (force)	N	0.2248
4.448	kip (force)	kN	0.2248
1.356	ft-lb (moment)	N-m	0.7376
1.356	kip-ft (moment)	kN-m	0.7376
16.0185	lb/ft^3 (density)	kg/m^3	0.06243
14.59	lb/ft (load)	N/m	0.06853
14.59	kip/ft (load)	kN/m	0.06853
6.895	psi (stress)	kPa	0.1450
6.895	ksi (stress)	MPa	0.1450
0.04788	psf (load or pressure)	kPa	20.93
47.88	ksf (load or pressure)	kPa	0.02093
$0.566 \times (^0F - 32)$	^0F	^0C	$(1.8 \times {^0C}) + 32$

EXAMPLE 2.3-1. Conversion between Systems of Units

Convert 23 $lb_m \cdot ft/min^2$ to its equivalent in $kg \cdot cm/s^2$.

Solution

As before, begin by writing the dimensional equation, fill in the units of conversion factors (new/old) and then the numerical values of these factors, and then do the arithmetic. The result is

$$\frac{23\ lb_m \cdot ft}{min^2}\left|\frac{0.454\ kg}{1\ lb_m}\right|\frac{100\ cm}{3.281\ ft}\left|\frac{1\ min^2}{(60)^2 s^2}\right. \quad \text{(cancellation of units leaves } kg \cdot cm/s^2\text{)}$$

$$= \frac{(23)(0.454)(100)\ kg \cdot cm}{(3.281)(3600)\ s^2} = \boxed{0.088\ \frac{kg \cdot cm}{s^2}}$$

U.S. Customary System of Units (USCS)

Fundamenal Dimension	Base Unit
length [*L*]	foot (ft)
force [*F*]	pound (lb)
time [*T*]	second (s)

Derived Dimension	Unit	Definition
mass [FT^2/L]	slug	$lb_f \cdot s^2/ft$

	SI/Metric	Comparable Imperial/US Customary Units
Length	meter (m)	foot (ft)= 0.3048 m yard (yd) = 0.9144 m
	centimeter (cm) = 10^{-2} m	inch (in) = 2.54 cm
	kilometer (km) = 10^3 m	mile (mi) = 1.609 km
Area	square meter (m^2)	square foot (ft^2) = 0.0929 m^2 square yard (yd^2) = 0.8361 m^2
	square centimeter (cm^2) = 10^{-4} m^2	square inch (in^2) = 6.452 cm^2
	hectare (ha) = 10^4 m^2	acre (A or ac) = 43,560 ft^2 = 0.4047 ha.
	square kilometer (km^2) = 10^6 m^2 = 100 ha	square mile (mi^2) = 640 A = 2.590 km^2
Volume	liter (l or L)	gallon (gal) = 3.785 l cubic foot (ft^3) = 7.476 gal = 28.32 l
	cubic centimeter (cm^3) = 1 milliliter (ml)	cubic inch (in^3) = 16.39 cm^3
	cubic meter (m^3) = 10^3 l	cubic yard (yd^3) = 0.7645 m^3
Temperature[a]	degrees Celsius (°C)	degrees Fahrenheit (°F) = 9/5 (° C) + 32
Mass[b]	kilogram (kg)	pound (lb) = 0.4536 kg
	gram (g) = 10^{-3} kg	ounce (oz) = 1/16 lb = 28.35 g
	metric tonne or metric ton (t) = 10^3kg	short ton (commonly called "ton") = 2000 lb = 0.9071 t long ton = 2240 lb = 1.016 t
	quintal (q) = 10^2 kg	hundredweight (cwt) = 100 lb = 0.4536 q
Force/weight[b]	newton (N)	pound (lb) = 4.448 N
Pressure	pascal (Pa) = 1 N/m^2	
	kilopascal (kPa) = 10^3 Pa	pounds per square inch (psi) = 6.893 Pa
	torricelli (torr) = 1 mm of mercury (mm Hg) = 0.1333 kPa	inches of mercury (in Hg) = 25.4 mm Hg = 0.491 psi
	1 bar = 10^5 kPa	atmosphere (atm) = 1.013 bar
Energy[c]	joule (J)	foot-pound (ft-lb) = 1.356 J
	calorie (cal) = 4.187 J	
	kilocalorie (kcal or Cal) = 10^3 cal	British thermal unit (Btu) = 1055 J = 0.252 kcal
Power	watt (W) = joules per second (J/s)	
	kilowatt (kW) = 10^3 W	horsepower (hp) = 0.7457 kW

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SUMMARY: Units and Conversion

SI is the abbrevation of "Systeme International d'Unites"
This is the international system of units is based upon :
- seven base units as "length", "time", "temperature", "mass", etc
- two supplementary units
- derived units

Base units of SI

Base Unit	Name	Name
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd
Amount of Substance	mole	mol

Supplementary units of SI

Supplementary Units	Name	Name
Plane Angle	radian	rad
Solid Angle	steradian	sr

The derived units may be divided into three groups :
- units which are expressed in terms of base and supplementary units
- units which have been given special names and symbols
- units which are expressed in terms of other derived units

Some **derived units** expressed in terms of base and supplementary units.

Derived Unit	Name	Name
Acceleration	metre / second squared	m / s^2
Angular Acceleration	radian / second squared	rad / s^2
Area	square metre	m^2
Density	kilogram / cubic metre	kg / m^3
Kinematic Viscocity	square metre / second	m^2 / s
Mass Flow Rate	kilogram / second	kg / s
Molar Mass	kilogram / mole	kg / mol
Specific Volume	cubic metre / kilogram	m^3 / kg
Velocity	metre / second	m / s
Volume	cubic metre	m^3

Some derived units have special names and symbols.

Derived Units	Name	Symbol
Force	Newton	1 N = 1 kg.m / s
Pressure, Stress	Pascal	1 Pa = 1 N / m
Energy, Work, Quantity of Heat	Joule	1 J = 1 N.m
Power, Radiant Flux	Watt	1 W = 1 J / s
Electric Potential, Potential Difference	Volt	1 V = 1 W / A
Electrical Resistance	Ohm	1 Ω = 1 V / A

Onwards are :

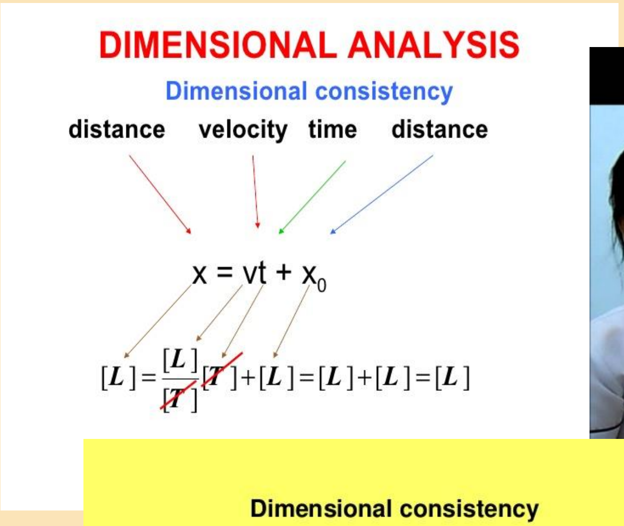
kilopascal (kPa) = 10^3 N / m^2 = kN / m^2
kilonewton (kN) = 10^3 kg.m / s^2
kilojoule (kJ) = 10^3 N.m = kN.m

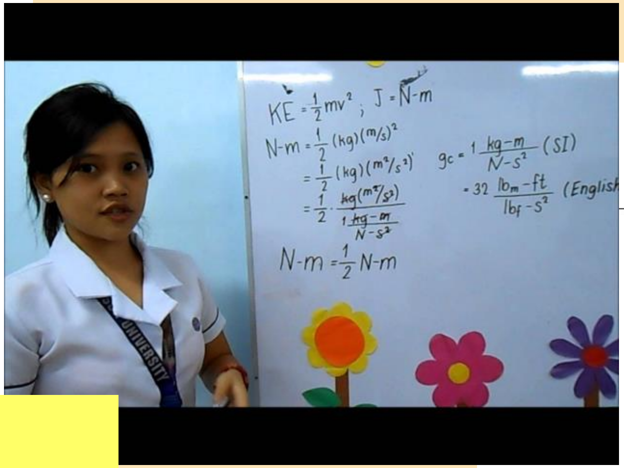
Conversion Table
From the old (metre-kilogram-second-ampere) system to units of SI.

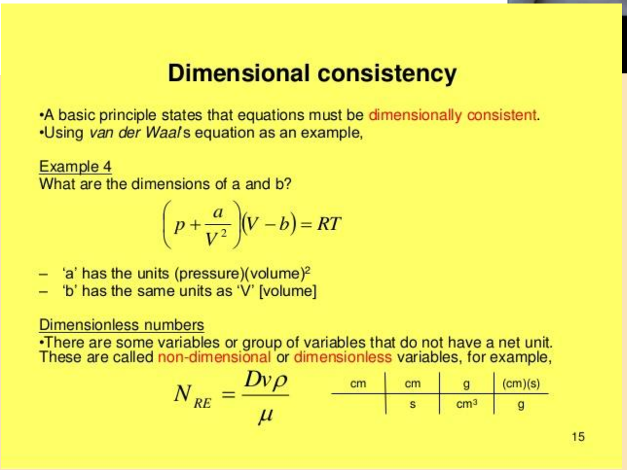
1 Bar	= 100 kPa (0.1 N / mm^2)
1 Btu (British Thermal Unit)	= 1.055 kl = 1055 J
1 cP (Centipoise)	= 10^{-3} Pa.s
1 cSt. (Centistokes)	= 10^{-6} m^2 / s
1 dyne	= 1 g.cm / s^2 = 10 N
1 erg	= 1 dyn.cm = 10 J
1 hp (Horsepower)	≈ 745.7 W
1 kcal	= 4.1868 kJ = 4186.8 J
1 kcal / h	= 1.163 W
Kelvin	≈ °C + 273
1 mbar (Milibar)	= 100 Pa
1 mmHg (Torr)	≈ 133.32 Pa
1 mwc	≈ 9.81 kPa (9.81 kN / m^2)
1 pk (paardekracht NL)	≈ 735.5 W
1 psi	≈ 6.89 kPa (6.89 kN.m^2)
1 kgf	≈ 9.81 N
1 kgf / cm^2	≈ 98.07 kPa

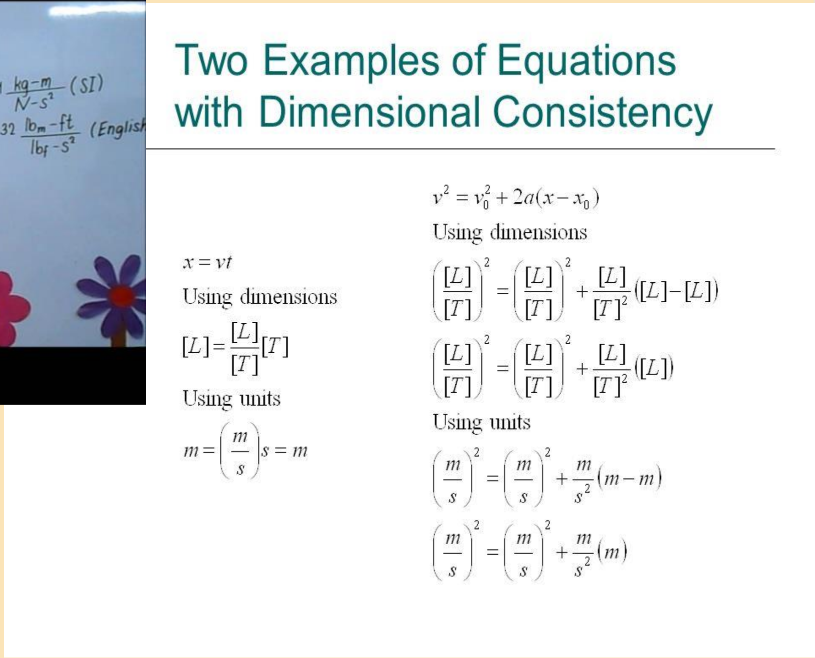
1 in	= 1 inch	= 25.4 x 10^{-3} m
1 ft	= 1 foot	= 0.3048 m
1 in^2	= 1 $inch^2$	= 0.64516 x 10^{-3} m^2
1 ft^2	= 1 $foot^2$	= 0.0929 m^2
	1 lb	= 0.454 kg
	1 lb /h	≈ 0.12599 x 10^{-3} kg / s
	1 in^3	≈ 16.387 x 10^{-6} m^3 (= 16.387 cm^3)
	1 UK gal	≈ 4.546 x 10^{-3} m^3 (= 4.546 dm^3)
	1 US gal	≈ 3.785 x 10^{-3} m^3 (= 3.785 dm^3)

Dimensional Consistency: Examples









ESTIMATION IN ENGINEERING

In the earlier stages of design, engineers nearly always make approximations when solving technical problems. Those estimates are made to reduce a real system, as imperfect and non-ideal as it may be, into its most basic and essential elements.

- **Assumption (inviscid, adiabatic, isothermal and etc)**
- **Linearised**
- **Simplified model**
- **Boundary Conditions**
- **Uncertainties**
- **Time and Cost**

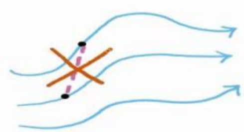
Examples of engineering estimation:

1. Bernoulli's Equation [assumptions: steady, inviscid and incompressible flow]

$\frac{1}{2}\rho v^2 + \rho g h + p = \text{constant}$ (along a streamline)

Assumptions

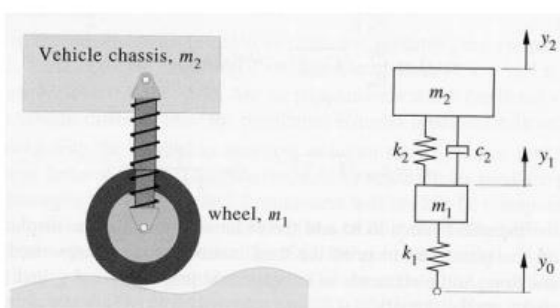
Applied along a streamline →



$$\frac{V_1^2}{2g} + \frac{p_1}{\rho g} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho g} + z_2$$

2. Mass-spring-damper to model vehicle suspension

A car and its suspension system traveling over a bumpy road can be modeled as a mass/spring/damper system. In this model, y_1 is the vertical motion of the wheel center of mass, y_2 is the vertical motion of the car chassis, and y_0 represents the displacement of the bottom of the tire due to the variation in the road surface.



Spring/mass/damper model for an automobile suspension system.

Variations in Engineering

Variations

- *Inconsistency*
- *Fluctuations*
- *Disturbances*
- *Errors*

→

Quantify

- *Accuracy*
- *Tolerance*
- *Uncertainty*
- *Precision*
- *True value*

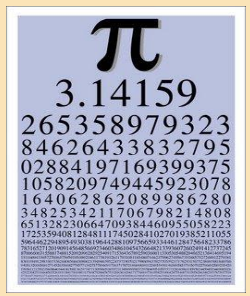
→

Requirements

- *Significant Digits*
- *Dimensional Consistency*
- *Estimation in Engineering*
- *Statistical Probability*

Examples of variations:

(1) Significant digits of pi



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Significant digits
π = 3.142….

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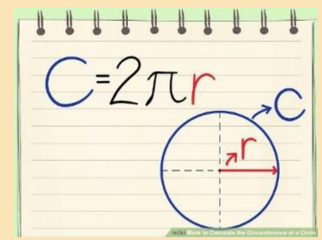
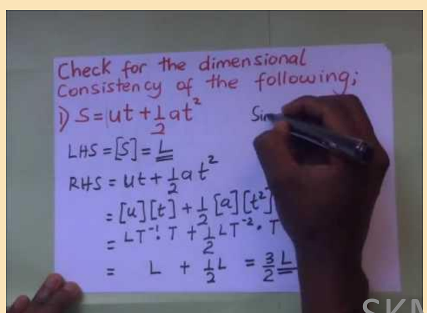


(2) Dimensional Consistency



Coefficient Inconsistency (Drag Coefficient)

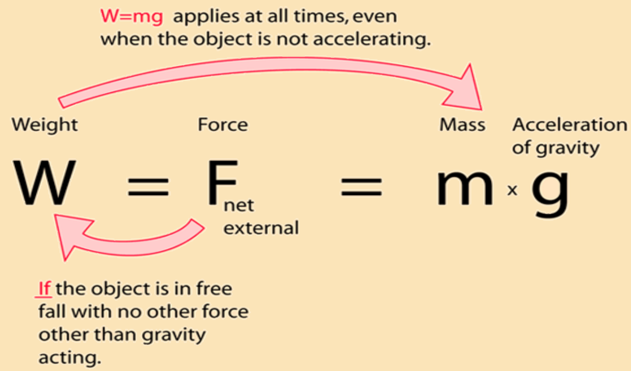
*CD = Drag Force/ (Dynamic Pressure * Area)*

Aircraft: Area = wing area

Automobile: Area = frontal area

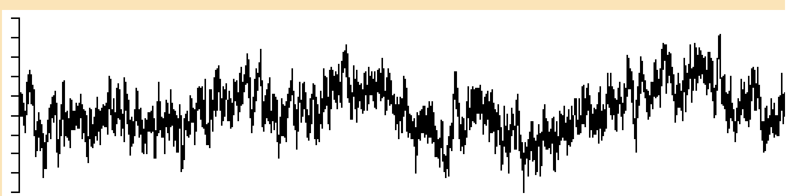
(3) Variation in gravity

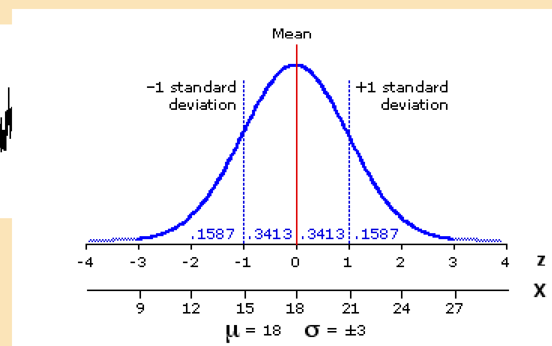
g values (m/s^2):
Standard = 9.80665
Equatorial = 9.78033

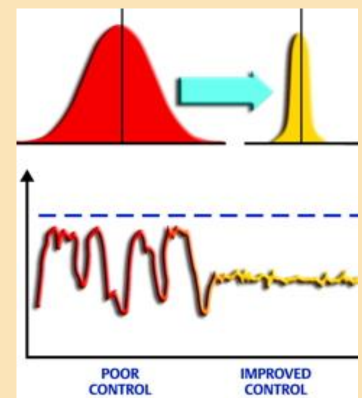


(4) Fluctuation in data and signal measurement (Systematic Error + Random Error)

Statistics: Mean, Root-Mean-Square (RMS) and Standard Deviation (Sigma)







Resources

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RESOURCES

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2. Dr. Eric P. Soulsby, ***University Learning Skills: A First Year Experience Orientation Course for Engineers***, 29th ASEE/IEEE Frontiers in Education Conference Session 11a7-6
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