Chapter 16

Math and Science Applications

Engineering Design An Introduction

Measurement: The Real World of Variability

- Nothing can be measured or fabricated with infinite accuracy
- Variation needs to be considered:
  - To ensure parts fit together correctly

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- Example: calculate volume of a gold brick with known dimensional variability

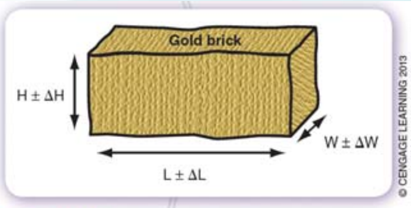

Figure 16-5: Example of a solid, three-dimensional gold brick with known variability in each dimension.

$$V_{min} = (20.95\text{ cm})(11.45\text{ cm})(5.95\text{ cm}) = 1{,}427.3\text{ cm}^3$$
$$V_{nom} = (21\text{ cm})(11.5\text{ cm})(6\text{ cm}) = 1{,}449.0\text{ cm}^3$$
$$V_{max} = (21.05\text{ cm})(11.55\text{ cm})(6.05\text{ cm}) = 1{,}470.9\text{ cm}^3$$

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Measurement: The Real World of Variability (cont'd.)

- Gold brick example (cont'd.)

$$V_{brick}=1450 \pm 20\text{cm}^3$$

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Units Analysis

- Important to carry units with each number
  - When performing a calculation
- Example: value of gold brick
  - Price in 2011 was $1,700 per troy ounce
  - Need to know density of gold
    - Mass divided by volume
    - 19.3 grams/cubic cm
  - One troy ounce equals 31.1 grams

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Units Analysis (cont'd.)

- Example: value of gold brick (cont'd.)

$$\text{Mass} = (1450 \pm 20\ \text{cm}^3)(19.3\ \text{g/cm}^3) = 28{,}000 \pm 400\ \text{g}$$

$$\text{Value} = (28{,}000 \pm 400\ \text{g})(1\ \text{Toz}/31.1\ \text{g})(1700\ \$\text{US/Toz}) = 1{,}530{,}000 \pm 20{,}000\ \$\text{US}$$

- Units analysis
  - Common technique for verifying answer
  - If units obtained are not desired units:
    - Calculation is very likely incorrect

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Absolute versus Relative Graphs (Using Cartesian Plotting)

- Absolute plot
  - Real, numerical values are used
- Relative plot
  - Relative values are used

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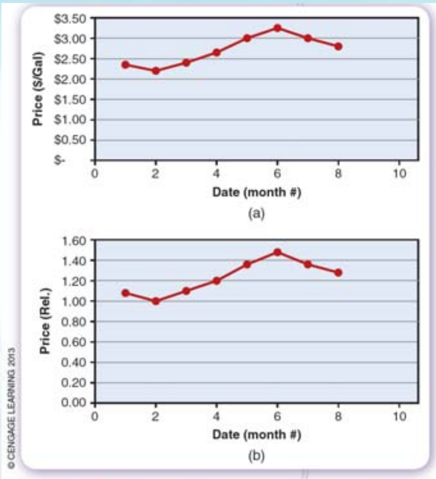

Figure 16-7: Gasoline prices plotted as (a) an absolute plot and (b) a relative plot. The data in plot (b) is relative to the lowest price of $ 2.20 (month 2).

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Polar (Non-Cartesian) Graphing

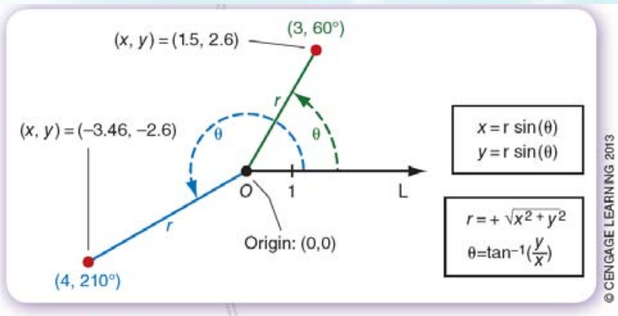

Figure 16-9: Examples of points expressed in polar (colored, ordered pairs) and Cartesian coordinates (colored, ordered pairs). Also shown are equations for translating between polar and Cartesian coordinates.

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Spreadsheets and Structured Programming

- Microsoft Excel
  - Standard spreadsheet program
- Other useful tools
  - MathCAD
  - Mathematica
  - Calculator

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Spreadsheets and Structured Programming (cont'd.)

- Common uses of spreadsheet programs
  - Organization of data / information
  - Calculations
  - Graphing
    - Pie/bar charts
    - Plotting
    - Curve fitting
  - Statistics

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	A	B	C	D
1	Difference	Difference		
2	(unity)	(non-unity)	Date	Text
3	–3	2.56	Jan	Year1
4	–2	2.68	Feb	Year2
5	–1	2.8	Mar	Year3
6	0	2.92	Apr	Year4
7	1	3.04	May	Year5
8	2	3.16	Jun	Year6
9	3	3.28	Jul	Year7

Figure 16-13: Examples of automatic enumerating, by column. Columns A and B show examples of numeric enumeration (difference of 1 and 0.12), while columns C and D show examples of date and text enumeration, respectively.

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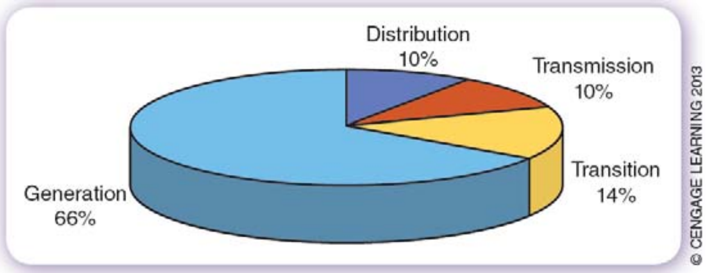

Figure 16-18: *Components of a utility bill displayed as a pie chart. A utility bill is composed of several fees: (a) generation, (b) transition, (c) transmission, and (d) distribution. Generation costs are by far the largest contributor.*

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Newton's Three Laws of Motion

- Newton's first law
  - Every body persists in its state of rest or uniform motion (constant speed) in a straight line unless it is compelled to change that state by forces impressed on it
- Newton's second law
  - The acceleration of an object is equal to the force imparted on it divided by its mass

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Newton's Three Laws of Motion (cont'd.)

- Newton's third law
  - For every action there is an equal and opposite reaction
  - Example: basketball thrown to the ground
    - Basketball pushes on the earth
    - Earth pushes equally hard on the basketball

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Statics and Vectors

- Statics
  - Study of structures that do not move
- Examples of static structures
  - Bridge, house
- Vector
  - Represented by an arrow of a certain length:
    - Pointing in a certain direction
  - Describes magnitude and direction of a force

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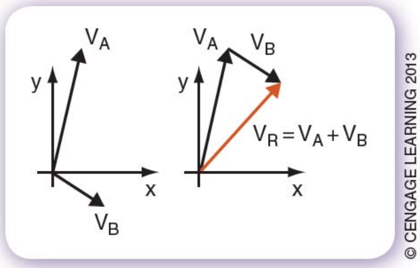

Figure 16-26: Two vectors are added by simply stacking them tail to head as shown here. The resultant vector, V_R, is the sum of the two vectors.

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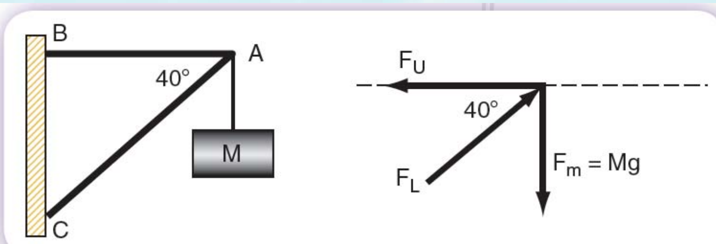

Figure 16-28: A static brace design and its free-body diagram. This model of a brace accurately represents a variety of real-world items like shelving and plant hangers.

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Dynamics

- Study of objects in motion
- Acceleration
  - How quickly velocity is increased or decreased over time
  - Rate of change of velocity
  - Measured in meters per second per second

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Dynamics (cont'd.)

- Free-falling objects
  - Governed by the following three equations

$$a = g \qquad \text{Eq. 16-6a}$$

$$V = gt + V_{\text{initial}} \qquad \text{Eq. 16-6b}$$

$$S = \frac{1}{2}gt^2 + V_{\text{initial}}t + S_{\text{initial}} \qquad \text{Eq. 16-6c}$$

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Dynamics (cont'd.)

- Projectile motion
  - Motion of arrows, bullets, thrown rocks
- X and Y coordinates for a projectile thrust at an angle θ with the horizontal

$$x = V_{\text{initial}}\,[\cos(\theta)]t \qquad \text{Eq. 16-8a}$$

$$y = \frac{1}{2}gt^2 + V_{\text{initial}}\,[\sin(\theta)]t + H_{\text{initial}} \qquad \text{Eq. 16-8b}$$

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Dynamics (cont'd.)

- Rotational motion
  - Movement in angle over time
- Angle measured in radians

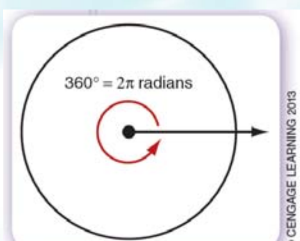

Figure 16-33: A circle consists of 360 degrees. That is, when a wheel (circle) is rotated by one revolution, it has rotated 360 degrees, which is the same as 2π radians.

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Swinging Doors

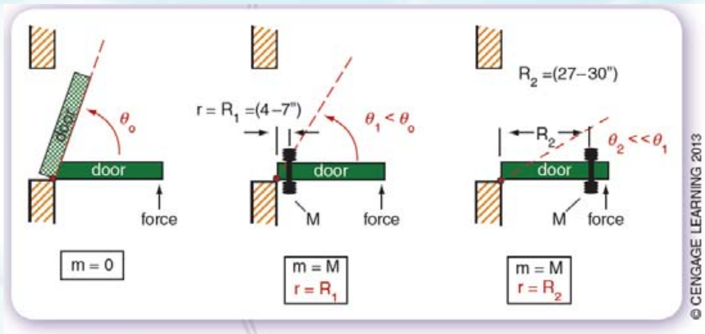
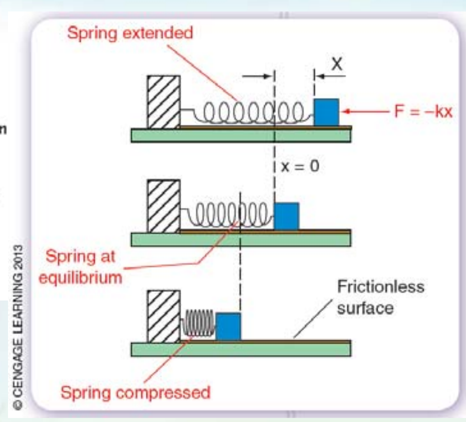


Figure 16-34: Top views of a swinging door. A swinging door can be used to understand rotational forces, torques, by experimenting with position of mass and position of the applied forces.

Springs: Nature's Trigonometric Function

Figure 16-40: Diagram showing the motion of a mass on a spring. The spring always acts against the motion of the mass in a linear fashion. That is, the force applied by the spring to the mass, F_s, is given by $F_s = -kx$, where k is a constant (the "spring" constant) and x is the position of the spring.



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Exponential Functions

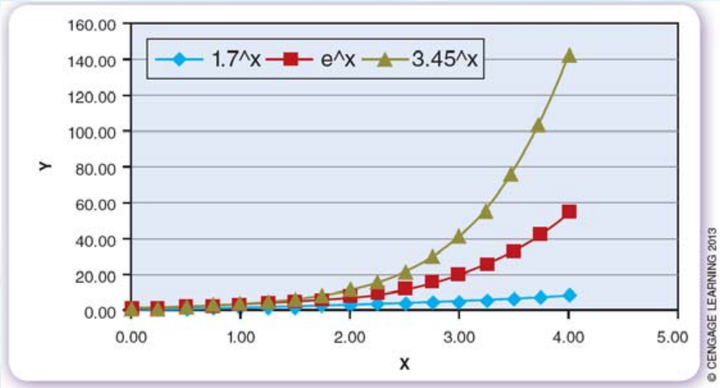

Figure 16-41: Plots of three exponential functions: $y = (1.7)^x$, $y = e^x$, and $y = (3.45)^x$. Exponential functions grow extremely fast.

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Probability/Statistics: Applications

- Manufacturing processes
  - Often governed by a Gaussian distribution
  - Describes the variability of a population

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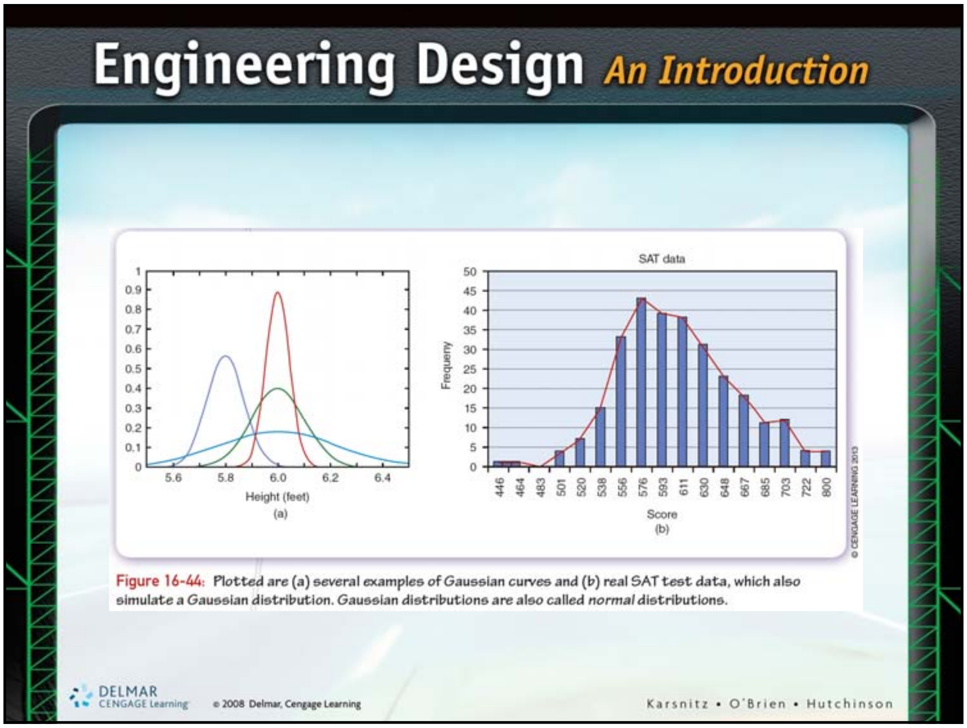

Figure 16-44: Plotted are (a) several examples of Gaussian curves and (b) real SAT test data, which also simulate a Gaussian distribution. Gaussian distributions are also called *normal* distributions.