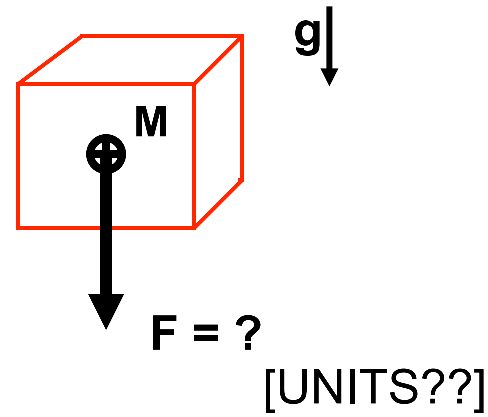
2.00AJ / 16.00AJ Exploring Sea, Space, & Earth: Fundamentals of Engineering Design
Spring 2009

Exploring Earth, Sea & Space: FUNdaMENTALs of Design

Intro. To Engineering Analysis

Units and Dimensions

Base Unit		SI unit
Mass	[M]	kg
Length	[L]	m
Time	[T]	s
Temperature	[[illegible]]	K
Electric Current	[I]	Amps
Amt of Matter	[mole]	Mol



1 Newton = 1 kg*m/s^2

[Force] = [M * L * T^{-2}]

Always double check your units!

Derived Units

Derived Unit		**SI Units**
Area, A	$[L^2]$	m^2
Volume, V	$[L^3]$	m^3
Velocity, *v*	$[L T^{-1}]$	m/s
Acceleration, *a*	$[L T^{-2}]$	m/s^2
Pressure, *p = F/A*	$[M L^{-1} T^{-2}]$	$N/m^2 = kg/m/s^2$
Stress, *t*	$[M L^{-1} T^{-2}]$	$N/m^2 = kg/m/s^2$
Force, *F= p*A*	$[M L T^{-2}]$	$N = kg*m/s^2$
Energy, *E* Work, *W = F*x*	$[M L^2 T^{-2}]$	J = N*m
Power, *P = F*v*	$[M L^2 T^{-3}]$	W = J/s = N*m/s

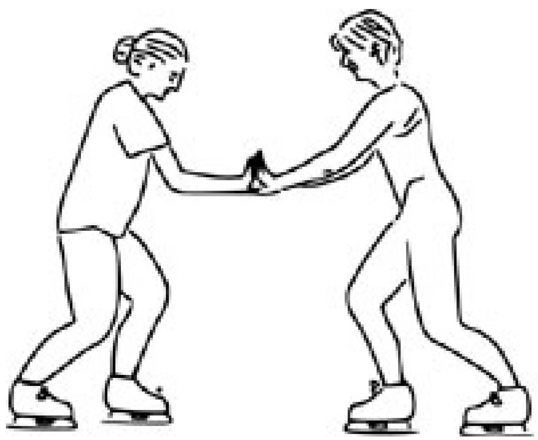
Always double check your units!

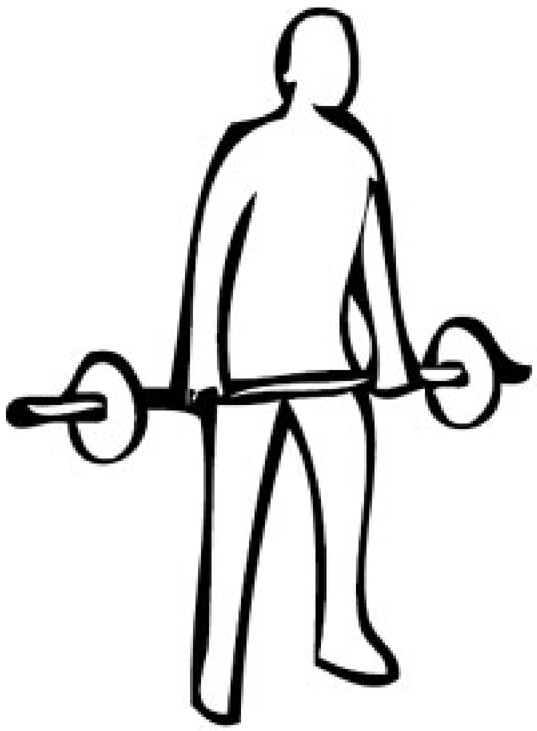
Free Body Diagrams

ALWAYS SKETCH IN YOUR DESIGN NOTEBOOK!

WHERE DO THE FORCES ACT?

Images of a horse-drawn sleigh, a rock falling off a cliff, a crash-test dummy, and a hand holding a shoe removed due to copyright restrictions.





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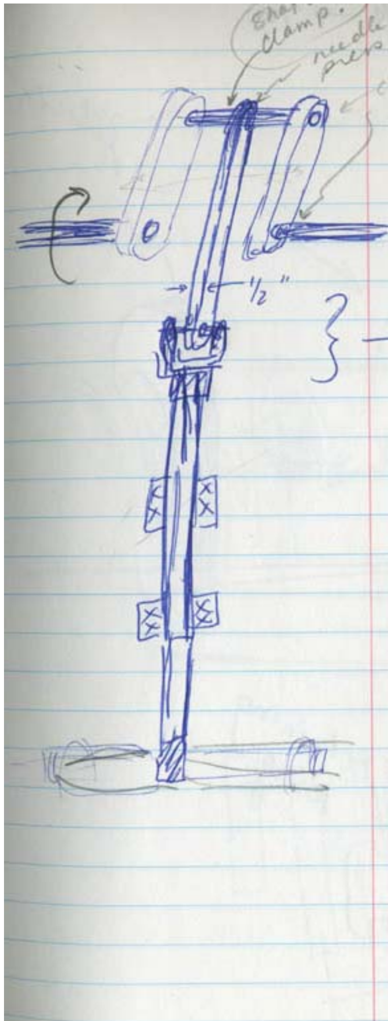
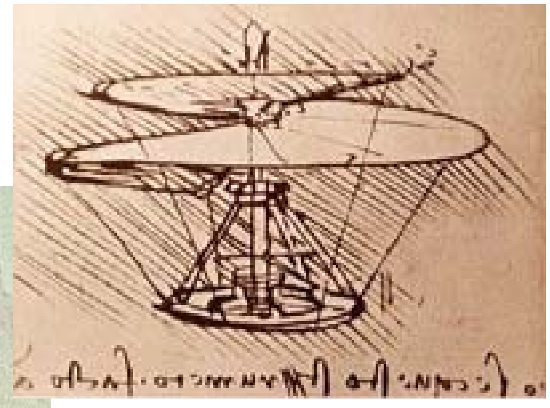
Sketches





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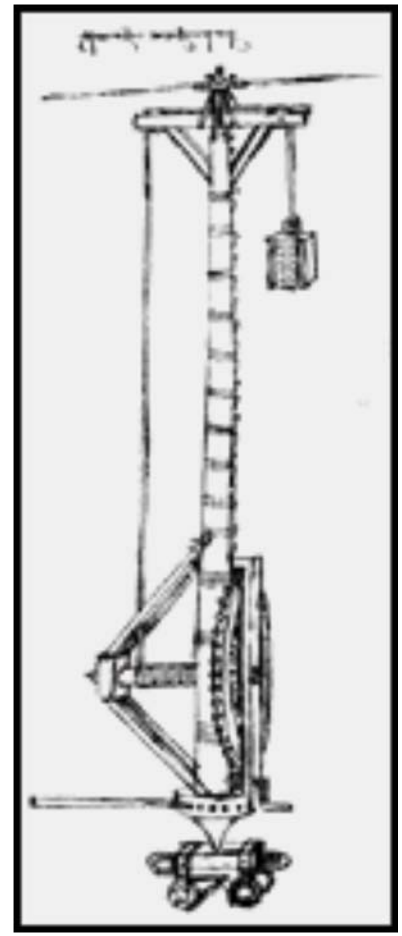
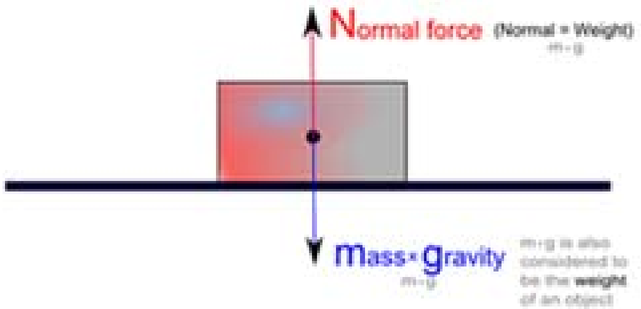
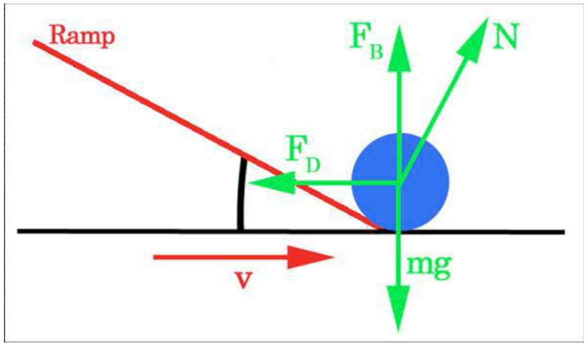
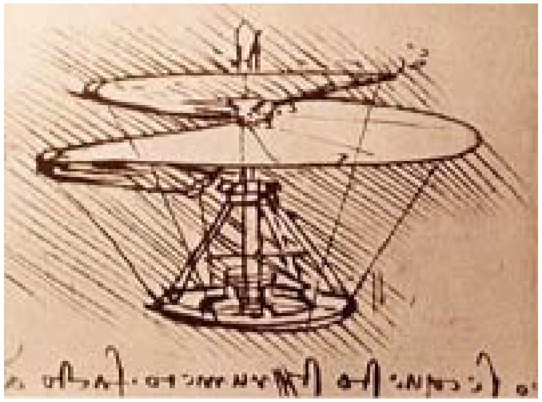
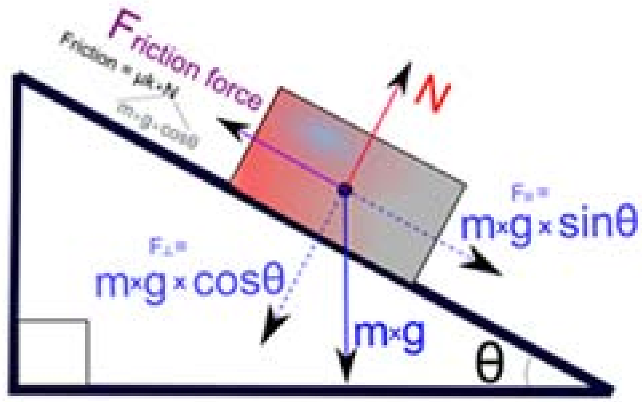


Free Body Diagrams









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Please see http://www.globalsecurity.org/military/library/policy/army/accp/al0966/al0966b0019.gif

Forces: $\Sigma\vec{F} = m\vec{a}$

Sir Isaac Newton (1642 - 1727)

- Types of forces?

$$\mathbf{F} = \frac{\mathrm{d}\mathbf{p}}{\mathrm{d}t} = m\mathbf{a}$$

Forces: $\Sigma\vec{F} = m\vec{a}$

Sir Isaac Newton (1642 - 1727)

- Types of forces:
  - Shear Forces (Tangent to surface): e.g. Friction
  - Normal forces (Perpendicular to surface): e.g. Pressure forces
  - Gravity
  - Body forces
  - Others?

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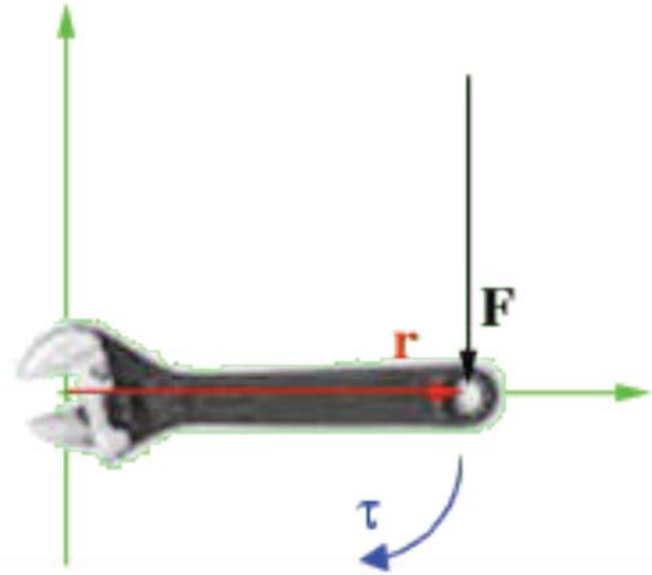
$$\mathbf{F} = \frac{\mathrm{d}\mathbf{p}}{\mathrm{d}t} = m\mathbf{a}$$

- FORCES do WORK and transfer ENERGY
- If FORCES act on a body and there is ***NO*** ACCELERATION then the body is in EQUILIBRIUM
- **Keep in mind where each force acts when designing (*center of forces & lines of action*)**

Torque , *t*

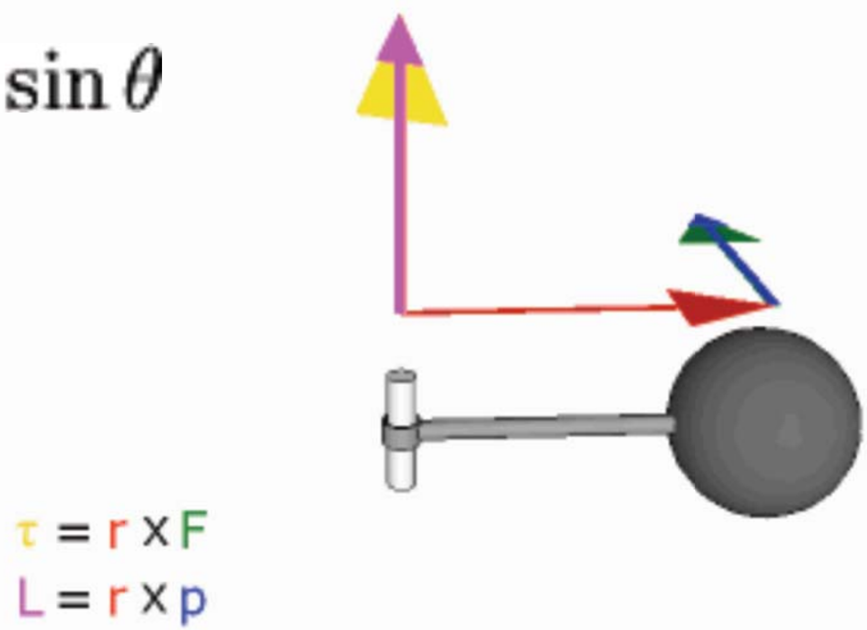


- Torque, ***t***
  - Force, ***F***, applied at a distance, *r*:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F} \quad \textbf{\textit{or}} \quad \boldsymbol{\tau} = rF\sin\theta$$

  - Rate of change of a[…]mentum, ***L***

$$\boldsymbol{\tau} = \frac{\mathrm{d}\mathbf{L}}{\mathrm{d}t}$$



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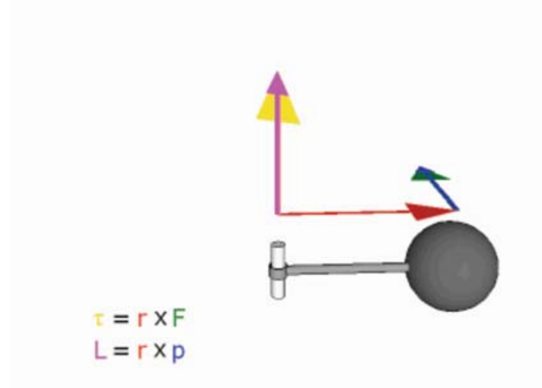
Momentum:



- Linear momentum

$$\mathbf{p} = m\mathbf{v}$$

- m = mass of object
- $\mathbf{v}$ = velocity vector

- Angular momentum

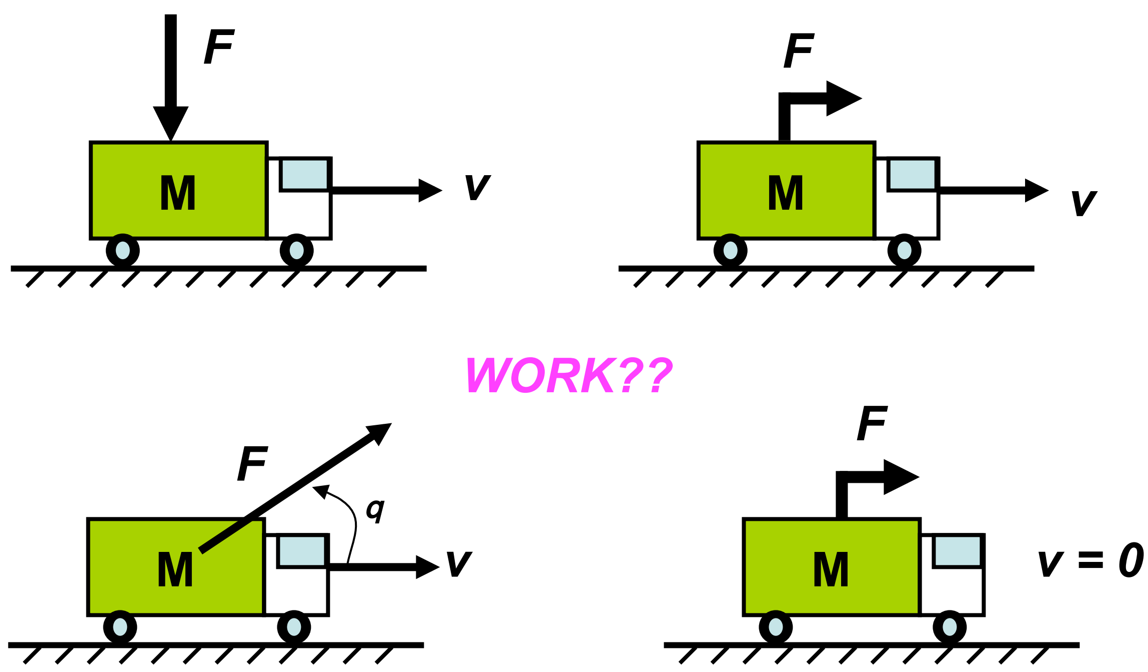
$$\mathbf{L} = I\omega$$

- I = *moment of inertia*
- w = *angular velocity*

Work:

$$W = \int F dx$$

In order for WORK to be done FORCE must act on an object *AND* the object must MOVE in the direction of the FORCE.



Work: $W = \int F dx$

In order for WORK to be done FORCE must act on an object ***AND*** the object must MOVE in the direction of the FORCE.

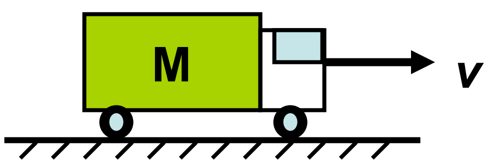
	Force in direction of motion	Force not in direction of motion
Constant Force:	$W = Fx$	$W = F\cos\theta x$
Variable Force:	$W = \int F dx$	$W = \int F\cos\theta dx$

WORK requires ENERGY

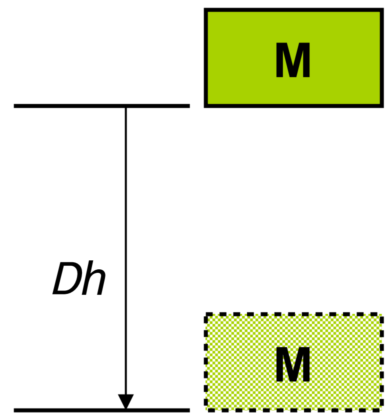
Energy:

- Kinetic Energy

$$KE = \frac{1}{2} m \mathrm{v}^2$$



- Potential Energy



$$PE = mg\Delta h$$

Power:

- POWER is the *rate* of doing WORK or *rate of using ENERGY*
- *ENERGY used must equal the WORK done*

$$\overline{P} = W / t$$

$$P_{\text{instantaneous}} = \vec{F} \cdot \vec{V}$$

Efficiency:

- *Efficiency* measures how "well" power is transmitted or the process is performed

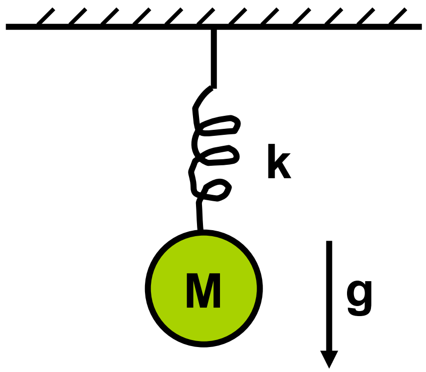
$$\eta = \frac{P_{out}}{P_{in}} < 1.0$$

$$P = F\,V = F\cos\theta\,V$$ (for *F*, *V* constant)

Conservation Laws

Momentum	Energy	Angular Momentum
Collisions (elastic/inelastic; 1D or 2^+D) Fluid motion Design Analysis	Einstein: $E = mc^2$ Useful for solving mechanics Problems!	Rotating Bodies Torques Motors and spinning wheels
Impulses External forces $\frac{d}{dt}\left(m\vec{V}\right)=\Sigma\vec{F}$	Fluids – Bernoulli's Equation Electrical Circuits – Voltage Laws Heat/Thermo-1st Law of Thermodynamics	Angular velocity times moment of inertia Vector Quantities!

Example: Spring-Mass System



- When it is in an equilibrium position draw a free body diagram.
  - What are the forces acting on it?
  - Write an equation for the force balance?

- What happens if you give it a light push down and let it go?
  - How would you write an equation of motion to describe this? Consider the force balance.
  - Is there a specific frequency that this mass will oscillate at? Why do we care?

- How do you determine ***k*** if it is not given?

- How much ***work*** must be done to stretch the spring some distance ***x***?

Tacoma Narrows Bridge Video

archt01. "Tacoma Narrows Newsreel." May 21, 2006. YouTube. Accessed September 24, 2009.