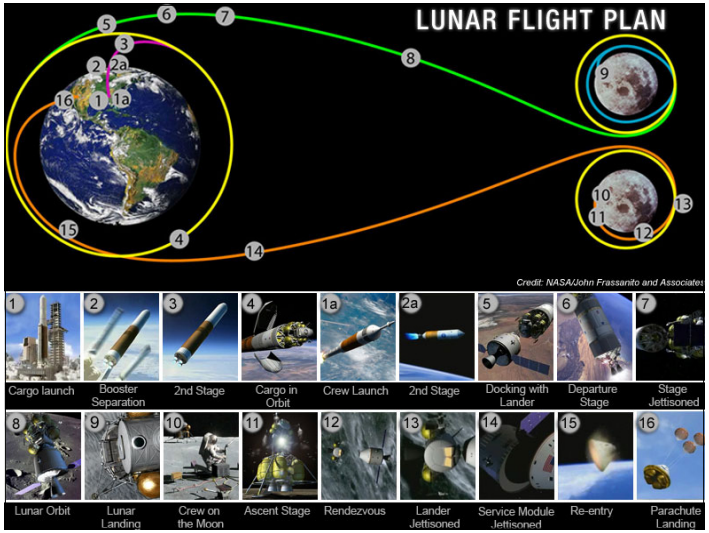
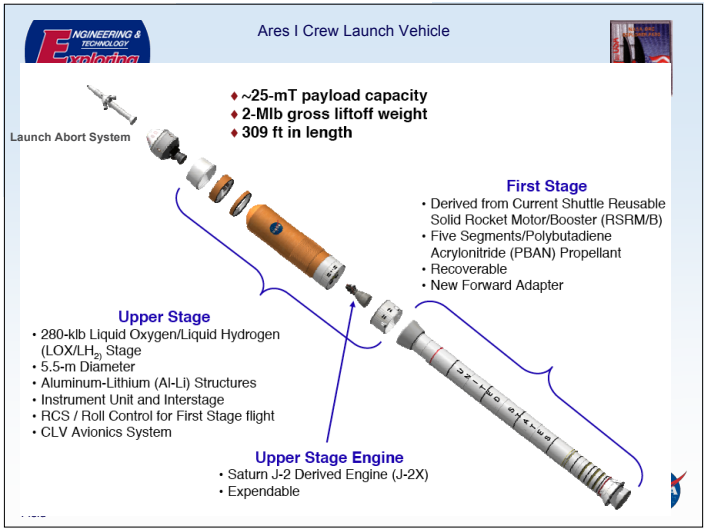
Introduction to Model: A General View and Application to Model Rocket Engines

J. Lee

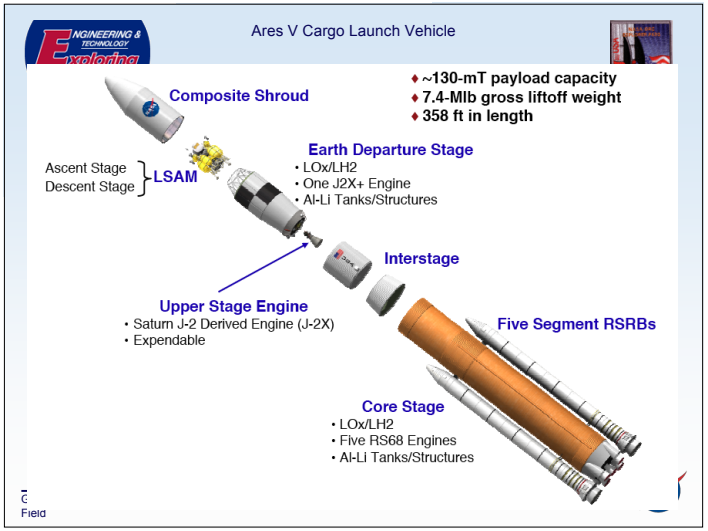
Glenn Research Center at Lewis Field



Ares I Crew Launch Vehicle



Ares V Cargo Launch Vehicle

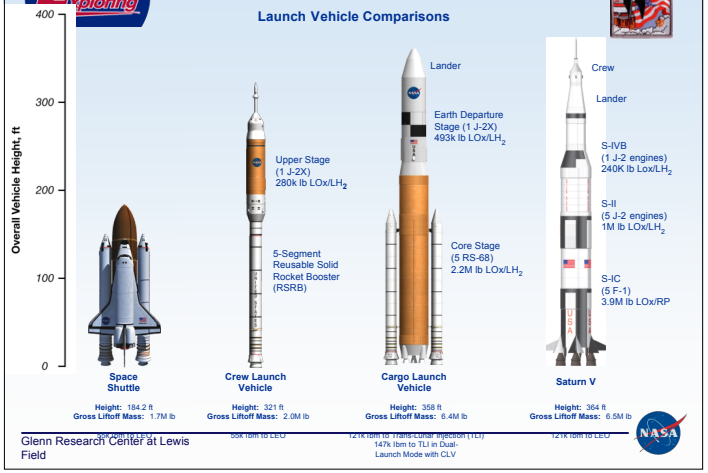


Constellation Launch Vehicle Elements

Crew Launch Vehicle **Cargo Launch Vehicle**

Building on a Foundation of Proven Technologies

Launch Vehicle Comparisons



Need work on the details

Advisor Comments

- Melted 6 parachutes performed 10 successful launches ! (3 Altimeter data points)
- All rockets recovered
- All of them flew straight !
- Congratulation to all for job well done!

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Model Rocket Launches

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Model Rocket Launches

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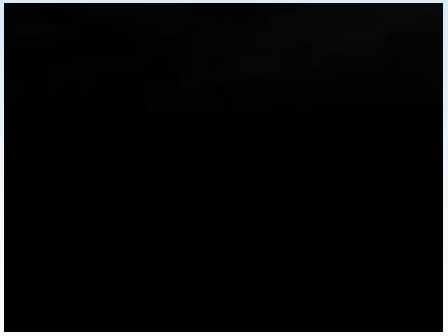
Model Rocket Launches



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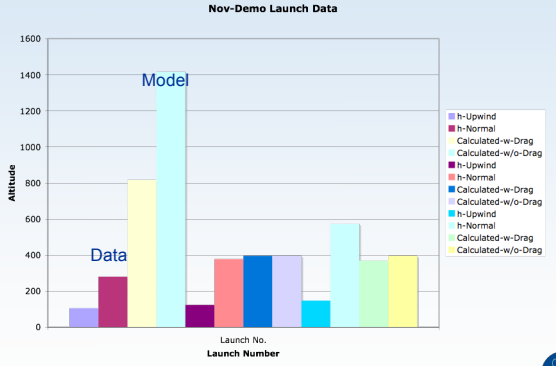
Altitude measured vs. Computed



Newton's Law

$$F = \frac{d}{dt}(mV) \qquad F = ma$$

$$F = \frac{dm}{dt}(V) \qquad F = m\frac{dV}{dt}$$

Newton's Law

$$F = \frac{dm}{dt}(V)$$

Generate a large Velocity

Move a lot of Mass

Boeing 777

- State of the ART
- 1990 Design

777 INFO

- 777-200
- Take off Weight 506,000 lbs
- Range 4350 nmi
- Fuel Capacity ~ 37000 gals
- Engines GE90, PW4084, RRTrent 890
- Thrust Class, 105,000 lbf (Peak GE90), ~90,000 lbf, 84,600lbf(PW 4084), demonstrate 90,000 lbf, 90,000 lbf (Trent 800)

Space Shuttle

- 4.5 million lb (~8 of 777)
- Payload capacity 65,000lbs
- 1.4 % payload fraction
- SSME ~ 400,000 lb
- 1.6 million lb propellant (35.5 %)
- ~ 1 million lb Solids (22 %)
- ~ 5.2 million lb thrust
- ~ 9 * 777 thrust

3-2-1 Launch

Newton's Law

$$F = ma$$

$$a = F/m$$

$$F = Thrust - Drag - Weight$$

Newton's Law

$$Drag = 1/2 C_D \rho V^2 A$$

$$m = mass \sim changes over time$$

$$V = \int a = \int F/m$$

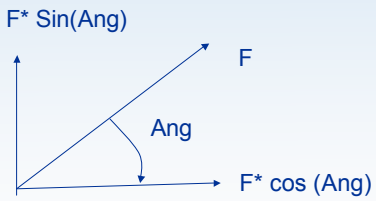
Newton's Law

$$x = \int V = \int \int a = \int \int F/m$$

In one Dimension

Newton's Law

In Two Dimension

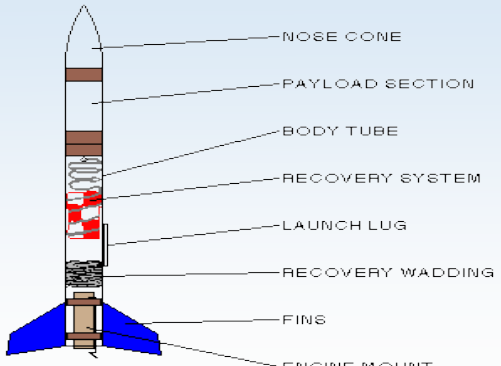


Simple use of the Newton's Law

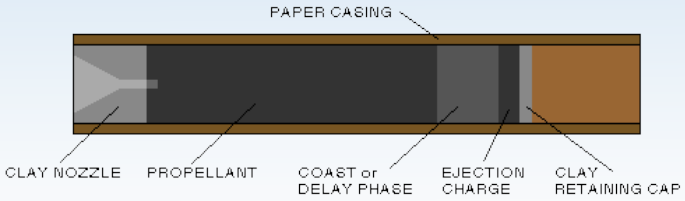
Once the relationship is developed than we can predict things like

How high
How far
Etc…

Model Rockets



Model Rockets



Chemistry/Combustion

- $21NH_4ClO_4 + 10(C_4H_6) \rightarrow 21HCl + 34.5\ H_2 + 27\ H_2O + 23\ CO + 17\ CO_2$
- Ammonium perchlorate
- Note: Far more interesting than
- $H_2 + 1/2\ O_2 \rightarrow H2O$

Published Motor Data

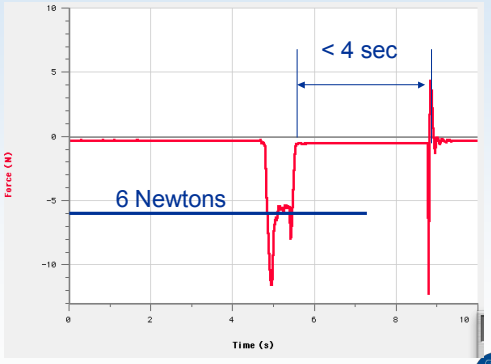
A	1.26-2.5	N-s
B	2.51-5	N-s
C	5-10.	N-s
E	20-40	N-s

A 6 -4

Class — Thrust (Newtons) — Delay (sec)

Measured Motor Data

B 6 -4



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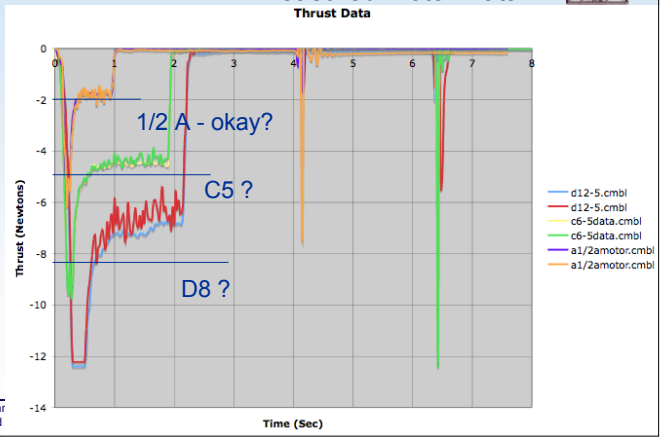
Measured Motor Data



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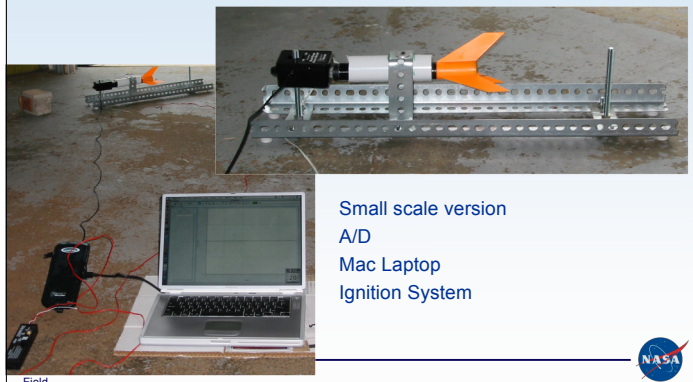
Thrust Stand



- Small scale version
- A/D
- Mac Laptop
- Ignition System

Field

Test Runs

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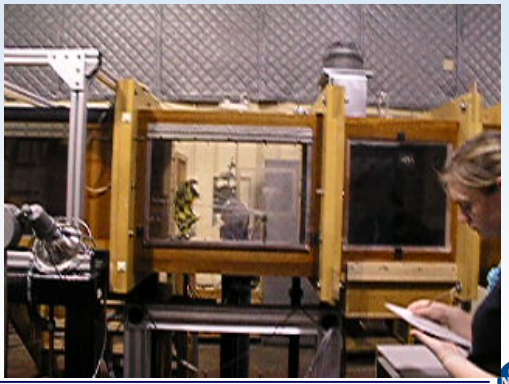
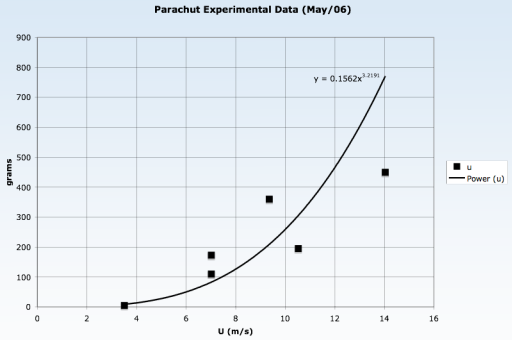
Test Runs

Test Run



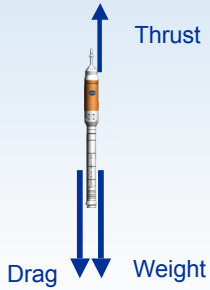
Raw Data



Reference Information

Application of Newton's Law (Ascent)

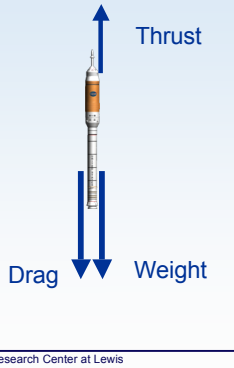
$\Sigma F = 0 = Mass * Accleration = Thrust - Drag - Weight$

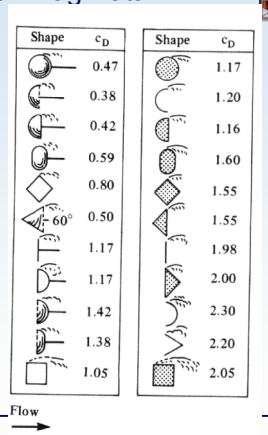


The Shaded cells need user input

Rocket altitude Calculations					
Input Variable	Input Data	Units	Converted Data	Converted Unit	
Initial Motor Mass	0.018	kg	0.008	lbm	Relavent for A
Rocket Mass	0.000	kg	0.000	lbm	
Burnout Motor Casing Mass	0.011	kg	0.005	lbm	
Thrust timeduration	0.800	sec	0.800	sec	
Ejector delay Time	10.000	sec	10.000	sec	
Thrust Force of Engine	20.000	N	89.000	lbf	
Frontal Area	0.020	m2	0.215	ft^2	
Drag Coefficient(Rocket)	0.100				
Frontal Area with Chut	0.100	m2	1.076	ft^2	
Drag Coefficient (Chut)	0.200				
Air Density	1.230	kg/m3	0.077	lbm/s	
Total Mission time	20.000	sec	20.000	sec	
Launch Angle	65.000	Degrees	1.134	radians	Relavent for 2
Cross breeze Velocity	0.000	m/s		ft/s	
L/D	0.000				
Solver Parameter					
Total no of Calculation points	602.000	pts			
time step	0.033	sec			
fuel mass burn rate	0.009	kg/s	0.020	lbm/s	Linear Rocke
Universal Gravitational Acceleration					
Gravitation Accleration	9.800	m/s2	32.200	ft/s2	
Mass and Aero property					
Total Vehicle Mass (Motor and Rocket)	0.018	kg			
Specific Drag Ascent	1.230E-03	N/(m2/s2)	1/2 rho Cd A		
Specific Drag Decent	1.230E-02	N/(m2/s2)			

Typical Drag Data





Application of Newton's Law (Ascent)

Acceleration = (Thrust -weight-Drag)/ΔMass

Drag = $1/2\rho V^2 C_d * Area$

Acceleration=dV/dt~ΔV/Δt

Vnew = Vold + Δt* Acceleration

Velocity=dY/dt~ΔY/Δt

Ynew = Yold + Δt* Velocity

The Shaded cells need user input

Rocket altitude Calculations					
Input Variable	Input Data	Units	Converted Data	Converted Unit	
Initial Motor Mass	0.018	kg	0.008	lbm	Relavent for A
Rocket Mass	0.000	kg	0.000	lbm	
Burnout Motor Casing Mass	0.011	kg	0.005	lbm	
Thrust timeduration	0.800	sec	0.800	sec	
Ejector delay Time	10.000	sec	10.000	sec	
Thrust Force of Engine	20.000	N	89.000	lbf	
Frontal Area	0.020	m2	0.215	ft^2	
Drag Coefficient(Rocket)	0.100				
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Total no of Calculation points	602.000	pts			
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Universal Gravitational Acceleration					
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Mass and Aero property					
Total Vehicle Mass (Motor and Rocket)	0.018	kg			
Specific Drag Ascent	1.230E-03	N/(m2/s2)	1/2 rho Cd A		
Specific Drag Decent	1.230E-02	N/(m2/s2)			

Application of Newton's Law (Descent)

$\Sigma F = 0 = Mass * Accleration = +Drag - Weight$

Drag

This is now the relevant drag device

What happen to thrust?

Why is drag positive?

Weight

Application of Newton's Law (Descent)

The Shaded cells need user input

Decent Relevant Inputs

Rocket altitude Calculations				
Input Variable	Input Data	Units	Converted Data	Converted Unit
Initial Motor Mass	0.018 kg		0.008 lbm	Relavent for A
Rocket Mass	0.000 kg		0.000 lbm	
Burnout Motor Casing Mass	0.011 kg		0.005 lbm	
Thrust timeduration	0.800 sec		0.800 sec	
Ejector delay Time	10.000 sec		10.000 sec	
Thrust Force of Engine	20.000 N		89.000 lbf	
Frontal Area	0.020 m2		0.215 ft^2	
Drag Coefficient(Rocket)	0.100			
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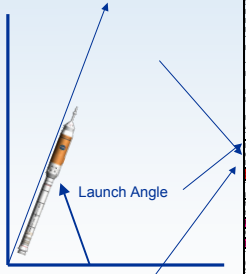
Air Density	1.230 kg/m3		0.077 lbm/s	
Total Mission time	20.000 sec		20.000 sec	
Launch Angle	65.000 Degrees		1.134 radians	Relavent for 2
Cross breeze Velocity	0.000 m/s		ft/s	
L/D	0.000			
Solver Parameter				
Total no of Calculation points	602.000 pts			
time step	0.033 sec			
fuel mass burn rate	0.009 kg/s		0.020 lbm/s	Linear Rocke
Universal Gravitational Acceleration				
Gravitation Accleration	9.800 m/s2		32.200 ft/s2	
Mass and Aero property				
Total Vehicle Mass (Motor and Rocket)	0.018 kg			
Specific Drag Ascent	1.230E-03 N/(m2/s2)		1/2 rho Cd A	
Specific Drag Decent	1.230E-02 N/(m2/s2)			

Application of Newton's Law (Other INPUTS)

wind



Launch Angle

Aerodynamic Lift

The Shaded cells need user input

Rocket altitude Calculations				
Input Variable	Input Data	Units	Converted Data	Converted Unit
Initial Motor Mass	0.018 kg		0.008 lbm	Relavent for A
Rocket Mass	0.000 kg		0.000 lbm	
Burnout Motor Casing Mass	0.011 kg		0.005 lbm	
Thrust timeduration	0.800 sec		0.800 sec	
Ejector delay Time	10.000 sec		10.000 sec	
Thrust Force of Engine	20.000 N		89.000 lbf	
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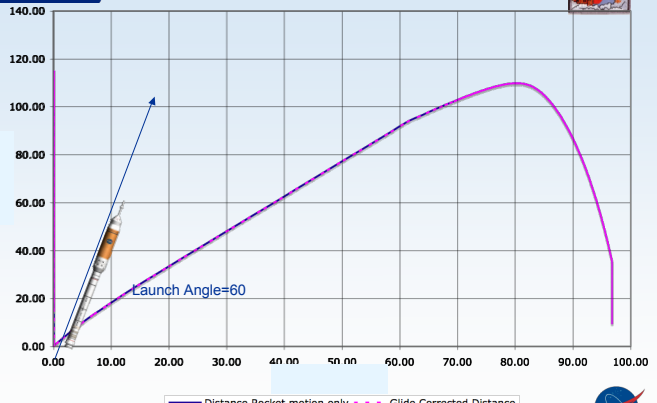
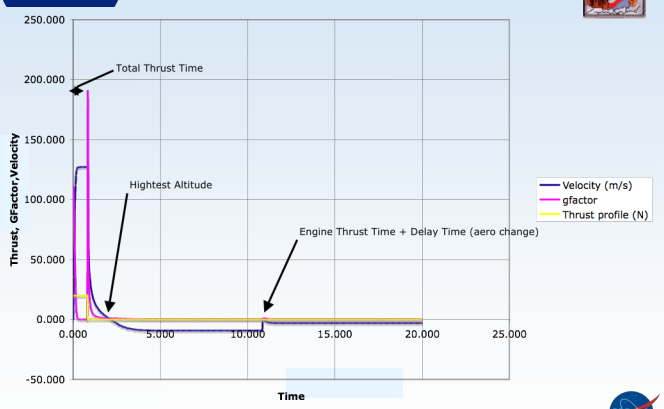
Cross breeze Velocity	0.000 m/s		ft/s	
L/D	0.000			
Solver Parameter				
Total no of Calculation points	602.000 pts			
time step	0.033 sec			
fuel mass burn rate	0.009 kg/s		0.020 lbm/s	Linear Rocke
Universal Gravitational Acceleration				
Gravitation Accleration	9.800 m/s2		32.200 ft/s2	
Mass and Aero property				
Total Vehicle Mass (Motor and Rocket)	0.018 kg			
Specific Drag Ascent	1.230E-03 N/(m2/s2)		1/2 rho Cd A	
Specific Drag Decent	1.230E-02 N/(m2/s2)			

Example





Reference Information

- Stine, Handbook of Model Rockets.
- National Association of Rocketry, http://www.nar.org/

Law of Inertia

An object at rest, or in uniform straight line motion, will remain at rest, or in uniform straight line motion, unless acted upon by a net external force.

This is easier to write mathematically.

$$\text{if } \sum_{i=1}^{\infty} \bar{F}_i = 0, \text{ then } \bar{v} = \text{constant}$$

which translates to: if we add up all of the forces acting on a body from 1 to infinity and get zero as the resultant, then the body is moving with constant velocity.

The converse of this is true as well.

Newton's 2nd Law

- A net force acting on a body produces on that body, an acceleration that is directly related to the force impressed upon the body and inversely related to the mass of the body.
- Newton also explains what happens when the forces do **not** add up to be zero

An easier way to state it is:

$$\text{if } \sum_{i=1}^{\infty} \bar{F}_i = \bar{F}_{net}, \text{ then } \bar{F}_{net} = m\bar{a}$$

Notice that the equation is a vector equation. The acceleration is in the same direction as the net force.

The units of force are directly derived from this formula

$$N = kg\ {}^{m}/_{s^2}$$

3rd Law, Weight, and Normal Force

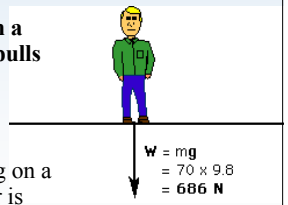
- For every action there is an equal but opposite reaction

or mathematically stated: $F_{ab} = -F_{ba}$

It is an observation of Newton, that forces naturally occur in pairs

Example: **Weight - the force with which a gravitational body (such as the earth) pulls on a body**

Mathematically: **W** = mg



When a person (mass = 70 kg) is standing on a floor the force that they exert on the floor is their weight

Post 630 Rocket Design Mission

All most be accomplished with original vehicle configuration

- **Photographic (Video) from Altitude**
- **High altitude (motor size fixed)**
- **Safe recovery of fragile payload get to a fixed altitude (motor may vary based on load)**
- **Most accurate telemetry prediction**
- **+ Open ideas ?**

Must have a performance model

- **At Least 1D spreadsheet model of the Newton's Law! or**
- http://exploration.grc.nasa.gov/education/rocket/rktsim.html

Explorer Rocket Design Mission

Constraints:

- **Specific Impulse of < 13 per seconds.**
  = Newton/FuelFlow= 1 Newton/(.1 Newton/sec (Estimated burn out mass rate))
- **Total Thrust (<= 5 Newtons-Seconds (TBD!))**
- **Total Mass < .1 kg**
- **Must have Payload capability (Volume and Size)- Instrumentation are provided!**
- **All of launch accessories such as launch logs are not optional!**
- **Must have a design and safety both peer and advisor review**

Explorer Rocket Design Mission

Teams

- **Get to know each other.**
- **Pick a mission**
- **Pick a name for their launch system**
- **Assign roles/Start a discussion and assign roles**
- **Should do some calculations and see if what is possible**
- **Develop a plan of how to build what to test for and what it would look like**
- **Develop a story (Design) for a peer review**

- **Assign lead responsibility for Performance, Aerodynamic Design, Structural Design, Fabrication, Data Acquisition and System Readiness.**
- **Everyone contributes !**