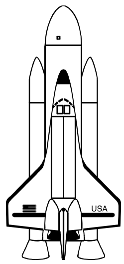
Calculations Manual

WATER ROCKET DESIGN COMPETITION

for SECME

CHOICES!

Explanation of Calculations for Rocket Flight Distance



Although you may be anxious to begin building your rocket, some important decisions need to be made about launch conditions that can help ensure a more accurate launch. Remember: the goal of the competition is to launch the rocket a specific distance. Your task is to ensure your rocket meets that requirement. The following calculations will help you determine what choices to make to predict how far your rocket will go!

These calculations are what is known as an iterative (repeated) process. First, choose the amount of air pressure and water to add to the rocket. Then calculate approximately how far your rocket is predicted to fly. If the resultant distance is not what you desire, choose another value for air pressure or water and re-calculate until you reach the answer you want.

Note: How your rocket really flies will not be *exactly* what is predicted here. The actual launch will vary due to real world elements such as wind changes, drag and differences in your rocket's physical design that will not be accounted for now. These factors are left out to simplify calculations. But the following pages will give you a general starting point for choosing water and air pressure values and will show you their effect on your rocket's flight.

Assume:

- **Air pressure** of the bottle rocket (from 30 to 80 psi) This is the amount of pressure that will be pumped into your rocket at the time of launch.

Find:

- The **Mass Flow Rate,** $\dot{m}$, of the water. This is the amount of water (mass) that flows out of the "rocket nozzle", or throat of the bottle over a period of time (in a second).

$$\dot{m} = A \times cd \times \sqrt{2 \times \rho \times \Delta P} \quad \text{(kg/sec)}$$

- Where A= **Area** of nozzle (m^2) = π x r^2 (r is half the diameter of the 2 liter bottle's throat)
- cd= **Discharge Coefficient**= 0.98 (a dimensionless constant based on nozzle shape and flow conditions)
- ρ= **Density** of water=998 (kg/m^3) (a constant)
- ΔP= Pi- Pf

  Pi = **Air Pressure** of bottle (chosen in step (1))

  Pf = **Atmospheric Pressure**= 14.7(psi) (or 101,300 Pa- 1Pa=1N/m^2) (a constant)

Find:

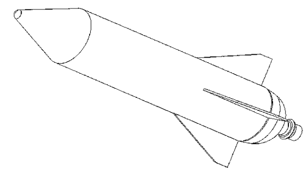
- Use your result from $\dot{m}$ to find the **Exit Velocity,** *V*, (velocity at the bottle exit), of the water. (m/sec)

$$V = \frac{\dot{m}}{(\rho \times A)}$$

Find:

Find the **Thrust**, f_t, of the Rocket. This is the amount of force that pushes the rocket in a forward direction. *(in Newtons)*

$$f_t = \dot{m} \times V$$



Assume:

Next choose the mass of water you will use to fuel your rocket. Remember ***mass= density x Volume.*** So, for example, if you plan to add 1Liter (volume, about the amount in a sports drink bottle) of water:

- Vol= 1Liter= 1000mL= 1000cm^3 or 0.001m^3
- ρ = **Density** of water= 998 (kg/m^3)(a constant)
- m_{H_2O} = ρ *x Vol* (in kg)

Find:

Thrust isn't the only force acting on your rocket. There are also **forces acting *against*** the rocket's motion. The **weight** (m_{ave} x g) of the rocket acts against its attempts to move forward. **Drag** (f_d), (the force of wind acting against the surface of the rocket) also acts on the rocket, but for these calculations, drag will be neglected. *(in Newtons)*

$$NetForce = f = f_t - f_d - (m_{ave} \times g)$$

- f_d = 0 since the rocket is very small.
- m_{ave}= ave. mass of the rocket= mass of Rocket empty + m_{H_2O}/2
- g = gravitational acceleration constant= 9.8 m/sec^2

Scholar's note: You may be beginning to see how the amount of water you add affects thrust. The Range equation (equation 8) shows that the higher the water mass, the longer time the rocket will be propelled, therefore seeming to increase the Range. So why not just fill the bottle up with water and make it soar? Well, keep equations 6 and 7 in mind. The mass of the water, has two functions. It not only increases the time the rocket is propelled, but it also adds to the force acting against the motion of the rocket (weight), decreasing acceleration. Too little weight can also be harmful; it can make the rocket easily affected by the 'neglected' elements discussed earlier, like wind changes. A balance must be achieved.

Find:

Find the **Acceleration**, *a (m/s²)*, of the rocket. Use the equation:

$$f = m_{ave} \times a \quad \textit{(force in Newtons: N)}$$

Now find the **Range**, *R*, or distance the Rocket will travel, for the water and air pressure conditions you have chosen.

$$\textbf{\textit{Range}} = R = \frac{V^2_{bottle} \times \sin 2\theta}{g} \quad \textit{(in meters)}$$

- Where: $V_{bottle} = a \times t$

- $t = \dfrac{m_{H2O}}{\dot{m}}$ = Time when all of the water is expelled from the Rocket.

- θ angle Rocket is being launched $= 50^\circ$

There are two remaining factors that will help better determine the actual range of your vehicle. Up until this point we have not taken Drag into consideration for purposes of simplification. Additionally, it has been assumed that the air pressure, P_i, forcing the water out of the bottle remains constant until the last drop of water has been expelled. It is necessary to account for Drag as well as the volumetric relationship between the amount of water and the amount of air in your bottle to predict your rocket's Final Range (R_F).

Recall, **Drag** is the resistance produced on bodies as they move through air. The effects of drag increase with respect to increases in velocity.

<u>Determining a Drag Factor</u>

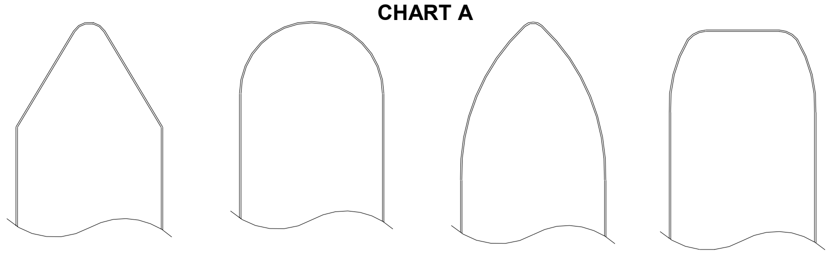
To account for the Drag force on your vehicle use the following formula:

$$D = 1 - (D_c)$$

where D_c : Drag coefficient
and D : Drag Factor

Select a value for D_c based your nose cone design. See Chart A and calculate D.

CHART A



$D_c = .31$ $D_c = .30$ $D_c = .29$ $D_c = .33$

Now, multiply your **Range (R)** times the **Drag Factor** following the equation below:

$$R_D = R \times D$$

You will use $\mathbf{R_D}$ in your final calculation, see next step!

Finally, you need to determine the effects that the water volume versus the pressurized air volume will have on your rocket's performance.

Remember the initial suggestion to make your calculations an iterative or 'repeated process? Well, iterations with water volume ONLY will indicate that your rocket's range will continuosly increase with increasing amounts of water based on the previous steps, however, this statement is true only up to a certain point. Eventually, increases in water volume will begin to LIMIT the range of your vehicle rather than increasing it.

Why???

Well there are two major reasons:

1. Our previous mass flow rate equation assumes that the air pressure in the bottle remains constant. Actually, **the bottle's internal pressure drops extremely fast** as the water is being expelled and the air volume inside the bottle expands.

Take a moment and think of a balloon that is full and one that is only half full, the air pressure in the half-full balloon is **LESS** than that in the full balloon.

2. Another important concept to understand is ***Gas Compression and Expansion*** (For our case the gas is Air). Compressed gases within a pressure vessel WILL EXPAND (increase in volume) once the vessel is opened to the atmosphere.

In your water rocket problem, the air in your bottle expands as it pushes the water out. Keep in mind that your bottle has a fixed volume (2L), therefore, as you INCREASE the VOLUME of WATER, the VOLUME of AIR inside your bottle DECREASES.

Take note:

LARGER VOLUMES of GAS will expand MORE than SMALLER VOLUMES of GAS at the SAME PRESSURE.

Think of the 2L bottles filled with soda you open during a pizza party: Even though the internal pressure of the bottles may reach as high as 40-50psi, the bottle WILL NOT fly wildly out of your hand because the air volume inside, though under significant pressure, is VERY SMALL.

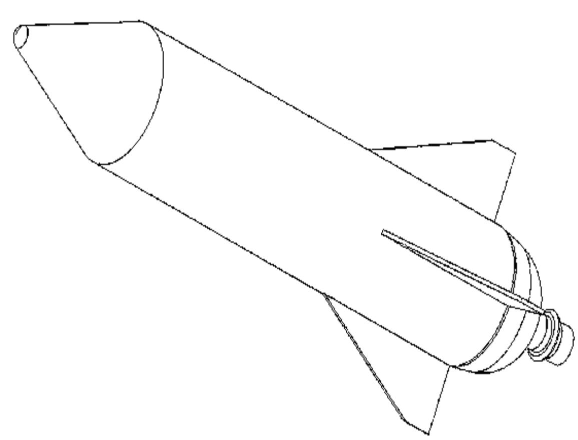
The following equation is based on controlled flight data and has been derived to help you account for the Air-to Water volume fraction within your bottle. Plug in the R_D value calculated in the previous step along with your rocket's water volume to determine the **Final Range (R_F)** of your rocket's trajectory.

$$R_F = R_D - (.00015 \times (V_{H_2O} - 700)^2) + 75$$

where V_{H_2O} = the rocket's water volume (mL)

Note: R_D MUST BE in meters and water volume in mL. Above equation derived based on the competition launch angle of 50°.

So, you've calculated the **Range**, or distance the rocket is predicted to travel, would the rocket reach the target? Would the rocket fly too far? Vary the values for water mass and air pressure. How does the Range Change?



Appendix A

Examples Section

Mass Flow Rate

Mass Flow rate is a measure of the amount of mass (Fluid) passing through a given area with respect to time. Some every day examples of mass flow rate are water traveling through a fireman's hose, soda flowing from a fountain into a cup, and propellant being rapidly expelled from a rocket's engines. The mass flow rate of a given fluid can be determined with the following equation:

$$\dot{m} = A \times cd \times \sqrt{2 \times \rho \times \Delta P}$$

Example 1

A mother needs to fill a bathtub half full so that her young daughter can take a bath. The tub has a total capacity of 80 liters. If water flows through the nozzle into the tub at flow rate of .20kg/sec how long will it take to fill the tub half way?

Step 1 Determine half the tub's volume capacity. Total capacity = 80L, so the half capacity = 40L.

Step 2 Next we must calculate mass for 40L of water. Convert the water volume to mass by multiplying the volume of water required by the density of water ρ_{H2O}. (ρ is pronounced 'rho').

$$\rho_{H2O} = 998\text{kg/m}^3$$

We know that $1\text{L} = .001\text{m}^3$

therefore, $40\text{L} = .04\text{m}^3$

now multiply, $.04\text{m}^3 \times 998\text{kg/m}^3 = 39.92\text{kg}$

Step 3 Now that we know the mass of water required we can determine the amount of time (t) required to fill the tub half full based on the defined mass flow rate of .20kg/sec, that is for every second that passes .20kg of water will flow into the tub.

$$t = \frac{m_{H_2O}(kg)}{\dot{m}(kg/\sec)}$$

$$t = \frac{39.92(kg)}{.20(kg/\sec)}$$

$$t = 199.6 \text{ sec or } 3 \text{ min } 19.6\text{sec}$$

Challenge: If the mass flow rate for the above example equals .20kg/sec, what is the volume flow rate equal to?

Example 2

A gardener must water his garden daily due to a severe drought. It is important that his small crop of vegetables get at least 200L of water each day. He uses a nozzle attached to a hose that supplies water at a pressure of 25psi. Considering the nozzle has an exit diameter of 2cm, determine the mass flow rate.

Comprehension:

It is critical to understand exactly what is occurring during this process. While the water is being supplied at a pressure (P_s) of 25 psi, it is being expelled into a pressurized environment 'Our Atmosphere'. While atmospheric pressure varies, it is safe to assume that atmospheric pressure P_{atm} equals 14.7 psi for this sea level application. This pressure will offer resistance to the water being ejected from the nozzle and therefore must be accounted for. Hence, the pressure difference or ΔP (pronounced 'delta' P) is derived by subtracting the atmospheric pressure P_{atm} or (14.7psi) from the supply pressure P_s (25psi). We will use ΔP for the mass flow rate calculation.

Likewise, it is necessary to calculate ΔP for your rocket's mass flow rate equation based on its initial 'vessel' or internal pressure and P_{atm}

Step 1 Given supply pressure (P_s) and atmospheric pressure (P_{atm}) calculate ΔP:

$$P_s = 25\text{psi}$$
$$P_{atm} = 14.7\text{psi}$$
$$\Delta P = P_s - P_{atm}$$
$$\Delta P = 10.3\text{psi}$$

For this metric calculation, psi (pounds square inch) must be converted to N/m^2 (Newton per square meter) so multiply 10.3 psi by 6.8948×10^3 or 6894.8,

$$\Delta P = 71016.4 \text{ N/m}^2$$

Step 2 We know the density of water ρ_{H2O} is 998 kg/m^3 at room temperature

Step 3 Calculate the 'effective flow area' for your nozzle. First, determine the area for a gardener's nozzle having a 2cm exit diameter. Multiply the result by .98, the discharge coefficient or c_d.

About Discharge Coefficients: Discharge Coefficients are used to account for flow losses caused by non-uniform flow paths. Since a gardener's nozzle converges down to 2cm from 4cm it is reasonable to assume that the flow rate will be reduced by a dimensionless factor of .98 or 2 percent due to the change in flow area.

You will be required to apply a discharge coefficient during the mass flow rate calculation for your rocket, due to the converging nozzle of your 2L bottle.

Example 2 Continued…………….

Area for a circle $(A) = \pi r^2$

where $\pi = 3.14$ and d=2cm or .02m

r = d/2 = 1cm

and 1cm = .01m

A = π x .(01m)^2

A = 3.14 x .1000m^2

A = .000314m^2

thus, Ac_d = .000314m^2 x .98

Ac_d = .000308m^2

Step 4 Now calculate the mass flow rate given:

ΔP = .01 N/m2

ρ_{H2O} = 998 kg/m^3

Ac_d = .000308m^2

$$\dot{m} = A \times cd \times \sqrt{2 \times \rho \times \Delta P}$$

$$\dot{m} = .000308\text{m}^2 \text{ x } \sqrt{2 \ x \ 998 \frac{kg}{m^3} \ x \ 71016.4 \frac{N}{m^2}}$$

Keep in mind that $1\text{N} = 1 \ \frac{kg \cdot m}{\sec^2}$

That is one Newton equals the acceleration of 1 m/sec^2 to a one kilogram mass.

$$\dot{m} = .000308\text{m}^2 \text{ x } \sqrt{2 \ x \ 998 \frac{kg}{m^3} x \ 71016.4 \frac{\frac{kg \cdot m}{\sec^2}}{m^2}}$$

Now pay close attention to what happens to the units……

$$\dot{m} = .000308\text{m}^2 \text{ x } \sqrt{14.17 \ x \ 10^7 \frac{kg^2}{m^4 \cdot \sec^2}}$$

$$\dot{m} = .000308\text{m}^2 \text{ x } 11905.8 \ \frac{kg}{m^2 \cdot \sec}$$

$$\dot{m} = .000308\cancel{\text{m}^2} \text{ x } 11905.8 \ \frac{kg}{\cancel{m^2} \cdot \sec}$$

$$\dot{m} = 3.67 \ \frac{kg}{\sec}$$

Thrust

Jet and rocket engines create thrust by accelerating propellants (usually hot gases) to high speeds. Other objects can create forces in similar ways, though. As Newton's Third Law states, all action forces create an equal and opposite reaction force. Thus any object that causes mass to accelerate in one direction will experience a 'thrust' force (f_t) in the opposite direction. The amount of force is described by the thrust equation:

$$f_t = \dot{m} \times V$$

where $\dot{m}$ is the mass flow rate (in kilograms/second) of the propellants out of the object and V is the velocity (in meters/second) that it exits. Note that if the exiting propellants are high-pressure fluids exiting into the air, thrust will be somewhat higher. Most of the time, though, we can assume that a jet of propellants exits at atmospheric pressure and use the above equation.

Example 3

Firefighters often need to spray large amounts of water to great heights. To do so, they use high-power pumps and heavy-duty hoses that accelerate the water to high speeds. This spraying creates a reaction force on the hose that could cause it to move backwards violently. Two or more firefighters thus often hold a firehose steady to counteract this thrust.

Consider one such firehose attached to a truck that pumps water at a mass flow rate of 80 kg/s. The diameter (d) of the nozzle is .1 meters. Find the thrust force on the hose created by the spraying of water (density = 998 kg/m^3). You may assume that the water exits the hose at atmospheric pressure.

Solution

The equation for thrust is:

$$f_t = \dot{m} \times V$$

where $\dot{m}$ is the mass flow rate and V is the velocity of the water exiting the nozzle. Though we are only given the value of mdot, we can find V from the equation:

$$V = \frac{\dot{m}}{(\rho \times A)}$$

where ρ is the density of the water. To find V we must first determine the exit area of the nozzle. Since we know that area = $\pi \times R^2$ where R is half the nozzle diameter, we have:

$$A = \pi \times r^2$$

$$A = \pi \times (d / 2)^2$$

$$A = \pi \times (.1\ m / 2)^2$$

$$A = .008\ m^2$$

Example 3 Continued……………….

Now we can find the exit velocity:

$$V = \frac{\dot{m}}{(\rho \times A)}$$

$$V = 80\ kg/s\ /\ (998\ kg/m^3 \times .008\ m^2)$$

$$V = 10.0\ m/sec$$

Now we know mass flow rate and velocity so we can find thrust:

$$f_t = \dot{m} \times V$$

$$f_t = 80\ kg/s \times 10.0\ m/sec$$

$$f_t = 801\ N$$

Thus the firefighters have to put almost 200 lbs of force on the hose to keep it from accelerating backwards!

Now take a moment to apply the above theory to your water rocket: Gravity acts on the mass of your rocket and keeps at rest on the launcher, at least until another force acts on the rocket. In order for the rocket to move, the other force acting on it MUST be GREATER than earth's gravitational pull. In Example 3 think of the force the firemen apply to the hose as gravity or a 'holding force'. Unlike the firemen's success with keeping the hose in position, the thrust force produced by the water rapidly exiting from your bottle will overcome the effects of gravity on the total mass of the rocket…………at least temporarily☺. Since the thrust force (f_t) is applied only for a short time, gravity will eventually win causing the rocket to return to earth.

Force & Acceleration

Newton's First Law of motion tells us that an object will only accelerate when a force is applied to it. Be careful, though! Often times, forces will cancel each other by acting in opposite directions. For example, your weight is a force that is pulling you toward the center of the earth. The chair you are sitting in, however, is exerting an upward support force that is exactly equal to your weight. Thus the *net force* is zero and you do not experience an acceleration.

When the net force on an object is not zero—i.e. when unbalanced forces exist—the object will accelerate. Newton's Second Law states this acceleration by the following equation:

$$F = ma$$

Solving for acceleration, $a = F / m$

Where F is the net force in Newtons, m is the mass in kilograms, and a is the acceleration in meters/second^2. Note that a and F will always act in the same direction.

Example 4

Rocket engines create thrust through the principle of reaction forces. In the previous example, the firemen applied a reaction force equal to the thrust force generated by the rapid mass flow rate of water being expelled. In this case, rocket engines accelerate propellants (usually hot gases) downwards to create an upward reaction force.

Consider the Space Shuttle, which weighs approximately 2,700,000 kg as it sits on the launch pad. Once the main engines and solid-rocket boosters have started and reached full power, they produce a total of 34,400,000N of thrust. The shuttle does not move upward, however, until explosive bolts release the boosters. Recalling that acceleration is a result of the net force acting on an object, calculate the instantaneous upward acceleration of the shuttle when the bolts release.

Solution:

The two forces acting on the shuttle are its weight and the thrust of the engines. The weight force W is simply the mass times the acceleration of gravity:

$$W = -mg$$

$$W = -(2{,}700{,}000\ \text{kg})(9.8\ \text{m/s}^2)$$

$$W = -26{,}460{,}000\ \text{N (downwards)}$$

Example 4 Continued……………

Again, $F_{net} = F_t + W$

$$F_{net} = 34{,}400{,}000 \text{ N} + (-26{,}460{,}000 \text{ N})$$

therefore, $F_{net} = 7{,}940{,}000\ N$

From the Second Law, we can thus find the initial acceleration:

$$F_{net} = F$$

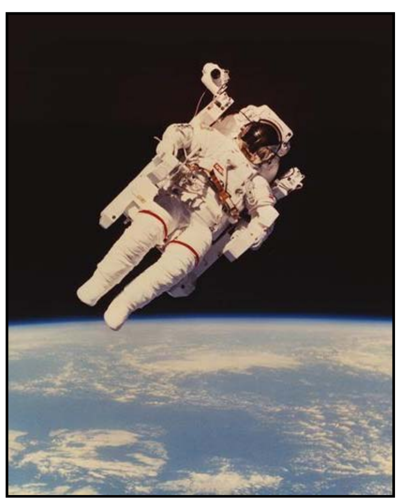
$$F = ma$$

$$a = F / m$$

$$a = 7{,}940{,}000\ N / 2{,}700{,}000\ kg$$

$$a = 2.94\ m/s^2$$

Note that the mass of the shuttle is actually constantly changing: propellants are being expelled from the engines at high speed. Thus the acceleration will continue to increase dramatically as the shuttle lifts off.



Acceleration and Velocity

We have just seen how Newton's laws help describe the relationship between an object's acceleration and the forces acting on it. This is important because we hope to predict the motion of our rocket and find its range. But how does knowing the acceleration help us? Remember that ***acceleration*** is simply how fast an object's ***velocity*** is changing at that moment. If we can assume that acceleration is constant during a time period t, then we can find the change in an object's velocity ($v - v_o$):

$$v - v_o = a \times t \qquad (3)$$

change in velocity = acceleration × time

or we can rewrite the equation:

$$v = a \times t + v_o \qquad (4)$$

final velocity = acceleration × time + initial velocity

This shows us that we only need to know the initial velocity and acceleration to find the final velocity after time t.

Example 5

A sports car is traveling forward at 62 ft/s when the driver lightly applies the brakes. The brakes cause a constant deceleration of 6 ft/s^2. **How much time will it take the car to come to a stop?**

Solution:

The time t can be found by rearranging equation (4) and substituting $v = 0$ (because the car will be stopped after time (t). The acceleration a = -6 m/s^2 is negative because it is in the direction opposite of the car's velocity:

$$v = a \times t + v_o$$

$$t = (v - v_o)/a$$

$$t = -62\ ft/s\ /\ -6\ ft/s$$

$$t = 10.3\ seconds$$

Range

Range is the distance an object will travel depending on its velocity and angle of trajectory (θ). Thus two objects having the same mass will travel the same distance unless acted upon by outside forces such air resistance (drag); this fact explains why it is difficult to toss a balloon filled with air, but rather easy to toss a balloon partially filled with water. Keep in mind that more force is required to accelerate a heavier mass to the same velocity as that of a lighter mass.

> **The dry mass of your rocket is critical for stability and for overcoming drag, but excluding drag rockets having the same velocity (speed) would travel the same distance. Air resistance will have a greater effect on the range of lighter masses than larger masses moving at the same velocity.**

Example 6

A women playing centerfield must quickly throw a softball to second base during a game to prevent a player on the opposing team from advancing from first base. If she releases the ball from her hand at an angle of 30^o, at what velocity must the ball be thrown in order to reach second base which is 50m away?

Note: For simplicity we will ignore the drag force of 'air' in this example, however, drag has a significant effect with many trajectory applications, including the trajectory calculation for your rocket.

Using the Range Equation

$$R = \frac{V^2 x \ \ \sin\theta}{g}$$

where,

R : Range = 50m
V : Velocity = ? (m/sec)
T : Release or 'Trajectory' Angle = 30^o
G : Gravitational Acceleration = 9.81m/sec^2

Determine Velocity:

First we must rearrange the range equation as shown:

$$V^2 = \frac{R \ x \ g}{\sin 2\theta}$$

$$V = \sqrt{\frac{R \ x \ g}{\sin 2\theta}}$$

Example 6 Continued……………

$$V = \sqrt{\frac{50m \ x \ 9.81\frac{m}{\sec^2}}{\sin(2x30^o)}}$$

$$V = \sqrt{\frac{490.5\frac{m^2}{\sec^2}}{.8660}}$$

$$V = \sqrt{566.4\frac{m^2}{\sec^2}}$$

therefore, $$V = 23.8\frac{m}{\sec}$$

Wow that's neat but I relate better to miles per hour (mph)……………..

Okay, to convert meters per second to miles per hour use the following relationship:

1m/sec = 2.2369 mph

So we multiply the result by 2.2369

23.8m/sec x 2.2369 = **53.2 mph!**

Example 7

A high school quarterback passes a football at velocity of 20m/sec to a receiver running down field directly in front of him. If the quarterback releases the football at an angle (θ) of 45^o, what distance must the receiver reach to catch the ball? (Assume that the receiver will catch the ball at the same height that it was thrown from.)

Again:

$$R = \frac{V^2 x \ \ \sin 2\theta}{g}$$

Example 7 Continued…………………

quickly, V= 30m/sec

$\theta = 45^o$

$g = 9.81\ m/sec^2$

$$R = \frac{\left(20\frac{m}{\sec}\right)^2\ x\ \sin 2\theta}{9.81\frac{m}{\sec^2}}$$

$$R = \frac{400\frac{m^2}{\sec^2}\ x\ \sin 90^o}{9.81\frac{m}{\sec^2}}$$

Considering $\sin 90^o = 1$,
$$R = \frac{400\frac{m^2}{\sec^2}}{9.81\frac{m}{\sec^2}}$$

R = 40.8m

Great, but I want to know the equivalent of 40.8m in feet (ft).

Well we know 1m = 3.2808 ft

so simply multiply 40m x 3.2808

We have **R= 133.8ft**

Congratulations on reading through this brief Appendix. These examples are intended to help you better understand how many of the physical principles of Rocketry relate to everyday applications. We encourage you to create and work through problems of your own to further stimulate your understanding of the concepts of Mass Flow, Thrust, The Laws of Motion, and Trajectory Calculation. More in depth equations and examples will follow in future editions of this manual. Good Luck Rockeeters as you aim for the Stars!

Note: A useful conversion table is provided on the following page.

Conversion Table

Multiply	*By*	*To obtain*
centimeter (cm)	3.2808×10^{-2}	feet
	3.9370×10^{-1}	inches
	1.0000×10^{-2}	meters
cubic centimeter (cm^3)	6.1024×10^{-2}	cubic inches
	1.0000×10^{-6}	cubic meters
cubic foot (ft^3)	2.8317×10^{4}	cubic centimeters
	1.7280×10^{3}	cubic inches
	2.8317×10^{-2}	cubic meters
cubic inch (in^3)	5.7870×10^{-4}	cubic feet
	1.6387×10^{-5}	cubic meters
cubic meter (m^3)	1.0000×10^{6}	cubic centimeters
	3.5315×10	cubic feet
	6.1024×10^{4}	cubic inches
foot (ft)	3.0480×10	centimeters
	3.0480×10^{-1}	meters
foot/second (fps)	1.0973	kilometers/hour
	3.0480×10^{-1}	meter/second
	6.8182×10^{-1}	miles/hour
inch (in)	2.5400	centimeters
	2.54×10^{-2}	meters
kilogram (kg)	1.0000×10^{3}	grams
	3.5274×10	ounces
	2.2046	pounds
	9.8067	newtons
kilogram/square meter (kg/m2)	9.8067	newtons/square meter
liter (l)	3.5315×10^{-2}	cubic feet
	2.6417×10^{-1}	gallons (U.S. Liquid)
	1.0000×10^{-3}	cubic meters
meter (m)	1.0000×10^{2}	centimeters
	3.2808	feet
meter/second (m/sec)	3.2808	feet/second
	3.6000	kilometers/hour
	2.2369	miles/hour
mile/hour	1.4667	feet/second
	1.6093	kilometers/hour
	4.4704×10^{-1}	meters/second
newton (N)	1.0197 x 102	grams
	1.0197×10^{-1}	kilograms
	2.2481×10^{-1}	pounds

Please Note: The above Conversion Table is provided as an aid. Use of the all of conversion factors is **not** required for the trajectory calculations. Be careful! Pay attention to units and exponents. Make sure you use only those conversions which are needed for your calculations.

newton/square meter newton/square meter (pascal (Pa)) (N/m2)	1.0197×10^{-1} 2.0885×10^{-2} 1.4504×10^{-4}	kilograms/square meter pounds/square foot pounds/square inch
ounce (oz)	2.8349×10 2.8349×10^{-2} 6.2500×10^{-2}	grams kilograms pounds
pound (mass) (lb)	4.5359×10^{2} 4.5359×10^{-1} 1.6000×10	grams kilograms ounces
pound (force) (lbf)	4.4482 4.4482	newtons kilonewtons
pound/square inch (psi)	7.0307×10^{2} 6.8948×10^{3} 1.4400×10^{2}	kilograms/square meter newtons/square meter pounds/square foot
square foot (ft^2)	1.4400×10^{2} 9.2903×10^{-2}	square inches square meters

Please Note: The above Conversion Table is provided as an aid. Use of the all of conversion factors is **not** required for the trajectory calculations. Be careful! Pay attention to units and exponents. Make sure you use only those conversions which are needed for your calculations.

Notes: