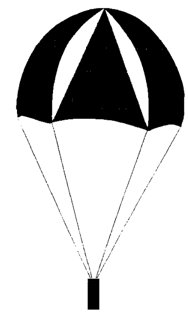
Title: It's a DRAG!!!

Brief Overview:



Drag is one of the four forces of flight, the others being Lift, Gravity, and Thrust. Within the atmosphere all things are affected by drag. This lesson details how to measure and calculate the drag coefficient for a parachute through hands-on experiments. Parachutes experience only two forces, drag and weight, and at terminal velocity DRAG = WEIGHT (see attachment Background Information). The calculations and formulas are applicable to other flying objects as well.

Links to NCTM Standards:

- **Mathematics as Problem Solving**
  The Physics and Aeronautics students will apply their knowledge of atmospheric pressure, dynamic pressure, velocity, and forces of flight. Students will work together in cooperative work groups to assemble parachutes and determine the drag coefficient of the parachutes. They will perform the assessment separately.

- **Mathematics as Reasoning**
  The students will demonstrate their ability to use geometrical spatial reasoning.

- **Statistics**
  The students will be asked to create graphs showing Hole Diameter vs. Time and Hole Diameter vs. Drag Coefficient.

- **Number and Number Relationships**
  Students will be asked to find the area of a triangle. They will have to calculate drag coefficient of a constructed parachute.

Grade/Level:

Grades 7-12

Duration/Length:

Two one hour sessions

Prerequisite Knowledge:

Students should have an understanding of the following:

- Forces of flight
- Density and pressure
- Velocity as a function of distance traveled and time
- Units
- Estimating, rounding and place value
- The y = tangent x graph or at least knowledge of the Cartesian coordinate plane

Objectives:

Students will:

- assemble a parachute.
- determine the drag coefficient for the parachute in four different cases.

Materials/Resources/Printed Materials:

- 18" hexagonal parachute made of plastic, nylon, Tyvek or other suitable material
- 3 shroud lines for the parachute. Each should be 3 times the width of the parachute.
- Compass to make circles
- Scissors or hobby knife
- Cellophane tape
- Empty film canister or other weight
- Scale
- Stop watch

NOTE. Parachutes may be purchased as kits from various sources, or educators can make their own by creating a template and having the students cut the parachutes from available material.

Development/Procedures:

Step 1:

Pose the question "What determines how much drag an object creates?". Answers include shape of the object, weight, velocity, and atmospheric density (constant at sea level). In aeronautics measurements of lift and drag coefficients are used to compare the efficiency of different shapes. To be able to perform a comparison a non-dimensional measure has to be used. These non-dimensional descriptors are called coefficients. The Drag Coefficient is a measure of how much drag an object generates. For airplanes, Drag is the force opposing Thrust, and a low drag coefficient is preferred, i.e., less drag leads to a more efficient airplane. For parachutes, Drag is the force opposing Weight, and a high drag coefficient is preferred, i.e., the more drag the slower it falls.

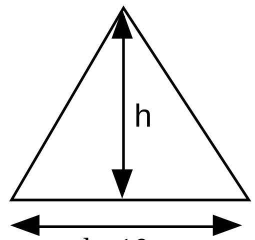
Step 2:

Assemble the parachutes. See instructions for the DragStar parachutes.

Step 3:

Start with having the students calculate the reference area for the parachute.The reference area will be used later in the Drag coefficient calculations. The 18" hexagonal parachutes can be divided into **six equilateral triangles with side lengths of 10"**. Show students how to perform the area calculation. Also, give students a copy of the Parachutes Worksheet. Have students calculate the area for the parachute, note that the following sample calculation is based on the 18" hexagonal parachute.

The **area for one triangle** is:



$$\text{Area} = \frac{1}{2}\ \text{bh}$$

b = base length (inches) = 10"

h = height (inches) = ?

$$h = \frac{1}{2}\ b\ \sqrt{3}$$

$$h = \frac{1}{2} * 10 * \sqrt{3}$$

$$h = 5 * \sqrt{3}$$

Height = 8.66 in

$$\text{Area} = \frac{1}{2} * 10 * 8.66$$

Area = 5 * 8.66

Area = 43.3 in^2

Area for the 18" parachute = 43.3 * 6 = 259.8 in^2. Multiply by 6, since there are 6 equilateral triangles in a hexagon. Convert inches to feet by dividing by 144. 259.8 in^2 / 144 = 1.80 ft^2

Step 4:

Have the students insert the shroud lines, below the confluence point (see assembly instructions), into an empty film canister and close the lid. (The film canister may be substituted for any other attachable weight, as long as the same weight is used for all parachutes.) **Weigh the Parachutes and record the weight. Prior to dropping the parachutes measure the drop distance (altitude).**

Step 5:

Drop the parachutes. **Time the drops from release to landing.** Have students record the time for their parachutes on the worksheet.

Step 6:

Have students calculate **Drag Coefficients (C_D)** for the parachute as follows:

DRAG = WEIGHT

Drag = q * s * C_D Or Weight = q * s *C_D

Where **q** = 1/2 ρV^2 and is the Dynamic Pressure

ρ = density of air at sea level = 0.002377 slugs/ft^3

V = Velocity (ft/sec) = $\frac{\text{Distant}}{\text{Time}}$ ← **Measured during drops**

s = reference area = Area of the parachute = 259.8 in^2 = **1.80 ft^2**

Solve for C_D

$C_D = \frac{\text{Drag}}{q * s}$ or $\frac{\text{Weight of Parachute}}{q * s}$

Example:

Assume 18" hexagonal parachute, with reference area **s** = 1.80 ft^2 and
weight = 0.2 lbs

distance dropped = 50 feet

time from release to landing = 7.5 seconds

V is then $\frac{50}{7.5}$ = 6.67 ft/sec

q = 1/2 ρV^2 = 0.5 * 0.002377 * 6.672 = 0.053 lbs/ft^2

C_D = $\frac{0.2 \text{ lbs}}{0.053 \text{ lbs/ft}^2 * 1.80 \text{ ft}^2}$

C_D = 2.10

Step 7:

Have the students cut holes in the center of the parachute, starting with a 4" diameter hole then increase the size to 8" and 12". Return to step 5 for each hole diameter.

Step 8:

Create graphs showing Hole Diameter vs. Time and Hole Diameter vs. Drag Coefficient. Discuss the results.

Performance Assessment:

Have students write a report relating what they learned from the experiments. Report evaluation factors may include, but are not limited to, the student's understanding of: DRAG and other forces of flight; the use of coefficients; graphic and numeric representation of data; atmospheric pressure; and velocity.

Extension/Follow Up:

The students can use different shape parachutes (cross chutes, circular chutes) while keeping the reference area the same and compare drag coefficients for the different shapes.

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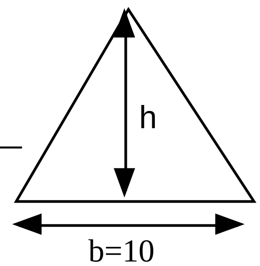
Parachutes Worksheet

The **area for one equilateral triangle** is:

Area = $\frac{1}{2}$ bh

Where:

b = base length (inches) = _________



h = Height = $\frac{1}{2} b \sqrt{3}$

h = height (inches) = __________

Area = ______________

s = Area for the 18" parachute = ___in^2 * 6 = ____

s = ________ in^2 = _________ ft^2

Weight: ______________

Drop distance: ____________

Calculate **Drag Coefficients (C_D)** for the parachute as follows:

DRAG = WEIGHT

Drag = q * s * C_D
or
Weight = q * s * C_D

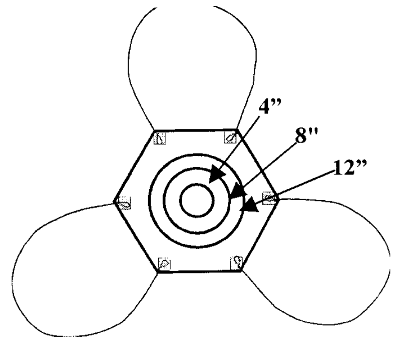
Where

q = 1/2ρV^2 and is the Dynamic Pressure

ρ = density of air at sea level = 0.002377 slugs/ft^3

V = Velocity (ft/sec) = $\frac{\text{Distance}}{\text{Time}}$

Solve for C_D =



Drop 1, hole diameter 0 inches

Time:___________________

Velocity:_________________

C_D:_____________________

Drop 2, hole diameter 4 inches

Time:___________________

Velocity:_________________

C_D:_____________________

Drop 3, hole diameter 8 inches

Time:___________________

Velocity:_________________

C_D:_____________________

Drop 4, hole diameter 12 inches

Time:___________________

Velocity:_________________

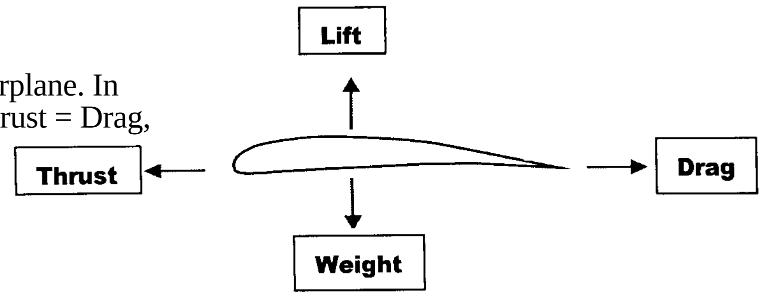
C_D:_____________________

C_D = $\frac{\text{Drag}}{q * s}$ or $\frac{\text{Weight of Parachute}}{q * s}$ = ___________________

Background Information

Forces of Flight

There are four forces that act on an airplane. In equilibrium or level constant flight Thrust = Drag, and Lift = Weight.



Terminal Velocity

Parachutes achieve terminal velocity, i.e. a constant velocity quickly after deployment. At terminal velocity there is no acceleration, the parachute is in equilibrium and Drag = Weight.

Pressure

Total Air Pressure at sea level is equal to about 14.7 psi (pounds per square inch). This is the force exerted by the atmosphere on every square inch of all objects on Earth.

Dynamic pressure (q) is a force exerted on an object due the motion of the air around the object. $\mathbf{q = 1/2\ \rho\ V^2}$

ρ is density of the fluid (Mass, slugs/Volume, ft3). For air at sea level, ρ =0.002377 slugs/ft3 (1.2250 kg/m3).

V is the velocity or speed of the fluid in (Distance, ft/Time, sec). Speed of sound = 1116 ft/sec at sea level.

Static pressure (P_0) is equal to atmospheric pressure in still air (2116.2 lbs/ft2). It exerts a force on an area(s).

Total pressure (P_T) is the sum of Dynamic Pressure and Static Pressure. Total pressure at sea level is 14.7 psi or 2116.2 lbs/ft^2 (1.013255 N/m^2). This is the total pressure exerted by the motion of the air molecules.

Total Pressure = Dynamic Pressure + Static Pressure **Bernoulli's equation**

or $\mathbf{P_T = 1/2\rho V^2 + P_0}$

The Total Pressure is a constant: if the velocity is increased then the dynamic pressure also increases, and the static pressure is reduced. The increase in the dynamic pressure and decrease in static pressure is how an airplane wing generates lift.

Lift Coefficient (C_L) and Drag Coefficient (C_D)

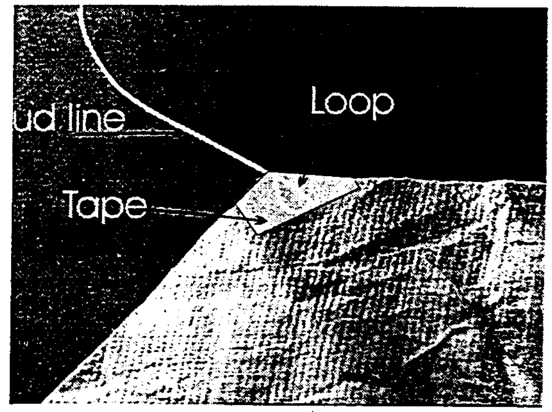
These coefficients are measures of how efficiently an object converts the dynamic pressure into lift or drag.

Airplanes:
A high lift coefficient means that a wing is efficient, i.e. the wing is shaped such that more of the dynamic pressure is converted into a lifting force. For the drag coefficient the case is the opposite, an efficient wing has a low drag coefficient.

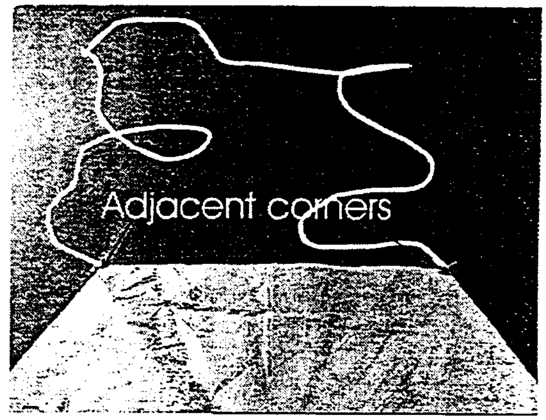
Parachutes:
In the case of parachutes a high drag coefficient is desirable. The more drag the parachute generates the slower it falls.

DragStar Parachute Assembly Instructions

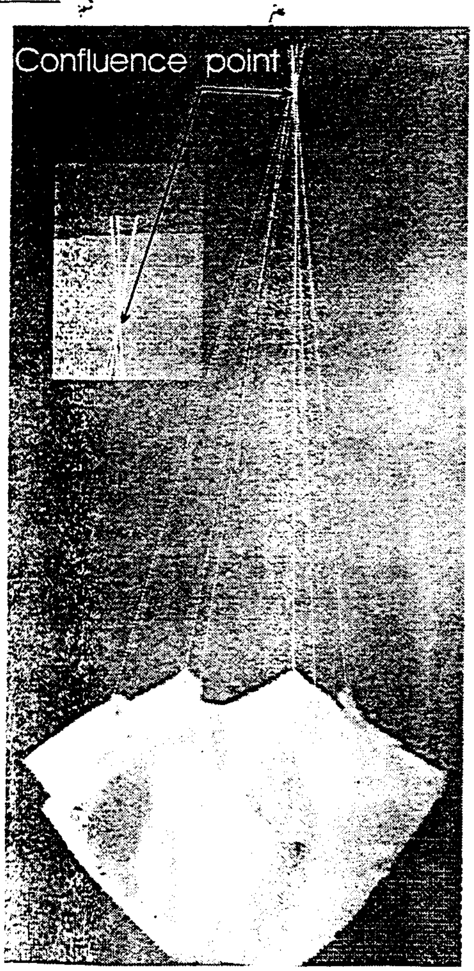
1. Make a loop at the end of the Shroud line. Secure the loop to the parachute with tape.

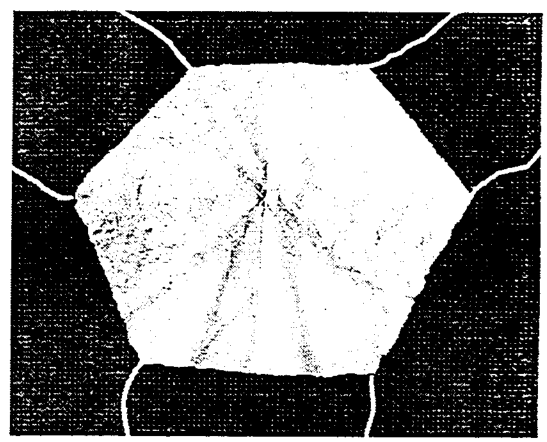


2. Make another loop at the other end of the shroud line. Tape the second loop to the adjacent corner of the parachute.



3.Repeat for all three shroud lines <u>Do NOT cut shroud lines..</u>





4. Hold parachute upside down. Spin the parachute a couple of times. The point where the shroud lines intersect is called the confluence point. Tie a knot at the confluence point.