

# *FALLING OBJECTS*

by

**Edna T. Diolata**

Brooklyn Technical High School

and

**David Latman**

Clara Barton High School For The Health Professions

## **INTRODUCTION**

A simple experiment on falling bodies such as the one we have devised will touch on many important lessons in a physics class- mass, weight, force of gravity, velocity, terminal velocity, acceleration, aerodynamic drag, and Newton's laws of motion. In a technology class, this experiment will be helpful in a project where students design a container for an egg that is to be dropped from a height of 20-30 feet without the egg breaking.

Our experiment looks at external forces, namely, the force of gravity and air resistance or aerodynamic drag. We want our students to analyze how the motion of falling objects is affected by these forces as well as by such factors as mass, initial height, and cross-sectional area.

## **BACKGROUND**

When an object falls through air, it usually encounters some degree of air resistance. Air resistance is the result of an object plowing through a layer of air and colliding with air molecules. The greater the cross-sectional area of an object, the greater the amount of air resistance it encounters since it collides with more air molecules. Furthermore, as an object falls, it is being pulled downward by the force of gravity. At the start of the fall, the force of gravity is an unbalanced force. This causes the object to gain speed or to accelerate. As it accelerates, it encounters air resistance or aerodynamic drag. The amount of air resistance depends upon the speed of the falling object. This can be explained by Newton's first and second laws and by the notion of terminal velocity. According to Newton's laws, an object will gain speed if the forces acting upon it are unbalanced; and, the amount of acceleration is directly proportional to the net force (unbalanced force) acting upon it. Falling objects initially accelerate because there is no

force large enough to balance the gravitational force. However, as an object gains speed, it encounters more air resistance. It will continue to gain speed until the upward air resistance force equals the downward force of gravity. When a falling object has a large mass, it weighs more and will encounter a greater downward force of gravity. (Weight is equal to the mass of the object times the gravitational acceleration, or  $W = mg$ ). It will have to accelerate for a longer period of time before there is enough upward air resistance to balance the downward force of gravity.

Once the aerodynamic drag is exactly equal to the weight of the falling object, there is no net external force acting on it anymore. Hence, it ceases to accelerate and the speed with which it falls becomes constant. Once this happens, the falling object is said to have reached terminal velocity.

## **LIST OF EQUIPMENT**

To conduct our experiment, we needed a device that can accomplish these tasks:

1. Drop an object from a certain height
2. Provide air flow that can be regulated at various rates
3. Measure the time of the object's fall and its speed at various times during the fall

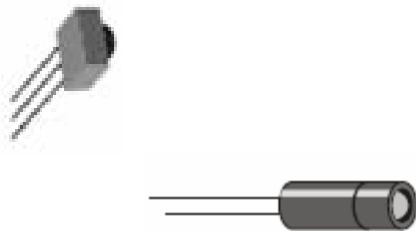
Shown below are the various equipments that we used:



Standard Rotation Servo



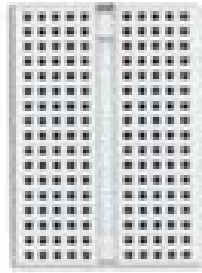
Ultrasonic Sensor (PING)



Infrared Detector and  
Infrared Light Emitting Diode



Board of Education and Basic Stamp2  
Microcontroller



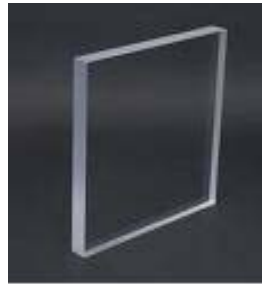
Solderless Breadboard



Resistors



Power Supply



Plexiglass

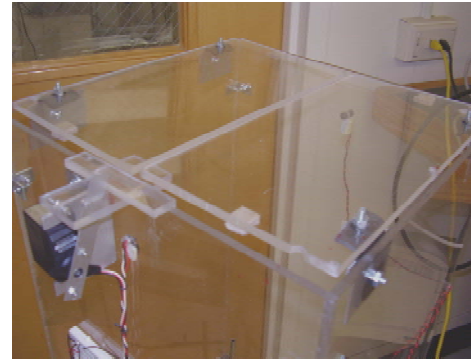
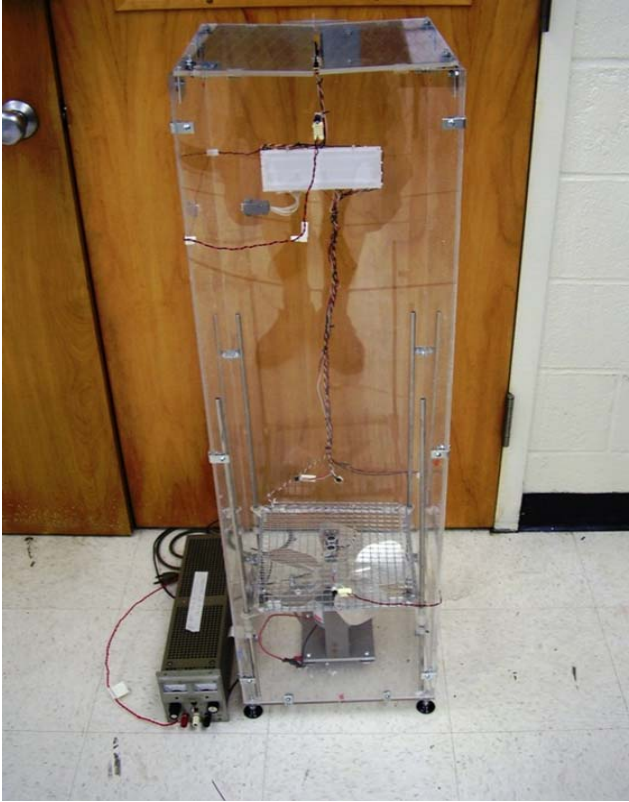


Fan

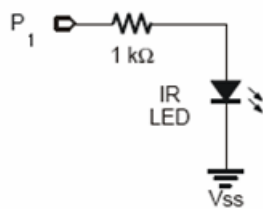
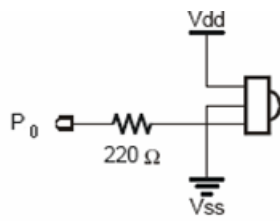


Jumper wires

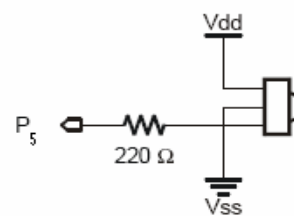
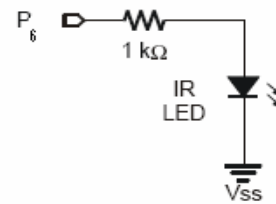
## THE COMPLETED DEVICE



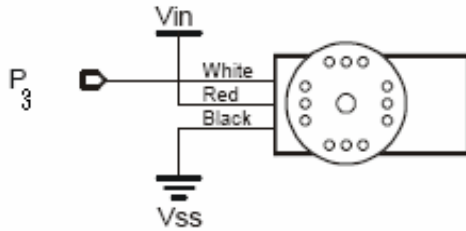
## SCHEMATIC DRAWING OF THE CIRCUITS



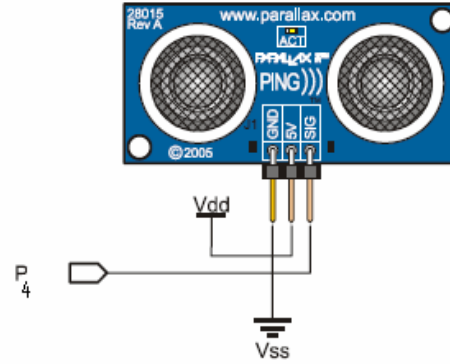
Top IR LED and IR Detector



Bottom IR LED and IR Detector



**Standard Rotation Servo**



**Ultrasonic Sensor**

## PROGRAMMING CODE

```
'{$STAMP BS2}
'{$PBASIC 2.5}
'Falling Objects Experiment

" -----I/O Definitions-----
Ping      PIN  4

' -----Constants-----
Trigger   CON  5           ' trigger pulse = 10 uS
Scale     CON  $200       ' raw x 2.00 = uS
RawToIn   CON  889       ' 1 / 73.746 (with **)
RawToCm   CON  2257      ' 1 / 29.034 (with **)
IsHigh    CON  1         ' for PULSOUT
IsLow     CON  0

'-----VARIABLES-----
counter   VAR Word
IRtop     VAR Byte
IRbottom  VAR Byte
IRbottom2 VAR Byte
user      VAR Byte
time      VAR Byte
cm        VAR Word
rawDist   VAR Word       ' raw measurement
totalTime VAR Word
duty      VAR Byte
duration  VAR Byte
counter1  VAR Word

'-----Main-----
Main:
LOW 3
PAUSE 20
```

```

PULSOUT 3, 500
PAUSE 20
PWM 2, duty, duration
DEBUG CLS
DEBUG "Select experiment:", CR
DEBUG "1: Shape and Size", CR
DEBUG "2: Mass", CR
DEBUG "3: Terminal Velocity", CR
DEBUGIN DEC user
IF user = 1 THEN GOSUB ShapeSize
IF user = 2 THEN GOSUB Mass
IF user = 3 THEN GOSUB TerminalVelocity
END

```

'-----SUBROUTINES-----'

```

Timer:
  FOR counter = 1 TO 10
    PULSOUT 3, 750
    PAUSE 20
  NEXT
DO
  FREQOUT 1, 1, 38500
  IRtop = IN0
LOOP UNTIL IRtop = 1
  counter1 = 0
  DEBUG CLS
  DEBUG HOME, "Time | Distance", CR
  DEBUG "(ms) | (cm)", CR
  DO
    counter1 = counter1 + 3 '10
    FREQOUT 6, 1, 38500
    IRbottom = IN2
    FREQOUT 6, 1, 38500
    IRbottom2 = IN5

    'IRbottom2 = IN5
    GOSUB sonar
    cm = rawDist ** RawToCm
    DEBUG DEC3 counter1, " | ", DEC3 cm, CR
    PAUSE 7'70
  LOOP UNTIL ( IRbottom = 1) OR (IRbottom2 = 1)
  RETURN

```

'-----ULTRASONIC-----'

```

sonar:
  Ping = IsLow           ' make trigger 0-1-0
  PULSOUT Ping, Trigger ' activate sensor
  PULSIN Ping, IsHigh, rawDist ' measure echo pulse
  rawDist = rawDist * / Scale ' convert to uS
  rawDist = rawDist / 2     ' remove return trip
  RETURN

```

'-----Shape and Size-----

ShapeSize:

```
GOSUB Timer
DEBUG "To repeat procedure press 1 or 2 to go to main", CR
DEBUGIN DEC user
  IF user = 1 THEN GOSUB ShapeSize
  IF user = 2 THEN GOSUB Main
END
```

'-----MASS-----

Mass:

```
GOSUB Timer
DEBUG "To repeat procedure press 1 or 2 to go to main", CR
DEBUGIN DEC user
  IF user = 1 THEN GOSUB Mass
  IF user = 2 THEN GOSUB Main
END
```

'-----ThermalVelocity-----

TerminalVelocity :

```
DEBUG CLS
DEBUG "Set the Speed of the fan", CR
DEBUG "Press 1 to Initiate", CR
DEBUGIN DEC user
  IF user = 1 THEN GOSUB Timer

  IF user = 1 THEN GOSUB TerminalVelocity
  IF user = 2 THEN GOSUB Main
END
```

## **EXPERIMENTAL PROCEDURE**

### **A. Goals**

1. To determine how objects of the same mass but different cross-sectional areas are affected by air resistance (henceforth will be referred to as *Experiment 1*)
2. To determine how objects of the same cross-sectional areas but different masses are affected by air resistance (henceforth will be referred to as *Experiment 2*)
3. To determine how air resistance and the mass and cross-sectional area of an object affect terminal velocity (henceforth will be referred to as *Experiment 3*)

### **B. Procedure**

For experiment 1, we have chosen three objects: a flat object with a wide cross-sectional area, a box, and a cup. With the use of a massing scale, we made sure that they all have the same mass. (An object's mass is the amount of matter it contains.) We begin the experiment by placing an object on the trapdoor at the top of the device. This trapdoor is secured by a pin that is powered by a servomotor. The trapdoor opens, drops the object,

and a pair of IR LED and Detector sense it and send a pulse to the Basic Stamp, which in turn sends a signal to the computer. The computer begins to mark the time of the object's descent in milliseconds. The fan at the bottom provides air flow, which is set at a constant rate. When the object hits bottom, another pair of IR LED and IR detector sense the object and again a signal is sent to the computer, which records the final time of the fall. Attached to the platform at the bottom is an ultrasonic sensor (PING) that measures the distance at each millisecond of the object's fall. This allows us to track the speed of the fall. The speed and time data is then copied onto a spreadsheet.

B. The same procedure used in Experiment 1 will be used in conducting Experiment 2. In this experiment, the input variable is the difference in mass of three objects of the same size and shape.

C. Experiment 3 involves dropping the same object but using four different rates of air flow.

### C. Results and Discussion

(Averages after three trials)

<b>Experiment 1</b>	Time of Fall in Milliseconds	
	With Air Flow	Without Air Flow
Disk shape	33	32
Box	30	31
Cup	28	28

<b>Experiment 2</b>	Time of Fall in Milliseconds	
	With Air Flow	Without Air Flow
Object1 (1.8 g)	94	46
Object2 (3.3 g)	65	40
Object3 (6.6 g)	35	33

<b>Experiment 3</b>	Terminal Velocity in Milliseconds	
High Air Flow		
Medium Air Flow		
Low Air Flow		
No Air Flow		

*Note: We were not able to conduct Experiment 3 due to limitations with the device.*

From the results shown above, we derive the following conclusions:

- When there's air flow, an object with greater surface or cross-sectional area fall slower. This is because it encounters more air resistance, which slows it down.



- When there's no air flow, objects in general drop faster. This is because they encounter less air resistance.
- Objects with greater mass encountering air resistance fall faster. This is because they are heavier and experience greater downward force of gravity.
- When there's no air resistance, mass has little impact on the speed of the fall.
- The height of the device at 32 inches does not give us appreciable differences in the results. The distance of the fall is too short and the air flow from the fan is not fast or strong enough to counter the force of gravity. Our solution to this problem was to use very light objects. However, the problem here is that they tend to bounce around inside the container causing the sensors to give the wrong signals.
- The design of the device needs to be revised in order to conduct Experiment 3.

How will this device be used in our classes? Our students will conduct their own experiments following the aforementioned experimental procedure, create their own tables and graphs of the results, extrapolate from these, and draw their own conclusions.

## **FUTURE WORKS**

1. Conduct further experiments on the motion of falling bodies, such as:
  - Objects of same mass, different cross-sectional areas, different air flow rates
  - Objects of varying mass, same cross-sectional area, different air flow rates
  - Find the terminal velocity of a falling object by dropping it through a funnel that is inserted into the device. The funnel will serve to concentrate the air flow and not cause the object to bounce around as it drops.
  - Create an experiment where an object is "levitated" when the aerodynamic force and the force of gravity is balanced.
2. Extend the height of the device by another meter and add another set of Infrared LED and Infrared Detector to increase the height from which objects will be dropped.
3. Incorporate the operation of the fan into the programming. At this time, the fan is being adjusted manually.

## **REFERENCES**

[www.lerc.nasa.gov/WWW/K-12/airplane/termv.html](http://www.lerc.nasa.gov/WWW/K-12/airplane/termv.html)  
[www.glenbrook.k12.il.us/GBSSCI/PHYS/mmedia/netlaws/efar.html](http://www.glenbrook.k12.il.us/GBSSCI/PHYS/mmedia/netlaws/efar.html)

## **ACKNOWLEDGMENTS**

We would like to thank SUMMIT Director Dr. Vikram Kapila, SUMMIT Training Assistants Nathan Lee, Anshuman Panda, and Padmini Vijayakumar, Teaching Assistants

Keith Ching, Billy Mark, Shing Lik Wong, and Jared Frank, and most specially our own indefatigable teaching assistant, Daniel Remiszewski, who devoted much of his time and expertise in helping us see our project through to completion.