CoreModels

Drag

A Core Learning Goals Activity for Science and Mathematics

Summary: Students will investigate Newton's Second Law of Motion in a variety of laboratory activities. Each activity will be followed by the building of a STELLA model.

Author: Charlotte M. Trout
Williamsport High School
Williamsport, MD
ctrout@isaac.williamsport.wa.k12.md.us
301-766-8423

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Applications of Force
Teacher Guide

Overview:
     This packet consists of a series of lab activities paired with model activities, all of which explore the effect of applied and opposing forces on motion. The models move from simple to more complex. The last two activities are model building only, though lab activities would be possible. In the laboratory activities, students investigate three possible opposing forces: weight, friction and drag.

Prior Knowledge / Skills Required:
     Students should already be familiar with Newton's Second law and have a basic knowledge of net force, applied force and opposing force. They should have some experience at reading graphs and relating motion to the appearance of the graph. Students should have previous experience with STELLA. They should have built the basic force model and saved it as a force template.

Best Practices
     The main emphasis of this series of activities should be that a wide variety of physical phenomena can be modeled by using the applied/opposing forces model. This is what students should be focused on. They should be led to realize that the opposing force may have a variety of names (friction, weight, drag) and that there are various equations necessary to calculate these forces. While not emphasized by the titles, it is also true that the models show the variety of names that may disguise an applied force (tension, weight, engine, trust). It is hoped that by the time the students have opened and modified the force template several times they will begin to see the fundamental nature of using forces to analyze problems.
     The falling filter activity and the parachute activity are very similar and probably only one needs to be done. When choosing, it should be noted that the filter lab is immediately translated into a model, while the parachute model is actually more fun and "real-world" relevant for students.

Core Learning Goals

Core Goal 1: Skills and Processes

3. Expectation: The student will carry out scientific investigations effectively and employ the instruments, systems of measurement and materials of science appropriately.

     (1) The student will develop skills in using lab and field equipment to perform investigative techniques.

     (3) The student will learn the use of new instruments and equipment by following instructions in a manual or from oral direction.

4. Expectation: The student will demonstrate that data analysis is a vital aspect of the process of scientific inquiry and communtication.

     (3) The student will determine the realtionships between quantities and

develop the mathematical model that describes these relationships.

    (5)   The student will choose appropriate summary statistics to describe tendencies revealed by data.

    (6)   The student will use spreadsheet, graphing and database programs and probeware on computers and/or graphing calculators.

    (8)   The student will use models and computer simulations to represent systems.

Core Goal 5: Concepts of Physics

1. Expectation: The student will know and apply the laws of mechanics to explain the behavior of the physical world.

    (3)   The student will analyze and explain how changes in an object's motion are described by Newton's Laws.

Activity One: Falling Filters Lab - Drag as Opposing Force

In this activity, you will investigate some of the factors which affect falling objects and lead many people to believe that different objects fall at different rates. Most notably, you will investigate air resistance.

Procedure: 1. Obtain three coffee filters. Nest one filter inside of another, keep the third separate. Drop the pair of filters from the same height and at the same time as the single filter.

Question 1.1 Which filter(s) hit first? __ **Student responses vary** ___

Question 1.2 Which variable had a greater affect on results, mass or surface area? ___ **Surface Area** _____

2.   Two paper baking cups have the same mass as one coffee filter. Get two baking cups and nest them. Drop the pair of baking cups at the same time as a single coffee filter.

Question 1.3 Which filter(s) hit first? ___ **Student responses vary** ___

Question 1.4 Which variable had a greater affect on results, mass or surface area? _ **Surface area** _____
3. Now obtain two film canisters, one empty and one full. Release them from the same height.

Question 1.5 Which canister hit first? __ **Student responses vary** ____

Question 1.6 Which variable had a greater affect on results, mass or surface area? _ **Mass has no effect and surface area the same** ____

4. Now obtain the number of coffee filters assigned to your group. Also, obtain a CBL, a calculator, a meter stick and an Ultrasonic Motion Detector (UsMD). Determine the mass of the 5 coffee filters and **record**. Calculate the average mass of one filter and **record**. Determine the diameter of the bottom of the filters and of the upper edge. **Record** these values. Calculate the cross-sectional areas for these two values and **record** these.

5. Set up the calculators, CBLs and motion detectors. Run the program BALLDROP. When the program starts running, the UsMD will start to click. Press the TRIGGER button on the CBL and drop the filter(s) from about 1.5 m onto the UsMD. **Sketch** the graph. Then press the PGM key and choose the program SELECT. The program will ask for the lower bound. Slide the cursor to the point on the left where the filter started to fall and press ENTER. For the upper bound, slide the cursor to the point where the filter stopped falling (or at least the detector stopped) and press RETURN. The program will redraw the selected points - **sketch** this graph.

6. Now choose STAT - CALC - 6:QuadReg. When the calculator returns the QuadReg prompt, type L$_3$, L$_4$ and ENTER. **Record** the data.

7. Gather data from the class.

Activity Two: The Falling Filters STELLA Model

In Activity One, you investigated the factors which affect a falling object when it is not in free-fall. As you knew from the beginning, air resistance creates a drag on an object which slows it down. This drag depends on several factors including cross-sectional area which you investigated. Specifically, the equation for drag (in terms of acceleration) is:

  drag = 0.5*C Av^2
  drag = 0.5*(drag coefficient * air density * cross sectional area *
     Velocity^2)

Procedure: Open your STELLA force template model. For a falling filter model, the applied force is weight and the opposing force is drag.   From previous models, you know how to enter weight. Create a new convertor for drag and attach this convertor to the oppposing force convertor. Then create three convertors (drag coefficient, cross sectional area and air density) to attach to drag.

Use the following values for your convertors:

  mass = enter mass in **kg** for your number of coffee filters
  air density = 1.16 {kg/m^3}
  cross sectional area = enter the value for the bottom only
  drag coefficient = 1
  g = -9.8 {m/s^2}

Then fill in the equation for drag.

Make sure you have set an initial distance (the height above the floor that you dropped them from). Set up three graphs (three pages on the same graph pad). The first graph should be for distance, the second for velocity and the third for acceleration. As you set up each page, click on the Comparative box in the upper left area of the graph dialogue box.

Also, it is useful to change the time settings for the model. Under the Run menu is a choice for Time Specs - choose this. Then change the length of the simulation so it runs from 0 to 2, with DT set to 0.05. Also, change the integration method to Runge-Kutta 4. Click OK. Run the model.
  See Appendix A

Question 2.1 On a piece of paper, describe how this graph differs from the straight free fall model. (If you want a comparison, change the cross-sectional area to 0 and rerun the model. The two graphs will appear together).

Distance graph starts out with same parabolic shape, but then has a linear portion. Velocity also slopes downward but then levels off.

Question 2.2 When is terminal velocity attained and how do you know?

When the velocity graph levels off - no faster velocity will occur.

Question 2.3 How do the results of the model compare to your experiment? What else would you like to know before you answer this question?

Student responses will vary

Run the model with the other setting for cross-sectional area (upper edge) and compare. You might also want to try different mass settings. (Hint: if the graphs get too cluttered, choose Model from the menu bar, then Restore and All devices. This clears the graphs.)

Activity Three: Parachute Activity

In this activity, you will investigate some of the factors which affect falling objects and lead many people to believe that different objects fall at different rates. Most notably, you will investigate air resistance.

Procedure:

1. Obtain two pieces of paper which are identical (same size, same weight). Fold one sheet of paper 8 times until it is 1/16 the size of the other. Start the two pieces of paper at the same height and release them.
Question 3.1 Which paper hit first?___ **The folded paper** ____

Question 3.2 Which paper has the largest mass?__ **Have the same mass** __

Question 3.3 Which paper has the largest surface area?_**Unfolded paper**_

2. Now obtain two film canisters, one empty and one full. Release them from the same height.

Question 3.4 Which canister hit first?___ **Hit at the same time** ___

Question 3.5 Which had the largest mass?____ **The full canister** ___

Question 3.6 Which had the larger surface area?__ **Have the same area** __

3. Now obtain two parachutes. Carefully measure the dimensions of your parachutes. They should be identical to each other, but different lab groups will have different sizes or shapes from yours. Attach the parachutes to your film canisters as shown by the teacher and release them at the same time from the same height.

Length of parachute: _____ Width: _____ **Student answers vary**

Cross-sectional area of parachute: _____

Question 3.7 Which canister hit first? __ **The full one** _____

Now release the empty canister only, but time its fall to the ground from a
height of 2 meters. Repeat this measurement 3 times. Record the times below.

Time to fall: _____   _____   _____   _____   **Student data**

Average your times: _____

Create a data table for class data. The table should have a column for cross-
sectional area and one for average time.

Question 3.8 Summarize the class findings.

Activity Four: The STELLA Parachute Model

In Activity Three, you investigated the factors which affect a falling object
and how a parachute can slow an object's rate of descent. As you knew from
the beginning, air resistance creates a drag on an object which slows it down.
This drag depends on several factors including cross-sectional area which you
investigated. Specifically, the equation for drag (in terms of acceleration)
is:

      drag = 0.5*C Av^2
      drag = 0.5*(drag coefficient * air density * cross sectional area *
                  Velocity^2)

 Procedure:

Open your STELLA Force Template model.   For a parachute model, the applied
force is weight and the opposing force is drag.   From previous models, you
know how to enter weight. Create a new convertor for drag and attach this
convertor to the oppposing force convertor.   Then create three convertors
(drag coefficient, cross sectional area and air density) to attach to drag.

Use the following values for your convertors:

      mass = 70 {kg} (about a 150 lb person)
      air density = 1.16 {kg/m^3}
      cross sectional area = 0.5 {m^2} (for human without chute)
      drag coefficient = 1

Then fill the equation in for drag and set the model to run for 15 seconds.
(NOTE: IF students are starting with the filter model, they will also need to
reset the DT to 0.25 and the integration method to Euler's).

Make sure you have set an initial distance. Sport parachutists generally jump between heights of 600 and 3600 meters. They must open their parachutes at 600 meters. Since we don't have a parachute yet, choose some height above 600. Make sure you have a graph that shows displacement, velocity and acceleration on the same graph page. Run the model. Look at the velocity graph.

Question 4.1 On a piece of paper, describe the graph. **See Appendix I**

Question 4.2 What velocity does the jumper level off at? **About 35 m/s**

Question 4.3 This is known as terminal velocity. How does terminal velocity depend on the mass of the jumper? Experiment with the model.

    Greater mass means a greater terminal velocity

Now we'll add a parachute that opens after three seconds of free fall. This extension requires you to modify the cross-sectional area of the object using the IF-THEN-ELSE construct. The easiest testing condition uses TIME, the built-in function which holds the total time.

    For example:
    cross_sectional_area = IF (TIME >= 3) THEN 5 ELSE 0.5

Before TIME = 3, the cross sectional area is 0.5; at or after TIME = 3, it is 5.0, the parachute is open.

Question 4.4 Try this and **record the results. See Appendix J**
Jumpers hope for terminal velocities between 5 and 13 m/s once the chute is open. Also the chute must open before the jumper reaches 600 meters but the jumper wants to remain in "freefall" as long as possible. Experiment with the model until you find the right combination of mass, time for chute opening and area of the parachute to achieve this. Record these values as well as the initial height. **Appendix K**

Question 4.5 Why is the term "freefall" in quotes above?

    Even with the chute closed, the jumper has some
    cross-sectional area and if they fall far enough will
    reach a terminal velocity.

Question 4.6 In the free fall unit, we stated that the rate of falling was independent of weight, yet this model contains weight.   Explain.

    Weight only becomes important when there are opposing
    forces like drag. For objects with very little cross-
    sectional area and short fall distances, weight is not
    a factor.

Activity Five: Rolling Car with Drag

In this activity, we will combine the Rolling Friction model with our understanding of drag to examine the forces acting on a car.

1. Open the Falling Filter model.
2. Create converters for friction and the coefficient of friction.
3. Drag and friction are both opposing forces. Because of the sign of g, friction is already negative, but drag is not. Change the sign of drag so that it is negative. Then make sure that the opposing force is the sum of drag and friction.

4. Push/pull is now the force of the engine. You might want to rename that converter.

5. Enter the following values into the model:

        mass = 1000 {kg}
        engine = 387 {N}
        acceleration due to gravity = -9.8 {m/s^2}
        coefficient of rolling friction = 0.015
        cross sectional area = 2 {m^2}
        drag coefficient = 0.5
        air density = 1.2 {kg/m^3}
        Initial Distance = 0 {m}
        Initial Velocity = 0 {m/s}

Everything else in the model should have an equation entered. You should also change the Time Specs so that the model runs for 300 sec and the DT is 1.0. Create a graph for distance, velocity and acceleration. Run the model.

Question 5.1 Have your teacher check the results and if ok, sketch the graph.
   **See Appendix E**

6. Experiment with different engine amounts until the car reaches 27 m/s (60 mph) at its equilibrium speed.

Question 5.2 What engine force will allow this? **about 590 N**

7. Try using an input graph to better model the actual force (start with zero force, then use more force at the beginning before reducing to the force required for constant velocity) demands on an engine. You will also have to use an IF-THEN statement in Net Force to keep drag from moving the car backward. Report on your results. **See Appendix F**

8. Save the model as **Rolling Car.**
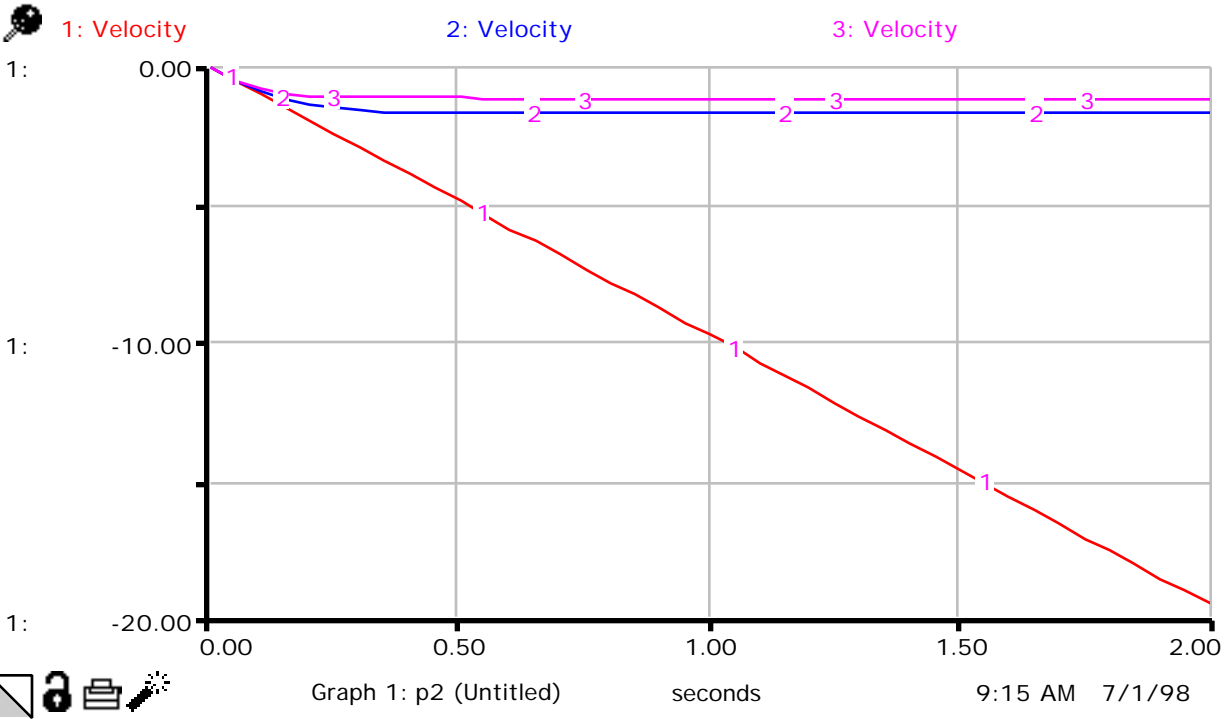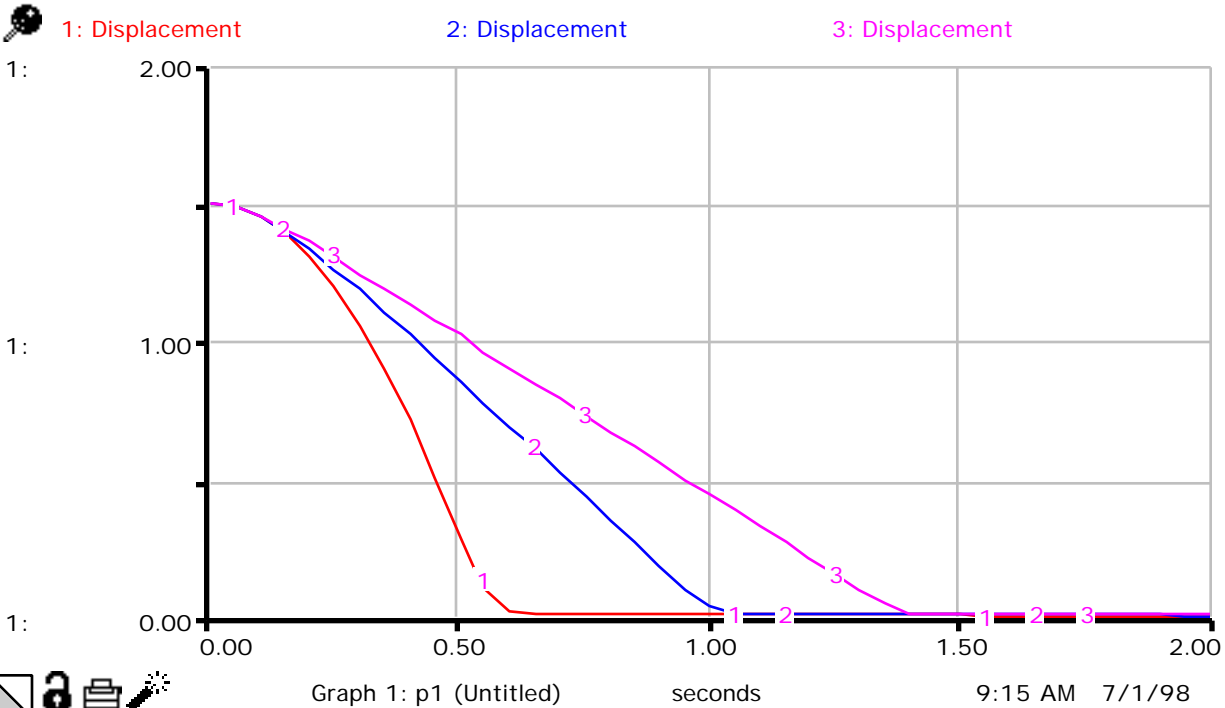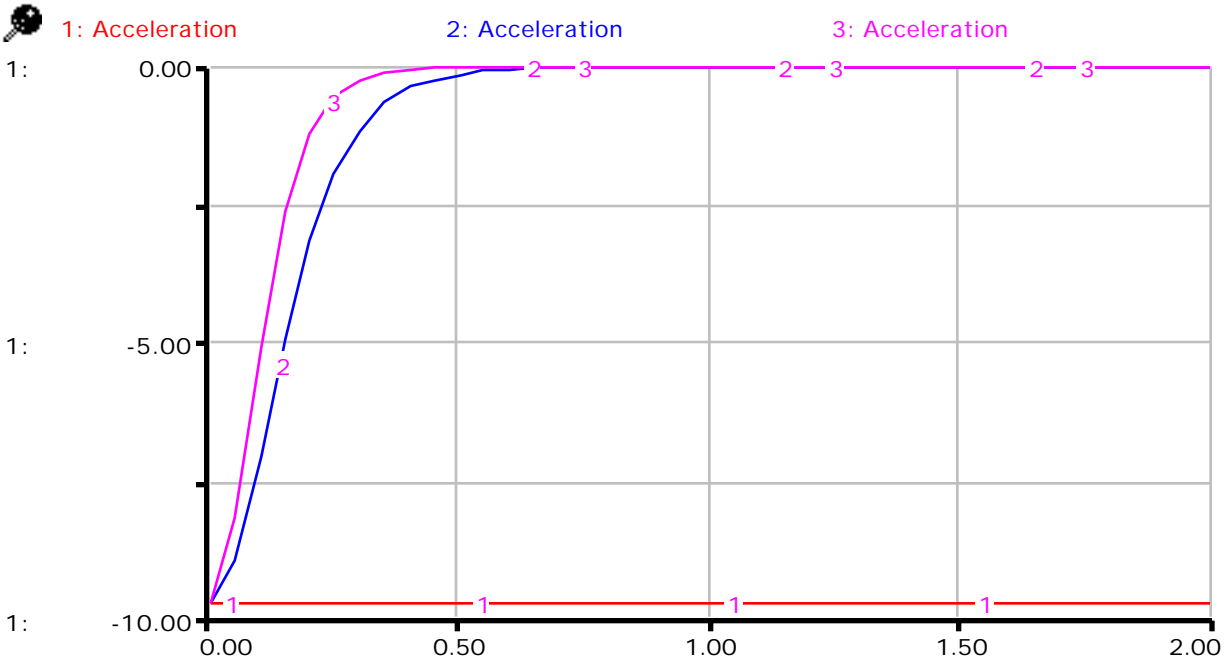
Appendix A
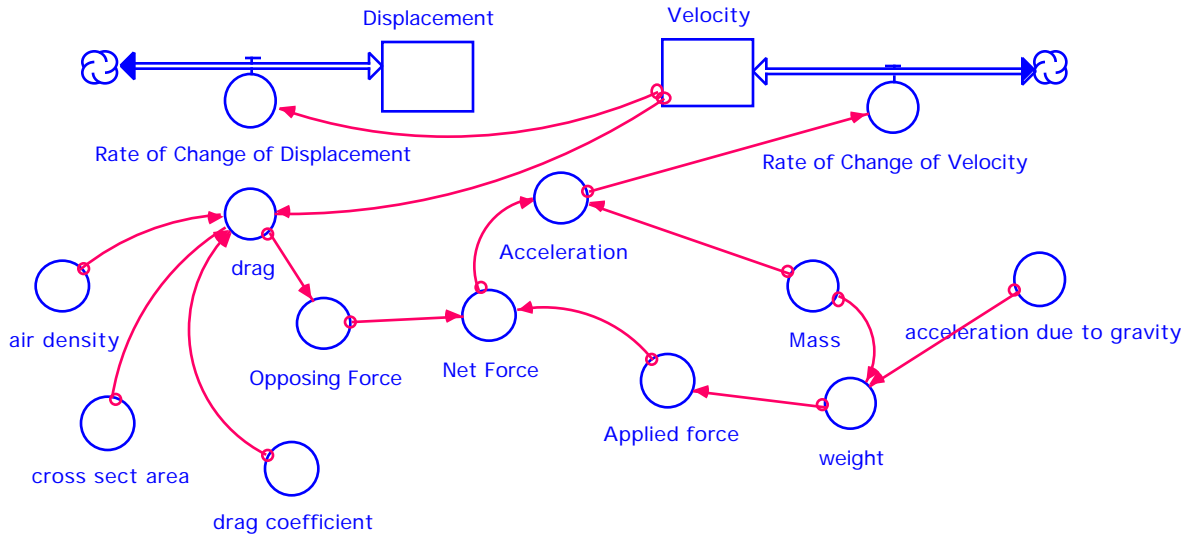

```
Displacement(t) = Displacement(t - dt) + (Rate_of_Change_of_Displacement) * dt
INIT Displacement = 1.5 {m}
Rate_of_Change_of_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Rate_of_Change_of_Velocity) * dt
INIT Velocity = 0 {m/s}
Rate_of_Change_of_Velocity = Acceleration
Acceleration = Net_Force/Mass
acceleration_due_to_gravity = -9.8 {m/s^2}
air_density = 1.16 {kg/m^3}
Applied_force = weight
cross_sect_area = 0.0133 {m^2}
drag = 0.5*drag_coefficient*air_density*cross_sect_area*Velocity^2
drag_coefficient = 1
Mass = 0.00105 {kg}
Net_Force = Applied_force+Opposing_Force
Opposing_Force = drag
weight = Mass*acceleration_due_to_gravity
```

The graphs which follow show three runs:

1: Freefall - Cross-sectional area = 0

2: Area = the area of the base of the filter = 0.0062 cm^2

3: Area = the area of a circle of same diameter as the top rim of the
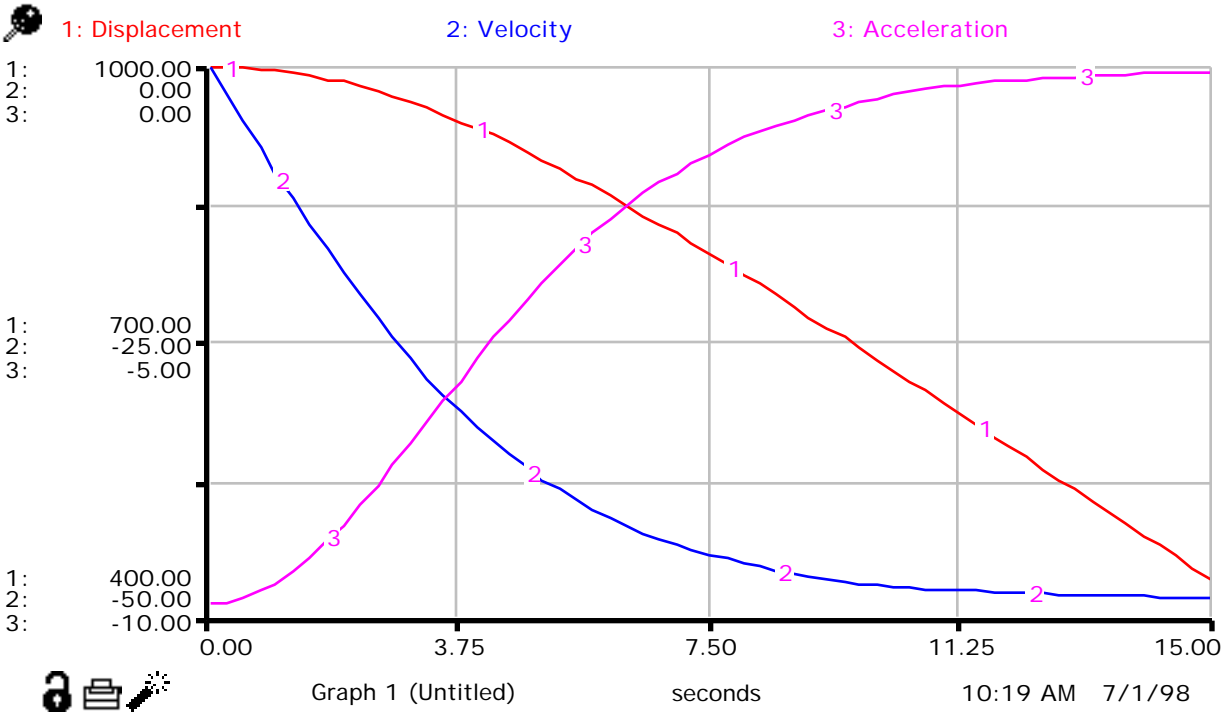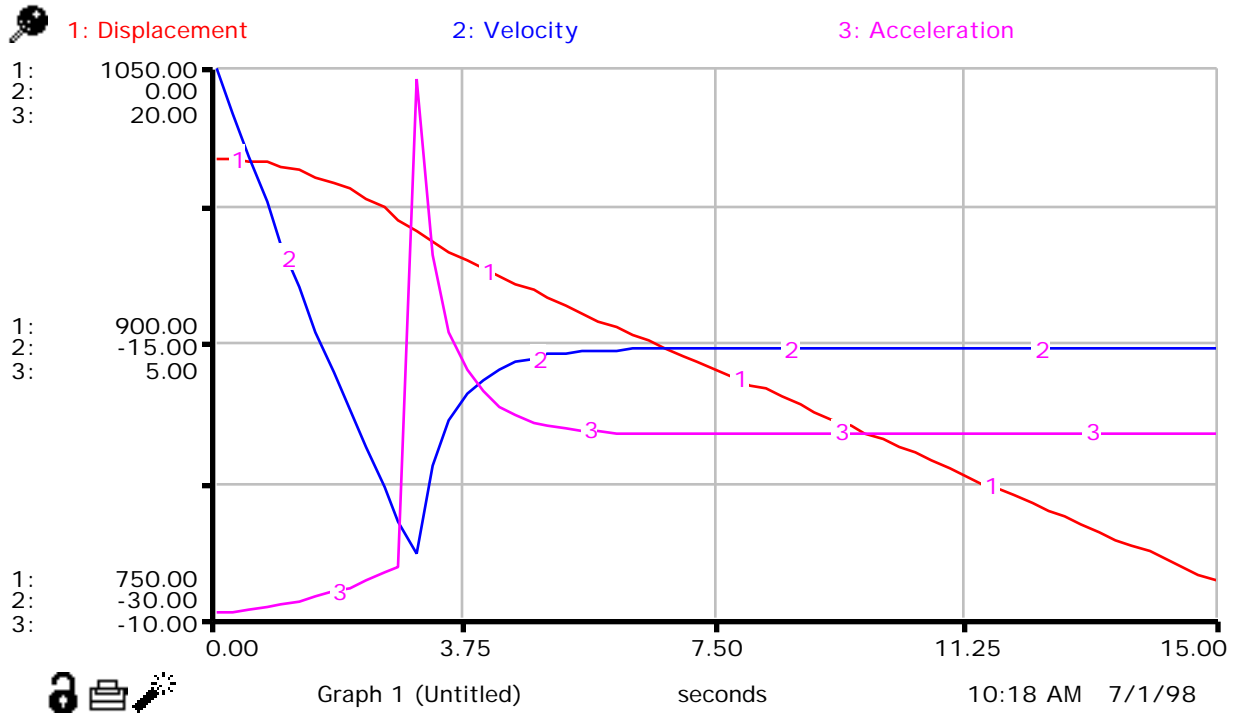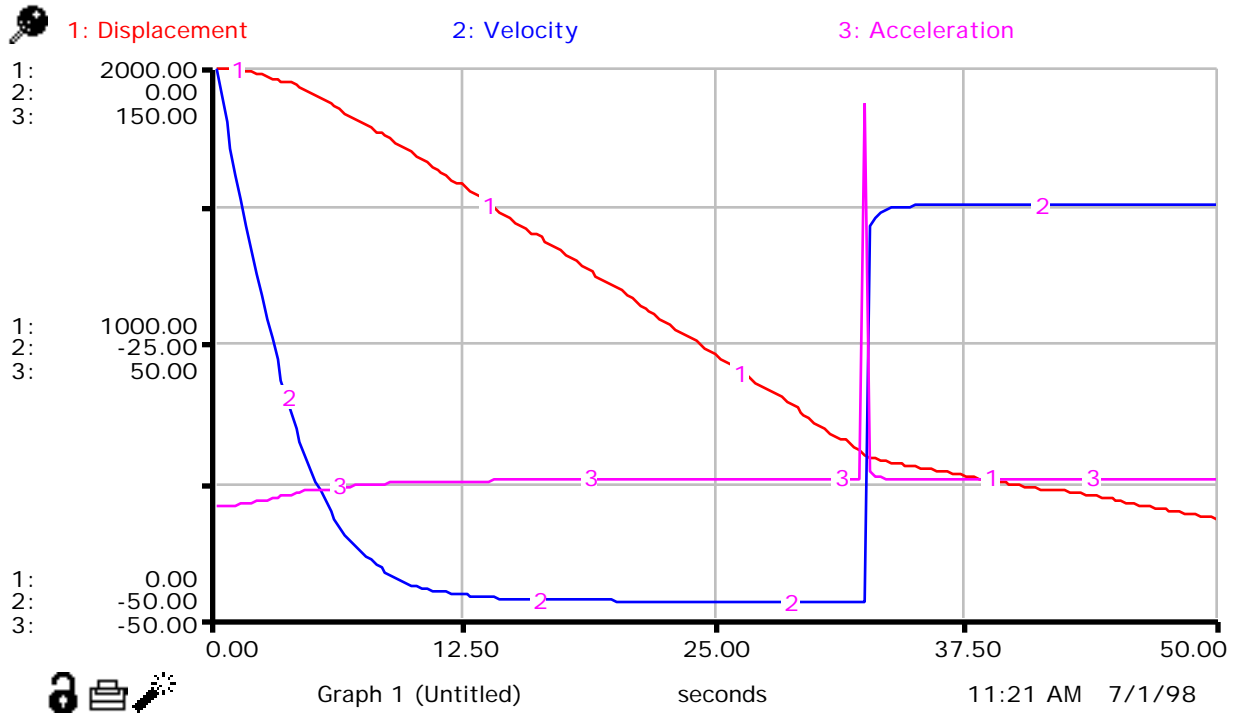   filter = 0.0133 cm^2

1: Displacement   2: Displacement   3: Displacement

```
1:    2.00 ┬─────────────────────────────────────
           │
           │  ╲1
           │   ╲2
1:    1.00 ┤    ╲3
           │
           │
           │
1:    0.00 ┤                          1  2  3    1  2  3
           └──────┬──────┬──────┬──────┬──────
          0.00   0.50   1.00   1.50   2.00
```

Graph 1: p1 (Untitled)   seconds   9:15 AM   7/1/98

1: Velocity   2: Velocity   3: Velocity

```
1:    0.00 ┬─────────────────────────────────────
           │ 1  2  3        3        3        3
           │
           │        1
1:  -10.00 ┤                    1
           │
           │                              1
           │
1:  -20.00 ┤                                   1
           └──────┬──────┬──────┬──────┬──────
          0.00   0.50   1.00   1.50   2.00
```

Graph 1: p2 (Untitled)   seconds   9:15 AM   7/1/98

T-10

Graph 1: p3 (Untitled)   seconds   9:15 AM 7/1/98
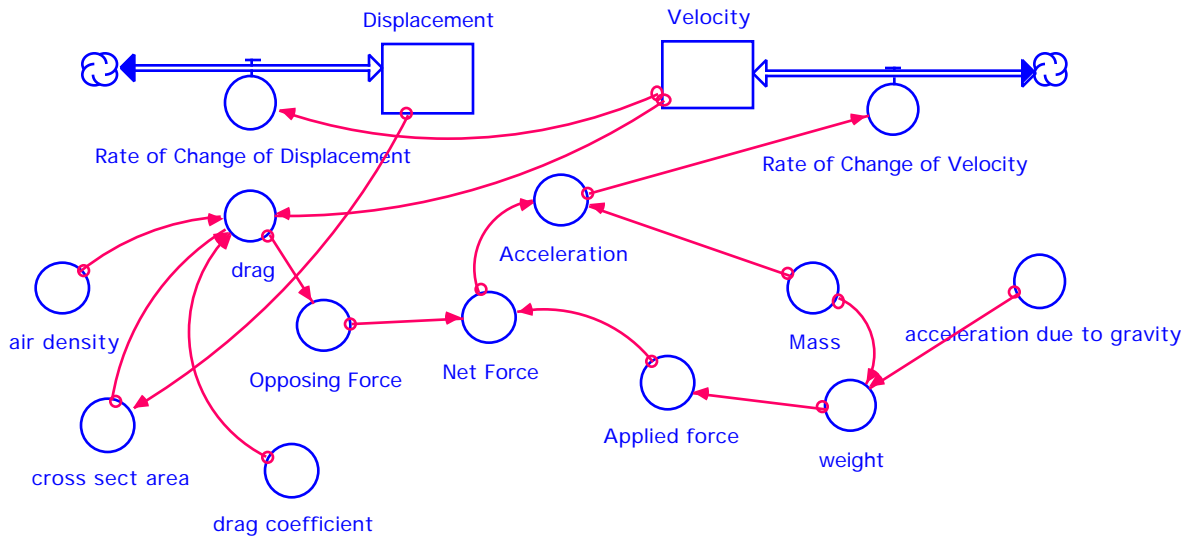
```
Displacement(t) = Displacement(t - dt) + (Rate_of_Change_of_Displacement) * dt
INIT Displacement = 1000 {m}
Rate_of_Change_of_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Rate_of_Change_of_Velocity) * dt
INIT Velocity = 0 {m/s}
Rate_of_Change_of_Velocity = Acceleration
Acceleration = Net_Force/Mass
acceleration_due_to_gravity = -9.8 {m/s^2}
air_density = 1.16 {kg/m^3}
Applied_force = weight
cross_sect_area = 0.5 {m^2}
drag = 0.5*drag_coefficient*air_density*cross_sect_area*Velocity^2
drag_coefficient = 1
Mass = 70 {kg}
Net_Force = Applied_force+Opposing_Force
Opposing_Force = drag
weight = Mass*acceleration_due_to_gravity
```
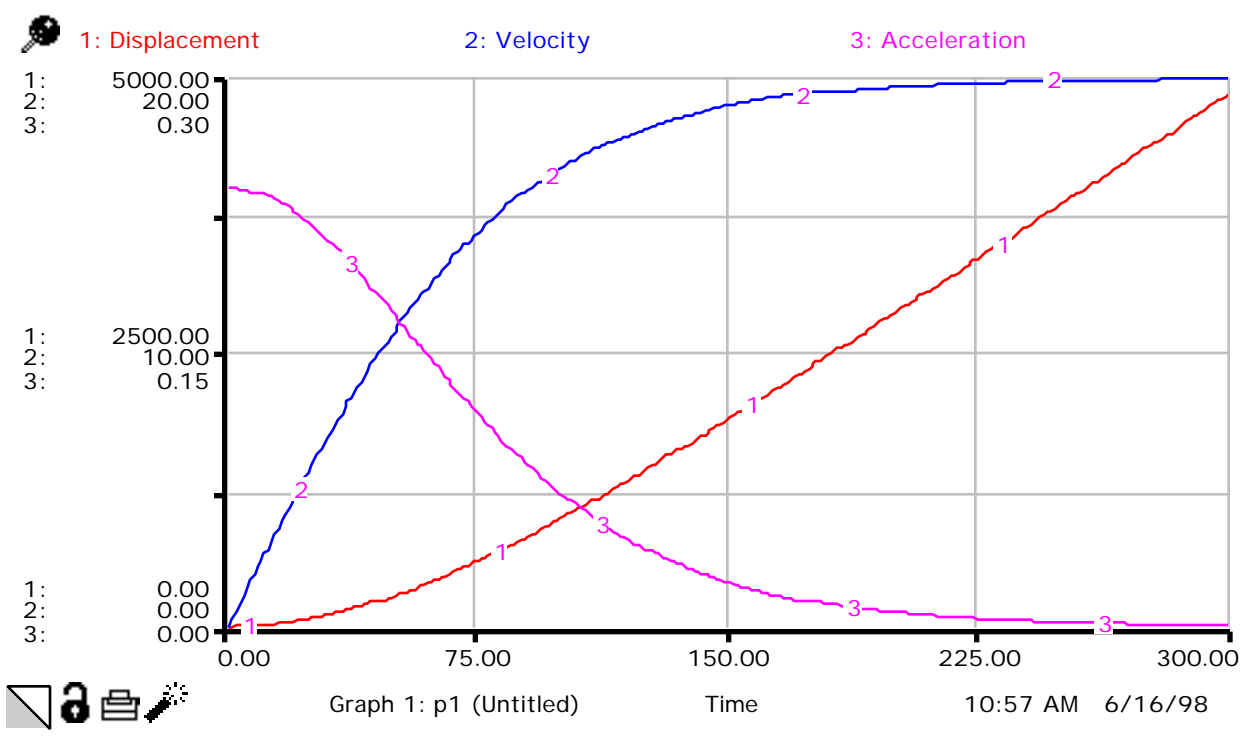
Graph 1 (Untitled)   seconds   10:19 AM   7/1/98

Appendix C

1: Displacement   2: Velocity   3: Acceleration

Graph 1 (Untitled)   seconds   10:18 AM   7/1/98

Appendix D

One possible solution using displacement as the determining factor in
when the chute opens. Note that the model is running for a longer time period
and that there are two terminal velocities, one before and one after the
parachute opens.

```
Displacement(t) = Displacement(t - dt) + (Rate_of_Change_of_Displacement) * dt
INIT Displacement = 2000 {m}
Rate_of_Change_of_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Rate_of_Change_of_Velocity) * dt
INIT Velocity = 0 {m/s}
Rate_of_Change_of_Velocity = Acceleration
Acceleration = Net_Force/Mass
acceleration_due_to_gravity = -9.8 {m/s^2}
air_density = 1.16 {kg/m^3}
Applied_force = weight
cross_sect_area = IF (Displacement<601) THEN 7.5 ELSE 0.5 {m^2}
drag = 0.5*drag_coefficient*air_density*cross_sect_area*Velocity^2
drag_coefficient = 1
Mass = 70 {kg}
Net_Force = Applied_force+Opposing_Force
Opposing_Force = drag
weight = Mass*acceleration_due_to_gravity
```


Graph 1 (Untitled)   seconds   11:21 AM 7/1/98
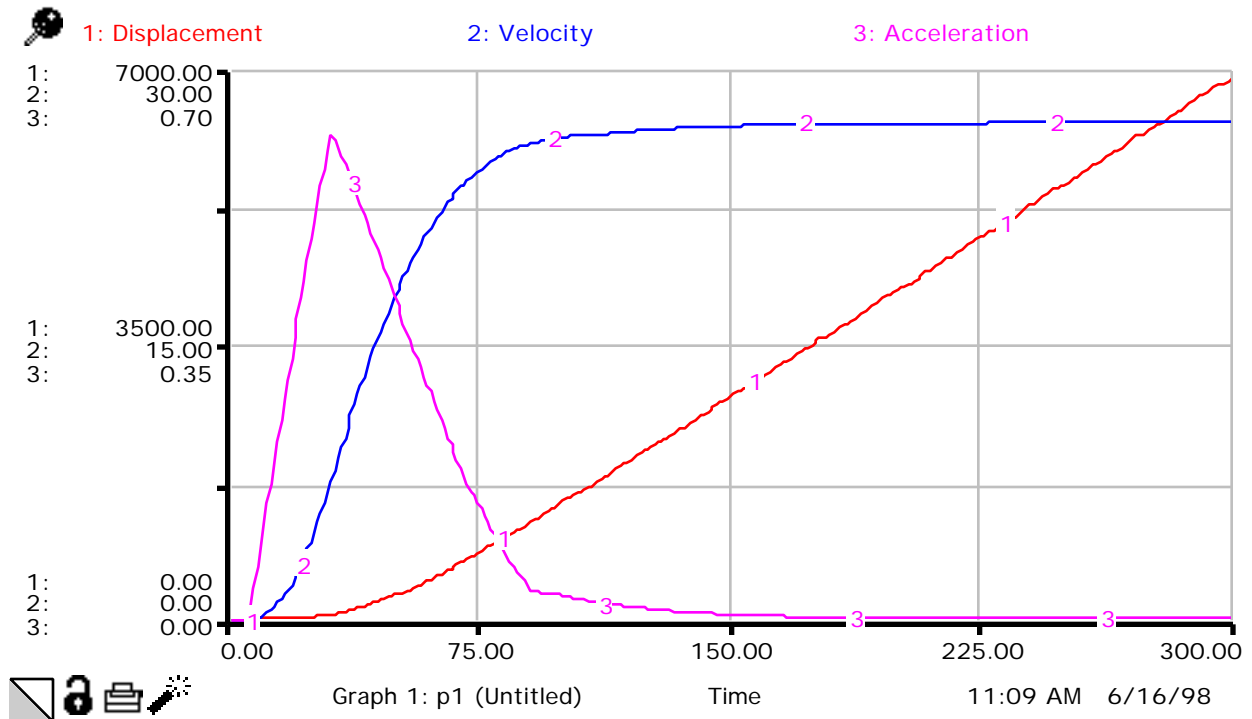
```
Displacement(t) = Displacement(t - dt) + (Rate_of_change_of_Displacement) * dt
INIT Displacement = 0
Rate_of_change_of_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Rate_of_change_of_Velocity) * dt
INIT Velocity = 0
Rate_of_change_of_Velocity = Acceleration
Acceleration = Net_force/mass
acceleration_due_to_gravity = -9.8
air_density = 1.2
Applied_force = Engine
coeff_rolling_friction = .015
cross_sect_area = 2
cross_sect_coeff = .5
drag = -0.5*cross_sect_coeff*air_density*cross_sect_area*Velocity^2
Engine = 387
friction = coeff_rolling_friction*Weight
mass = 1000
Net_force = Applied_force+Opposing_force
Opposing_force = drag+friction
Weight = mass*acceleration_due_to_gravity
```

```
Displacement(t) = Displacement(t - dt) + (Rate_of_change_of_Displacement) * dt
INIT Displacement = 0
Rate_of_change_of_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Rate_of_change_of_Velocity) * dt
INIT Velocity = 0
Rate_of_change_of_Velocity = Acceleration
Acceleration = Net_force/mass
acceleration_due_to_gravity = -9.8
air_density = 1.2
Applied_force = Engine
coeff_rolling_friction = .015
cross_sect_area = 2
cross_sect_coeff = .5
drag = -0.5*cross_sect_coeff*air_density*cross_sect_area*Velocity^2
friction = coeff_rolling_friction*Weight
mass = 1000
Net_force = IF (Applied_force+Opposing_force)<0 THEN 0 ELSE
Applied_force+Opposing_force
Opposing_force = drag+friction
Weight = mass*acceleration_due_to_gravity
Engine = GRAPH(time)
(0.00, 0.00), (30.0, 800), (60.0, 710), (90.0, 590), (120, 590), (150, 590),
(180, 590), (210, 590), (240, 590), (270, 590), (300, 590)
```


1: Displacement   2: Velocity   3: Acceleration

Graph 1: p1 (Untitled)   Time   11:09 AM   6/16/98

References and Acknowledgements