14 Impulse and Momentum
Blast Off

Purpose

To estimate the maximum speed and the maximum height of a model rocket.

Required Equipment and Supplies

Estes model rockets:
- ALPHA III or LIBERTY for high mass rockets
- RELIANT or YANKEE for low mass rockets

Estes rocket engine (2.5 N-s impulse, #A8-3)
rocket launcher
clinometer or Estes Altitrak

CAUTION: While model rockets are safe and educational, they must be launched in an open area, such as a football field, out of the flight paths of aircraft. Notify local agencies (FAA officials of nearby airports) of your launch date and time, and check with your local fire department or air terminal for regulations that might apply.

Discussion

Space transportation systems such as the space shuttle are a complex combination of conventional aircraft and rocket technology. Underneath the complexities, however, are some straight-forward physics principles that can be understood with a little effort.

In this experiment, you and your partner will launch a model rocket. Your task is to predict its launch speed and the maximum height it will reach. Three seconds after engine burnout, an ejection charge will fire to deploy the descent mechanism, effectively terminating the ascent. Although the tiny rocket may be difficult to see, the ejection charge produces a puff of smoke that greatly facilitates measuring the maximum height.

The impulse, $F\Delta t$, on the rocket during rocket burn will equal the rocket's change in momentum, Δmv.

$$F\Delta t = \Delta mv$$

$$= mv_f - mv_i$$

Since the initial momentum of the rocket is zero, the impulse given to the rocket during rocket burn will be equal to the momentum of the rocket at burnout time—the rocket's maximum momentum

$$F\Delta t = mv_{max}$$

We will make some simplifying assumptions in this experiment. First, we will assume that the force is constant during the burn, even though the force is *not* constant, and we'll use the factory rating for the impulse of the rocket engine for calculations. Second, we will assume that the rocket's mass remains constant throughout its flight, and compensate for the mass

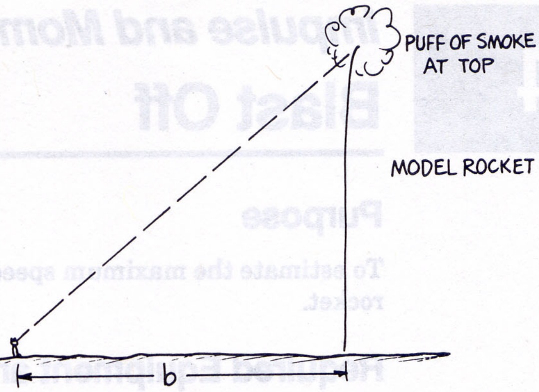

Figure 14.1

shed during burn by averaging the full-load and burn-out masses. We will also ignore air resistance.

After burnout, the rocket further ascends for about 3 seconds. The distance the rocket coasts after the burn is approximately (ignoring air resistance)

$$h = v_{max}t - \frac{1}{2}gt^2$$

where t should be close to 3 seconds, and the maximum speed of the rocket, v_{max}, can be calculated from the factory rating of impulse for the rocket engine. This speed is rather large and not easily measured directly.

The maximum height of the rocket can be measured by triangulation. By measuring the angle of the rocket at its maximum height viewed from a known distance, the height can be calculated as shown in Figure 14.1.

$$h = b\tan\theta$$

Another method for finding maximum height can be used. By measuring the terminal speed of the falling rocket and the time of descent from the maximum height, the maximum height can be calculated.

$$h = v_{fall}t$$

The falling speed can be measured by dropping the expended rocket from a known height and measuring the time it takes to fall.

Interestingly enough, the solid rocket boosters (SRB's) of the space shuttle are similar in many ways to the rocket engines used in this experiment. Once ignited, they burn until expended. For the shuttle, the thrust is more or less constant during the several minute-long burn. However, the burn of our model rocket is only a few tenths of a second, and a typical thrust versus thrust time graph is shown in Figure 14.2. Even though the thrust is clearly *not* constant, we will assume the acceleration of the rocket during the burn is constant. This assumption is not so bad if the distance traveled during the burn is small compared to the distance the rocket coasts after burnout, and the mass of the rocket is relatively large.

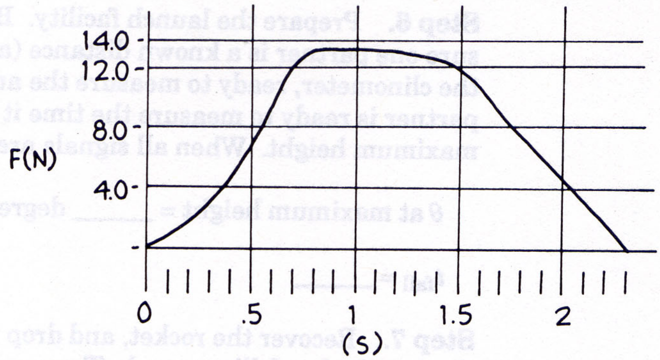

Figure 14.2

Procedure

Step 1. Measure the mass of the high mass rocket with an unexpended rocket engine. Repeat with an expended rocket engine. Calculate the average mass of the rocket.

mass (before burn) = ________

mass (after burn) = ________

mass (average) = ________

Step 2. Calculate the speed at burnout, v_{max}. Show your calculations.

v_{max} = ________

Step 3. Calculate the height at burnout assuming a constant acceleration for 0.23 seconds. Show your calculations.

h (at burnout) = ______

Step 4. Calculate the distance the rocket coasts *after* burnout. Show your calculations.

h (after burnout) = _______

Step 5. Calculate the maximum height of the rocket. Show your calculations.

h_{max} = _______ (method 1)

Step 6. Prepare the launch facility. Before launching the rocket, make sure one partner is a known distance (at least 100 meters) downrange with the clinometer, ready to measure the angle at maximum height and another partner is ready to measure the time it takes the rocket to descend from its maximum height. When all signals are go, launch the rocket!

θ at maximum height = ______ degrees

t_{fall} = ______

Step 7. Recover the rocket, and drop it from a known height and calculate the terminal or falling speed. Show your calculations.

v_{fall} = ______

Step 8. Calculate the maximum height from the time of descent from the maximum height and the terminal speed. Show your calculations.

h_{max} = _____ (method 2)

Analysis

1. How do your two predictions for the maximum height compare to the actual height as measured by the clinometer? Find the percentage difference.

2. How do the assumptions made in the discussion account for differences between your predictions and the actual height as measured by the clinometer?

Going Further

Step 9. Repeat the experiment several times using the same rocket and the same size rocket engines.

Repeat the experiment with a less massive (low mass) rocket.

3. How do your predictions compare for the rockets of different masses? Is one method more accurate at predicting the maximum height than the other? Why?