Exploring Space Through ALGEBRA

STUDENT EDITION

Algebra I

Space Shuttle Ascent

Background

Exploration provides the foundation of our knowledge, technology, resources, and inspiration. It seeks answers to fundamental questions about our existence, responds to recent discoveries and puts in place revolutionary techniques and capabilities to inspire our nation, the world, and the next generation. Through NASA, we touch the unknown, we learn and we understand. As we take our first steps toward sustaining a human presence in the solar system, we can look forward to far-off visions of the past becoming realities of the future.

The Vision for Space Exploration includes returning the space shuttle safely to flight, completing the International Space Station, developing a new exploration vehicle and all the systems needed for embarking on extended missions to the Moon, Mars, and beyond.

Since its first flight in 1981, the space shuttle has been used to extend research, repair satellites, and help with building the International Space Station, or ISS. However, by 2010 NASA plans to retire the space shuttle in favor of a new Crew Exploration Vehicle, or CEV. Until then, space exploration depends on the continued success of space shuttle missions. Critical to any space shuttle mission is the ascent into space.

The ascent phase begins at liftoff and ends at insertion into a circular or elliptical orbit around the Earth. To reach the minimum altitude required to orbit the Earth, the space shuttle must accelerate from zero to 8000 meters per second (almost 18,000 miles per hour) in eight and a half minutes. It takes a very unique vehicle to accomplish this.

Figure 1: Space Shuttle Discovery at Liftoff

There are three main components of the space shuttle that enable the launch into orbit. The orbiter is the main component. It not only serves as the crew's home in space and is equipped to dock with the International Space Station, but it also contains maneuvering engines for finalizing orbit. The external tank, the largest component of the space shuttle, supplies the propellant to the orbiter's three main maneuvering engines. The two solid rocket boosters, the third component, provide the main thrust at launch and are attached to the sides of the external tank (Figure 1). The components of the space shuttle experience changes in position, velocity and acceleration during the ascent into space. These changes can be seen when one takes a closer look at the entire ascent process (Figure 2).

The ascent process begins with the liftoff from the launch pad. Propellant is being burned from the Solid Rocket Boosters, or SRB, and the external tank, or ET, causing the space shuttle to accelerate very quickly. This high-rate of acceleration as the space shuttle launches through the Earth's atmosphere causes a rapid increase in dynamic pressure, known as Q in aeronautics. The structure of the space shuttle can only withstand a certain level of dynamic pressure (critical Q) before it suffers damage. Before this critical level is reached, the engines of the space shuttle are throttled down to about 70% of full power. At about one minute after launch the dynamic pressure reaches its maximum level (max Q). The air density then drops rapidly due to the thinning atmosphere, and the space shuttle can be throttled to full power without fear of structural damage.

At about 2 minutes after launch, the atmosphere is so thin that the dynamic pressure drops down to zero. The SRB, having used their propellant, are commanded by the space shuttle's onboard computer to separate from the external tank. The jettison of the booster rockets marks the end of the first ascent stage and the beginning of the second.

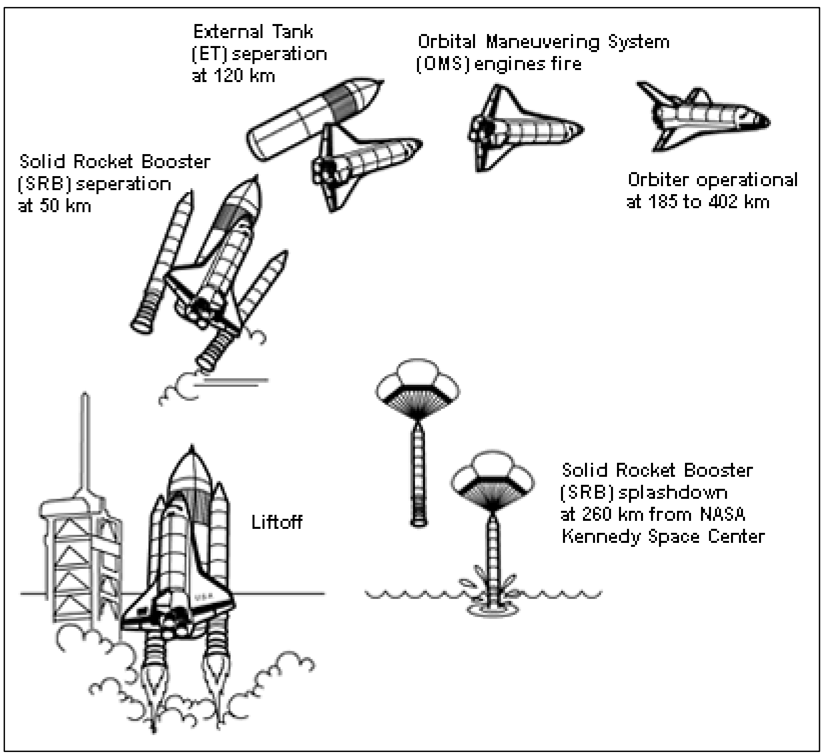

Figure 2: Space Shuttle Ascent Process

The second stage of ascent lasts about six and a half minutes. The space shuttle gains more altitude above Earth and the speed increases to the nearly 7,850 m/s (17,500 mph) required to achieve orbit.

The main engines are commanded by the onboard computer to reduce power, ensuring that acceleration of the space shuttle does not exceed 29.4 m/s^2 (3 g). This is 3 times the force of gravity that we fell while standing on the Earth's surface. Within thirty seconds the space shuttle reaches Main Engine Cut-Off, or MECO. For the next eleven seconds, the space shuttle coasts through space. At nine minutes, the command to jettison the nearly empty external tank is given by the onboard computer leaving the space shuttle's maneuvering engines to control any movement needed to achieve final orbit.

As we look to the future of space exploration, the ascent stage will remain a critical part of any successful mission.

For more information about space shuttle ascent and the Vision for Space Exploration, visit www.nasa.gov.

Instructional Objectives

- You will create scatterplots from a data table.
- You will determine correlation and interpret its meaning.
- You will find linear and quadratic regression equations.
- You will select an appropriate regression to fit the data.
- You will find the slope and y-intercept from an equation.
- You will communicate the meanings of slope and y-intercept as they relate to a real-world problem.

Problem

On July 4, 2006 Space Shuttle Discovery launched from Kennedy Space Center on mission STS-121, to begin a rendezvous with the International Space Station, or ISS. Before each mission, projected data are compiled to assist in the launch of the space shuttle to ensure safety and success during the ascent. To complete these data, flight design specialists take into consideration a multitude of factors such as space shuttle mass, propellant used, mass of payload being carried to space and of that returning. They must also factor in atmospheric density, which is changing throughout the year. After running multiple tests, information is compiled in a table showing exactly what should happen each second of the ascent.

The data for mission STS-121, showing the mass and altitude of the space shuttle every 10 seconds from liftoff to Solid Rocket Boosters, or SRB, separation, are displayed in Table 1.

It is during the first stage of the ascent, that the space shuttle is burning the greatest amount of propellant. You can see in the table that the space shuttle has a mass of an amazing 2,051,113 kg. After 2 minutes its mass is 880,377 kg. The burning of this vast amount of propellant is needed to get the space shuttle through Earth's atmosphere and into orbit. It is amazing to see how quickly the space shuttle can cover so much distance.

Table 1: STS-121 Ascent Data

Time (s)	**Space Shuttle Mass** (kg)	**Altitude** (m)
0	2,051,113	-8
10	1,935,155	241
20	1,799,290	1,244
30	1,681,120	2,872
40	1,567,611	5,377
50	1,475,282	8,130
60	1,376,301	11,617
70	1,277,921	15,380
80	1,177,704	19,872
90	1,075,683	25,608
100	991,872	31,412
110	913,254	38,309
120	880,377	44,726

1. Enter the information from flight STS-121 into your graphing calculator; enter time in L1, mass in L2, and altitude in L3. Create a scatterplot of the mass vs. time. You may need to adjust your viewing window. What is the correlation of the data (positive, negative, constant, or no correlation)? Explain this in terms of the problem.

2. Use your calculator to find the linear regression equation for the function of mass vs. time. Make sure you graph the equation with the scatterplot to verify that it represents the data. Using function notation, what is the function of mass in relation to time, *t*? Round coefficients and constants to the nearest whole number.

3. What is the slope of the equation found in question 2? Explain what this represents in relation to the space shuttle.

4. What is the *y*-intercept of the equation found in question 2? Explain what this represents in relation to the space shuttle. How close is this to the data found in Table 1? Express this as a percent error rounded to the nearest tenth.

5. Create a scatterplot of the altitude versus time. Again, you will need to adjust your viewing window. What is the correlation of the data? Explain this in terms of the problem.

6. What kind of function would best describe the change in altitude vs. time? Explain your reasoning.

7. Find the regression equation for the function of altitude vs. time. After selecting the regression option also input (L1, L3) before pushing enter. Otherwise the calculator will automatically use L1 and L2. Once again, be sure to graph the equation with the scatterplot to verify it represents the data. Using function notation, what is the function of altitude in relation to time, *t*? Round coefficients and constants to the nearest whole number.