# Intermediate Model Rocketry

## Unit 3
## 4-H Manual

COLORADO STATE UNIVERSITY
EXTENSION

# Acknowledgements

This revised 2025 edition of the Unit 3 Intermediate manual was compiled by the following contributors.
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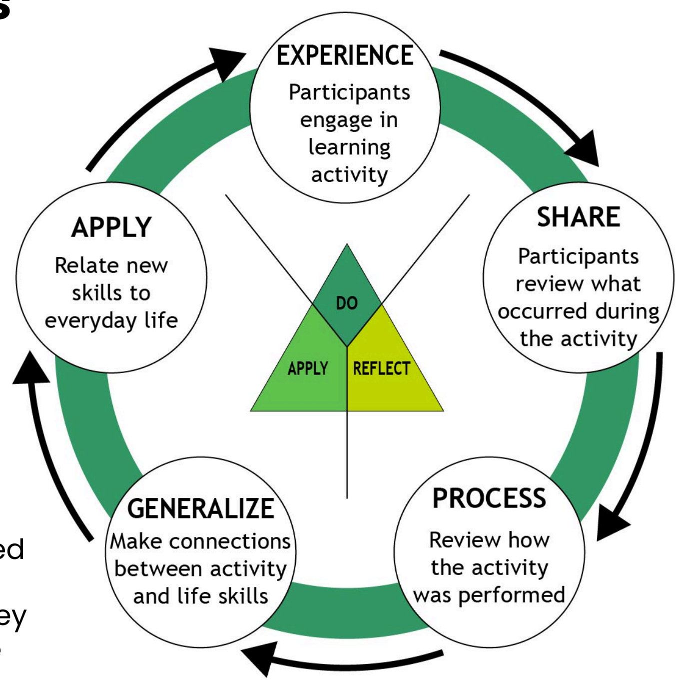
# Experiential Learning Process

The 4-H program utilizes a process where adult leaders ask open-ended questions that challenge youth to think. Through this inquiry, youth can propose hypotheses and determine their own solutions. The Experiential Learning Model developed by Pfieffer and Jones (1985) and modified by 4-H includes five specific steps that can be summarized into three main processes: Do, Reflect, and Apply.




The Experiential Learning Model encourages discovery with minimal guidance from others. A situation, project or activity is undertaken for individual thought and problem solving. Minimum outside assistance is provided, but support is offered to the individual by questioning at each stage. The youth participating in an activity reflect on what they did and then assess how what they learned can be applied to a life situation. Below are questions that might help during each stage of learning.

**1) Experience (Doing)**
Questions: What sources of information are available? What is possible? What do you expect to see? How is it working? What else might you try?

**2) Share (Reflecting on what occurred)**
Questions: What was your goal for this project/activity when you began? What happened? What were the results? What was most difficult? How do you know? What did you learn? What surprised you? How did you share this project/activity with others?

**3) Process (Reflecting on what's important)**
Questions: What problems seemed to reoccur? How did you solve them? What similar experiences have you had? How was the experience like or unlike experiences others had? Would you do anything differently? What did you learn about making decisions? What suggestions would you have for someone else who wanted to do a similar project/activity? What life skills were you developing through your project? Why are life skills important? What new questions do you have about yourself, others, and future goals?

**4) Generalize (So what?)**
Questions: What did you learn about yourself or about the activity? What key points have you learned? How did you decide what to do? What else could you have done? How does this relate to something else in life? Where have you faced similar challenges in your life? Where might this situation occur in the future? Why is it important to have plenty of information before making decisions? What did you learn about your own skill in communicating with others?

**5) Apply (Now what?)**
Questions: How does this project/activity relate to your everyday life? Why is this project/activity important to you? Where else can this skill be used? How will you use this in the future? What will you do differently after this experience? How can I make an impact? What will I create next? In what ways do people help each other learn new things? What are qualities you think are important in a leader? If someone helped or mentored you in this project, what would you tell them you learned and what difference it has made in your life? How would you express your appreciation?

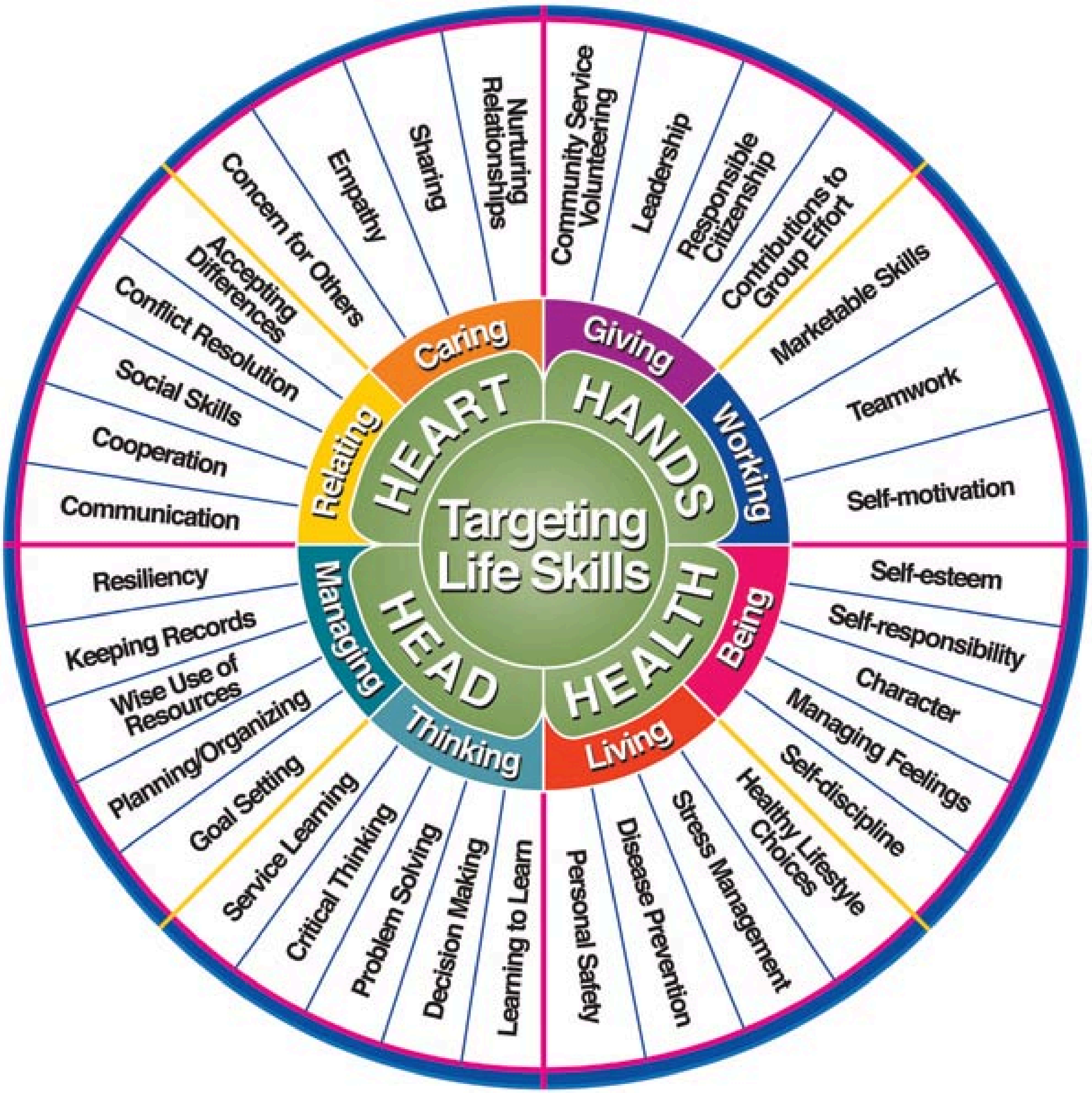



Image: Hendricks, P. (1998) "Developing Youth Curriculum Using the Targeting Life Skills Model" http://www.extension.iastate.edu/4H/skls.eval.htm

## Targeting Life Skills

A skill is a learned ability. Life skills are those abilities that assist individuals to lead successful, productive, and satisfying lives. In 4-H, we use the Targeting Life Skills Model to help youth become competent and prepared for adulthood. The Targeting Life Skills Model categories are based on the four H's from the 4-H clover (Head, Heart, Hands, and Health). Under each of these main categories, there are four categories and eight subcategories listing specific skills youth learn in 4-H. The main goal in 4-H positive youth development is to provide developmentally appropriate opportunities for youth to experience life skills and to be able to use them throughout a lifetime. By understanding the importance of the 4-H framework and its structure, 4-H members, parents, professionals, and leaders will know the expectations and will be able to effectively use 4-H delivery methods to help youth learn these life skills.

# Unit 3 -Intermediate Model Rocketry

## General Information

Unit 3 is written for the rocketeer who has completed Unit 2 Construction and Flight of Model Rockets. Now you are ready for more detail in Intermediate Model Rocketry. This unit will cover new and exciting areas not covered in Unit 2. Welcome back to the “hands-on” hobby of today and tomorrow. You just may be a future astronaut. Discover what is ahead of you since you now have the basics. First, review the following safety codes.

# Federal Aviation Regulation

**FEDERAL AVIATION REGULATION PART 101**

APPLICABILITY - The FAA has defined three classes of amateur rockets. The complete regulations are posted at https://www.ecfr.gov/cgi-bin/text-idx?SID=a1d0965b604a5b7d5e8ddaabb6e8afd9&mc=true&node=pt14.2.101&rgn=div5#sp14.2.101.c.

**National Fire Protection Association Code**

1. **NFPA 1122:** Code for Model Rocketry applies to the design, construction, limitation of propellant mass and power, and reliability of model rocket motors and model rocket motor reloading kits and their components, for use by the public for purposes of education, recreation, and sporting competition.
2. **NFPA 1125:** Code for the Manufacture of Model Rocket and High Power Rocket Motors: Covers the manufacturing of model rocket and high power rocket motors.

**Class 1 Model Rockets**

Class 1 rockets include what used to be known as model and large model rockets. They are defined at 14 CFR 101.22 (a) of the regulations and are listed as:
Class 1- Model Rocket means an amateur rocket that:

(1) Uses no more than 125 grams (4.4 ounces) of propellant;
(2) Uses a slow-burning propellant;
(3) Is made of paper, wood, or breakable plastic;
(4) Contains no substantial metal parts; and
(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.

Launching large model rockets used to require providing prior notification to the FAA. Now, no such notification is required. So long as the general operating limitations at 14 CFR 101.23 as listed below are followed, they can be launched freely.

(a) You must operate an amateur rocket in such a manner that it:

(1) Is launched on a suborbital trajectory;
(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;
(3) Is unmanned; and
(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

# CHAPTER 1


# Motor Types and Classification

## Types and Classification

If a motor is not coded to indicate its use, do not buy or use it. Such a motor is extremely dangerous to use. Estes uses a color code to indicate recommended use of the engine: green indicates use for single stage rockets; purple is to be used in top stage and multi-stage rockets; blue is for plugged engines, and red is for booster and intermediate stages of multi-stage models. They also use a letter and number combination code to help identify the performance of the engine. Take an engine with a code of B6-4 and see what it means. B indicates total impulse or power produced by the motor; 6 shows the motor's average thrust in newtons; 4 gives the delay in seconds between burnout and ejection charge.

**Safety Disclaimer**

Motor selection affects the performance of your rocket launches, so it is important to understand how to select the right motor for the rocket type (Single Stage, Multi Stage, Cluster, Gliders, Payload), weight (Light, Heavy), diameter (Minimum Diameter vs. Wide Body), weather conditions (Calm, Windy).

## Total Impulse Classification

A model rocket motor is designed to produce a precise amount of force for a determined length of time. This means each motor produces a certain total impulse, total impulse being equal to the average force produced multiplied by the time during which the force is generated. Units that are used to measure total impulse are mainly pound-seconds or newton-seconds. Numerous jobs can be achieved after thrust such as igniting another rocket engine (in staged rockets), activating the ejection charge to release the recovery system, activating or deactivating a circuit, taking a picture and releasing a glider. All commercially manufactured engines are thoroughly tested to meet standards set by the manufacturers plus national and international organizations.

| Code | Pound - Seconds | Newton - Seconds |
|---|---|---|
| 1/4 A | 0.00 - 0.14 | 0.00 - 0.625 |
| 1/2 A | 0.14 - .0.28 | 0.625 - 1.25 |
| A | 0.28 - 0.56 | 1.25 - 2.50 |
| B | 0.56 - 1.12 | 2.50 - 5.00 |
| C | 1.12 - 2.24 | 5.00 - 10.00 |
| D | 2.24 - 5.00 | 10.00 - 20.00 |

In conjunction with total impulse, the following is given, per Estes selection charts: Mini engines - single stage. This is just a partial list of Estes engines. Other engines can be found on their website at https://estesrockets.com.

ESTES education

## ENGINE TYPES: PERFORMANCE CHART

| OLD Prod. No. | NEW** Prod. No. | Engine Type | Total Impulse | Time Delay* | Est Max Lift Wt | | Max Thrust | | Thrust Duration | Initial Weight | | Propellant Weight | | Diameter | QTY Per Pack |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N-sec | Sec | oz | g | Newtons | Lbs | Sec | oz | g | oz | g | mm | |
| **SINGLE STAGE ENGINES** | | | | | | | | | | | | | | | |
| 1502 | 10010 | 1/4A3-3T | 0.625 | 3 | 1.0 | 28 | 4.90 | 1.1 | 0.25 | 0.21 | 5.9 | 0.05 | 1.3 | 13 | 4 |
| 1503 | 10011 | 1/2A3-2T | 1.25 | 2 | 2.0 | 57 | 8.30 | 1.9 | 0.30 | 0.23 | 6.4 | 0.07 | 1.9 | 13 | 4 |
| 1506 | 10012 | A3-2T | 2.50 | 2 | 2.0 | 57 | 6.80 | 1.5 | 0.60 | 0.25 | 7.1 | 0.12 | 3.3 | 13 | 4 |
| 1507 | 10013 | A3-4T | 2.50 | 4 | 2.0 | 57 | 6.80 | 1.5 | 0.60 | 0.26 | 7.4 | 0.12 | 3.3 | 13 | 4 |
| 1508 | 10014 | A3-6T | 2.50 | 6 | 2.0 | 57 | 6.80 | 1.5 | 0.60 | 0.27 | 7.7 | 0.12 | 3.3 | 13 | 4 |
| 1511 | 10015 | A10-3T | 2.50 | 3 | 3.0 | 85 | 13.00 | 2.9 | 0.80 | 0.29 | 8.1 | 0.12 | 3.5 | 13 | 4 |
| 1593 | 10016 | 1/2A6-2 | 1.25 | 2 | 2.0 | 57 | 8.90 | 2.0 | 0.30 | 0.48 | 13.6 | 0.10 | 2.7 | 18 | 3 |
| 1598 | 10017 | A8-3 | 2.50 | 3 | 3.0 | 85 | 10.70 | 2.4 | 0.50 | 0.55 | 15.5 | 0.14 | 4.1 | 18 | 3 |
| 1601 | 10018 | B4-2 | 5.00 | 2 | 4.0 | 113 | 13.20 | 3.0 | 1.10 | 0.66 | 18.6 | 0.27 | 7.6 | 18 | 3 |
| 1602 | 10019 | B4-4 | 5.00 | 4 | 3.5 | 99 | 13.20 | 3.0 | 1.10 | 0.68 | 19.2 | 0.27 | 7.6 | 18 | 3 |
| 1605 | 10020 | B6-2 | 5.00 | 2 | 4.5 | 127 | 12.10 | 2.7 | 0.80 | 0.61 | 17.3 | 0.23 | 6.5 | 18 | 3 |
| 1606 | 10021 | B6-4 | 5.00 | 4 | 4.0 | 113 | 12.10 | 2.7 | 0.80 | 0.63 | 17.8 | 0.23 | 6.5 | 18 | 3 |
| 1617 | 10022 | C5-3 | 10.00 | 3 | 8.0 | 227 | 20.40 | 4.6 | 1.85 | 0.83 | 23.6 | 0.39 | 11 | 18 | 3 |
| 1613 | 10023 | C6-3 | 10.00 | 3 | 4.0 | 113 | 15.30 | 3.4 | 1.60 | 0.83 | 23.4 | 0.43 | 12.2 | 18 | 3 |
| 1614 | 10024 | C6-5 | 10.00 | 5 | 4.0 | 113 | 15.30 | 3.4 | 1.60 | 0.85 | 24.0 | 0.43 | 12.2 | 18 | 3 |
| 1522 | 10025 | C11-3 | 10.00 | 3 | 6.0 | 170 | 22.10 | 4.9 | 0.80 | 1.13 | 32.1 | 0.44 | 12.4 | 24 | 2 |
| 1523 | 10026 | C11-5 | 10.00 | 5 | 5.0 | 142 | 22.10 | 4.9 | 0.80 | 1.18 | 33.4 | 0.44 | 12.4 | 24 | 2 |
| 1566 | 10027 | D12-3 | 20.00 | 3 | 14.0 | 396 | 32.90 | 7.4 | 1.60 | 1.57 | 44.5 | 0.85 | 24.2 | 24 | 2 |
| 1567 | 10028 | D12-5 | 20.00 | 5 | 10.0 | 283 | 32.90 | 7.4 | 1.60 | 1.61 | 45.7 | 0.85 | 24.2 | 24 | 2 |
| 1692 | 10029 | E12-4 | 30.00 | 4 | 17.0 | 482 | 30.60 | 6.9 | 2.70 | 2.16 | 61.2 | 1.30 | 36.9 | 24 | 3 |
| 1693 | 10030 | E12-6 | 29.50 | 6 | 14.0 | 397 | 29.60 | 6.7 | 2.70 | 2.23 | 63.2 | 1.30 | 36.9 | 29 | 3 |
| 1651 | 10031 | F15-4 | 49.61 | 4 | 21.0 | 595 | 25.26 | 5.7 | 3.45 | 3.59 | 101.5 | 2.12 | 60 | 29 | 2 |
| 1652 | 10032 | F15-6 | 49.61 | 6 | 17.0 | 482 | 25.26 | 5.7 | 3.45 | 3.66 | 103.7 | 2.21 | 60 | 29 | 2 |
| 1696 | 10033 | E16-4 | 33.68 | 4 | 20.0 | 566 | 26.44 | 5.9 | 2.09 | 2.86 | 81.0 | 1.41 | 40 | 29 | 2 |
| 1697 | 10034 | E16-6 | 33.68 | 6 | 16.0 | 453 | 26.44 | 5.9 | 2.09 | 2.92 | 82.7 | 1.41 | 40 | 29 | 2 |
| **UPPER STAGE ENGINES** | | | | | | | | | | | | | | | |
| 1504 | 10035 | 1/2A3-4T | 1.25 | 4 | 1.0 | 28 | 8.30 | 1.9 | 0.30 | 0.23 | 6.6 | 0.07 | 1.9 | 13 | 4 |
| 1599 | 10036 | A8-5 | 2.50 | 5 | 2.0 | 57 | 13.30 | 3.0 | 0.50 | 0.55 | 15.7 | 0.14 | 4.1 | 18 | 3 |
| 1607 | 10037 | B6-6 | 5.00 | 6 | 2.5 | 71 | 12.10 | 2.7 | 0.80 | 0.64 | 18.2 | 0.23 | 6.5 | 18 | 3 |
| 1615 | 10038 | C6-7 | 10.00 | 7 | 2.5 | 71 | 15.30 | 3.4 | 1.60 | 0.85 | 24.3 | 0.43 | 12.2 | 18 | 3 |
| 1524 | 10039 | C11-7 | 10.00 | 7 | 4.0 | 113 | 22.10 | 4.9 | 0.80 | 1.19 | 33.8 | 0.44 | 12.4 | 24 | 2 |
| 1568 | 10040 | D12-7 | 20.00 | 7 | 8.0 | 226 | 32.90 | 7.4 | 1.60 | 1.62 | 46.0 | 0.85 | 24.2 | 24 | 2 |
| 1694 | 10041 | E12-8 | 29.80 | 8 | 12.0 | 340 | 31.80 | 7.1 | 2.70 | 2.24 | 63.5 | 1.30 | 36.9 | 24 | 3 |
| 1653 | 10042 | F15-8 | 49.61 | 8 | 15.0 | 425 | 25.26 | 5.7 | 3.45 | 3.69 | 104.4 | 2.12 | 60 | 29 | 2 |
| 1698 | 10043 | E16-8 | 33.68 | 8 | 14.0 | 396 | 26.44 | 5.9 | 2.09 | 2.99 | 84.7 | 1.41 | 40 | 29 | 2 |
| **BOOSTER STAGE ENGINES** | | | | | | | | | | | | | | | |
| 1510 | 10044 | A10-0T | 2.50 | NONE | 4.0 | 113 | 13.00 | 2.9 | 0.80 | 0.24 | 6.8 | 0.12 | 3.5 | 13 | 4 |
| 1600 | 10045 | A8-0 | 2.50 | NONE | 3.0 | 85 | 13.30 | 3.0 | 0.30 | 0.47 | 13.5 | 0.14 | 4.1 | 18 | 3 |
| 1608 | 10046 | B6-0 | 5.00 | NONE | 4.0 | 113 | 12.10 | 2.7 | 0.80 | 0.55 | 15.7 | 0.23 | 6.5 | 18 | 3 |
| 1616 | 10047 | C6-0 | 10.00 | NONE | 4.0 | 113 | 15.30 | 3.4 | 1.60 | 0.76 | 21.4 | 0.43 | 12.2 | 18 | 3 |
| 1521 | 10048 | C11-0 | 10.00 | NONE | 6.0 | 170 | 22.10 | 4.9 | 0.80 | 1.03 | 29.2 | 0.44 | 12.4 | 24 | 2 |
| 1565 | 10049 | D12-0 | 20.00 | NONE | 14.0 | 396 | 32.90 | 7.4 | 1.60 | 1.43 | 40.4 | 0.84 | 23.8 | 24 | 2 |
| 1691 | 10050 | E12-0 | 28.80 | NONE | 16.0 | 454 | 31.30 | 7.0 | 2.60 | 2.05 | 58.1 | 1.30 | 36.9 | 24 | 3 |
| 1650 | 10051 | F15-0 | 49.61 | NONE | 19.0 | 539 | 25.26 | 5.7 | 3.45 | 3.32 | 94.0 | 2.12 | 60 | 29 | 2 |
| 1695 | 10052 | E16-0 | 33.68 | NONE | 18.0 | 509 | 26.44 | 5.9 | 2.09 | 2.58 | 73.2 | 1.41 | 40 | 29 | 2 |
| **PLUGGED ENGINES - FOR USE WITH ROCKET-POWERED RACERS** | | | | | | | | | | | | | | | |
| 1505 | 10053 | A10-PT | 2.50 | NONE | 3.0 | 85 | 13.00 | 2.9 | 0.80 | 0.26 | 6.83 | 0.13 | 3.5 | 13 | 4 |

# Rocket Motor Design

Low power model rocket engines have a slight center bore at the tip of the nozzle end of the propellant, which serves two purposes. It provides for easy ignition and produces initial high thrust. The slight center bore provides a large burning area for faster consumption of fuel. After initial thrust, a transition is made to an end-burning grain, and thrust drops to a sustaining level. Wind tunnel tests show this dual action thrust is best for lightweight rockets at subsonic speeds. Slow-burning delay and tracking charge is ignited at burnout of propellant. This charge produces no thrust and permits the rocket to coast to peak altitude. As the delay charge burns out, it ignites the ejection charge and pressurizes the rocket body tube.

## Rocket Motor Testing

Model rocket motors undergo rigorous testing to ensure safety, consistency, and compliance with national standards set by organizations like the National Association of Rocketry (NAR) and Tripoli Rocketry Association (TRA). Manufacturers test each motor design in controlled environments, measuring thrust, burn time, delay charge accuracy, and ejection charge effectiveness. These tests are conducted using static test stands equipped with load cells that record force output over time, generating thrust curves that help determine the motor's performance. Motors are also tested for reliability under different conditions, such as temperature extremes and varying humidity levels, to ensure they function properly in real-world launches.

You can also build a simple static test stand to measure the thrust of different model rocket motors. Using a securely mounted scale, a motor can be ignited in a safe outdoor area under supervision, and participants can record the thrust produced at various moments during the burn. By comparing thrust curves of different motors, they can analyze which motors provide higher acceleration, longer burn times, or better performance for different rocket designs. This experiment not only reinforces physics and engineering principles but also encourages data analysis and problem-solving skills in a fun and interactive way.

# What are Clustered Motors?

Clustered motors are a fascinating feature in model rocketry where multiple rocket engines are used together in a single launch vehicle. Instead of relying on a single engine, clustered motors utilize two or more engines igniting simultaneously to provide greater thrust and improve the rocket's performance. This technique is particularly useful for launching larger or heavier rockets that require more power to lift off successfully.

# How Clustered Motors Work

When using clustered motors, all engines are mounted in the rocket's base. Each motor must be ignited at the same time to ensure an even thrust and a stable flight. We will be learning more about how to build and launch model rockets with clustered motors in Unit 5 Designer Model Rocketry.

## Benefits of Clustered Motors

- **Increased Thrust:**
More motors mean more thrust, allowing for the launch of larger rockets or those with heavier payloads.
- **Redundancy:**
If one motor fails, the remaining engines can still provide some thrust, potentially saving the flight.

# Safety for Using Clustered Motors

**1** Double-Check Connections:

Ensure all electrical connections are secure and that each igniter is properly placed within its motor.

**2** Use Reliable Equipment:

Always use a reliable launch controller capable of handling multiple igniters.

**3** Test Before Launch:

Conduct a continuity check on each igniter to ensure they will all fire properly when the launch button is pressed.

**4** Proper Handling:

Handle the motors and igniters with care to avoid any accidental ignition or damage.

**5** Check Total Impulse:

Be sure that the total impulse of the combined motors does not violate Model Rocketry Safety Codes.

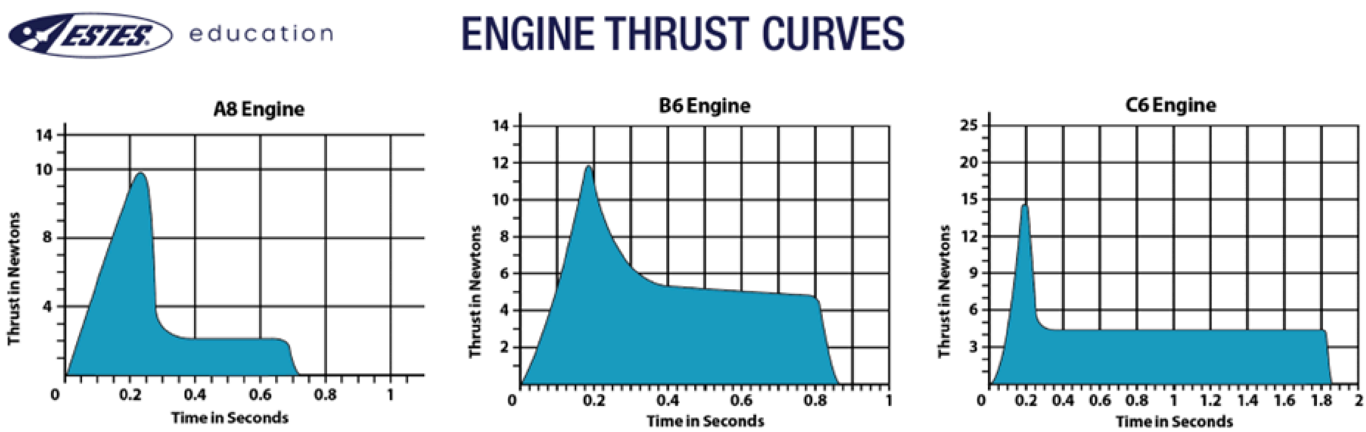
## Fun Fact!

Did you know that real-life space missions often use a form of clustered engines? The Space Shuttle, for example, used multiple main engines and solid rocket boosters working together to achieve the necessary thrust for launch. The new SpaceX Starship's Super Heavy Booster has 33 engines! Each of the SpaceX Raptor engines can produce almost 3 Meganewtons (MN) of thrust, or 3,000,000 Newtons (N) (670,000 Lbs). How many Newtons are all 33 engines making together? If an Estes C6-5 motor produces approximately 15 Newtons of thrust how many would you need in a cluster to match a single Raptor engine?

By understanding and utilizing clustered motors, you can take your model rocketry experience to new heights, both literally and figuratively!

# Comparative Time/Thrust Curves

All times and thrusts are average and also show high peaks. These charts show examples of a few engines made by Estes.




## Knowledge Check on Motor Types and Classification

1. What does the color code indicate?

________________________________________

________________________________________

________________________________________

2. What does A8-3 on a motor tell you?

A= ________________________________________

8= ________________________________________

3= ________________________________________

3. What are units called that measure total impulse?

________________________________________

________________________________________

# Knowledge Check on Motor Types and Classification

**4** List two motors and their pound-seconds and newton-seconds (refer to Total Impulse Classification).

___

___

___

**5** What are clustered motors?

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___

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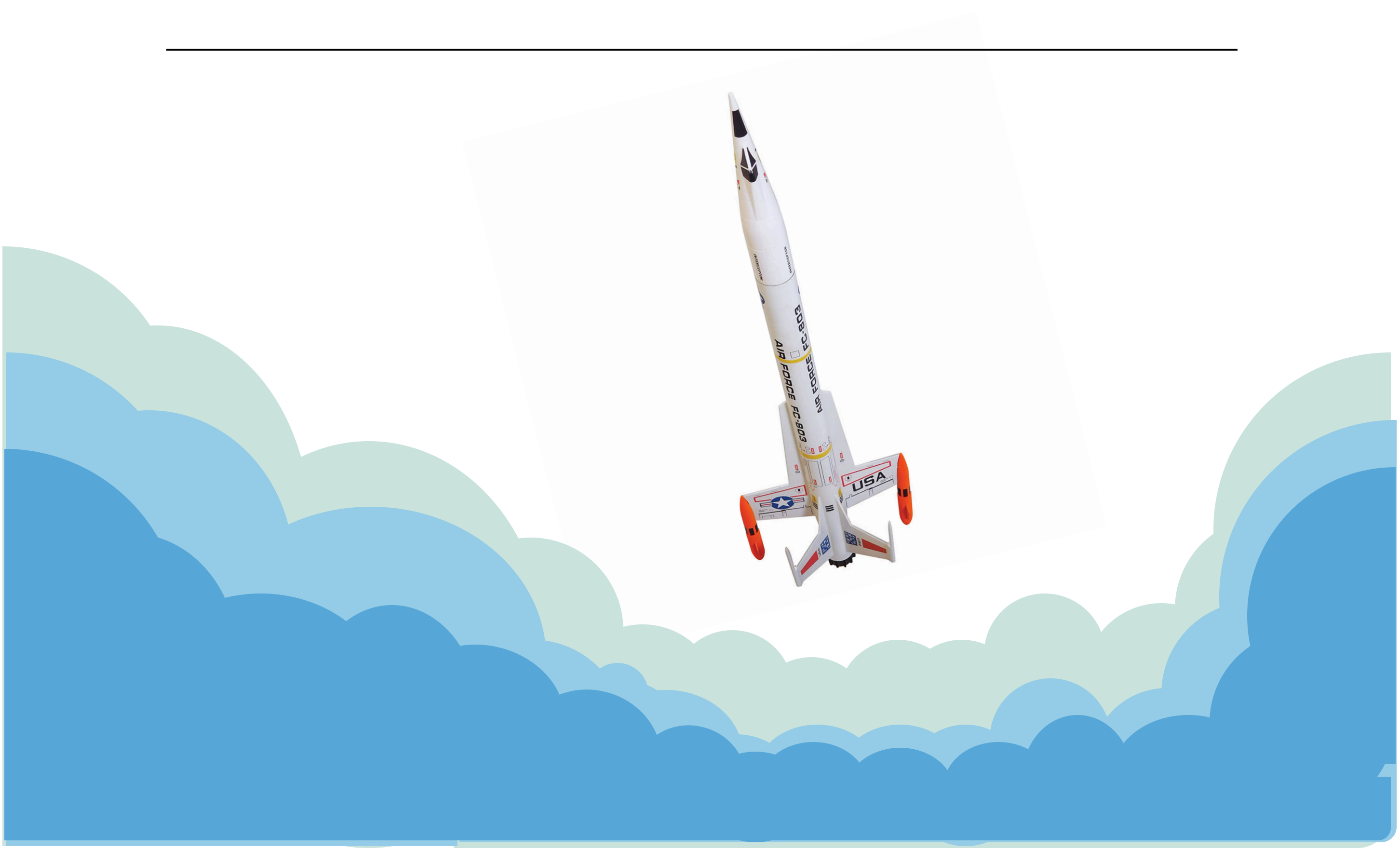


# Using Simulation Software: OpenRocket and RockSim

## Introduction to Simulation Software

As you now know, model rocketry is a fantastic hands-on hobby that combines creativity, physics, and engineering. As you progress in your rocketry skills, understanding how your rockets will perform before you launch them becomes increasingly important. Computer Simulation software like OpenRocket and RockSim allow you to design and test your rockets virtually. These tools help predict how high your rocket will fly, how stable it will be, and what changes you might need to make to improve its performance.

## What is OpenRocket?

OpenRocket is a free, open-source software designed for model rocket simulation. It is user-friendly and has a wide range of features that support both beginners and advanced users. Open rocket has tutorials and videos on how to use the software and learn more about model rocketry. You can even design parts for your rocket and export them as 3D models to print on a 3D printer.

## Features of OpenRocket:

**Design and Visualization:**

You can create a detailed 3D model of your rocket and view it from any angle.

**Simulation:**

OpenRocket lets you simulate the flight of your rocket. You can see how high it will go, how fast it will travel, and how stable it will be.

**Component Database:**

The software includes a database of common rocket components, making it easy to find and use the parts you need for your design.

**Stability Analysis:**

It provides a detailed analysis of your rocket's stability, helping you understand how it will behave in flight.

# Getting Started with OpenRocket:

## 1. Download and Install:

OpenRocket is available for free. You can download it from the OpenRocket website https://openrocket.info/ and install it on your computer.

## 2. Create a New Design:

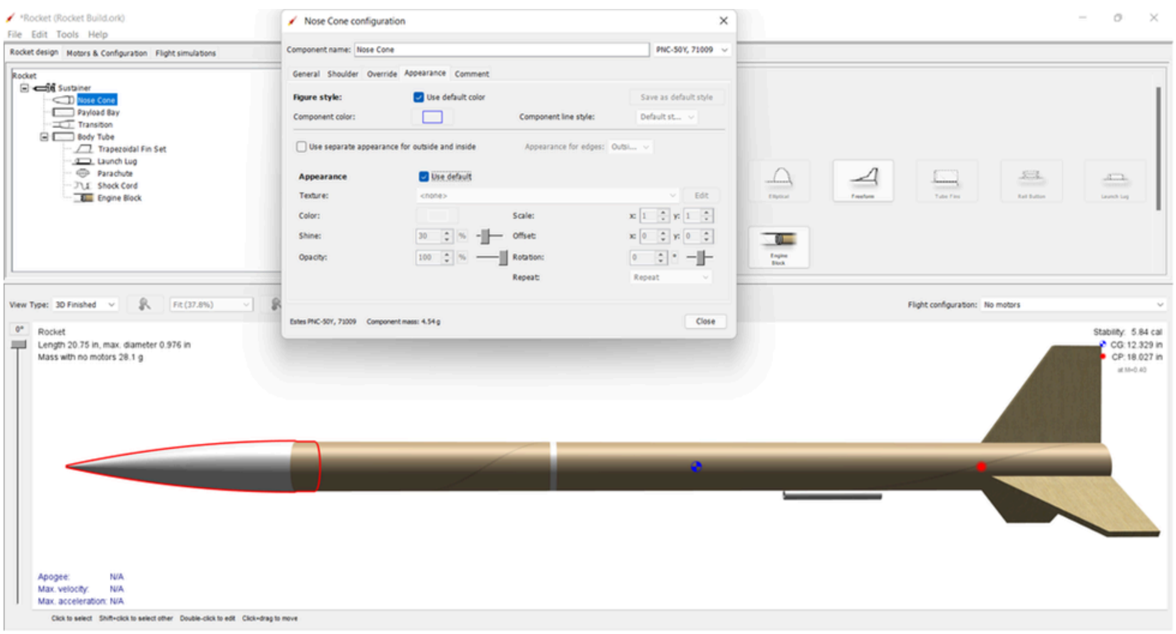
Start a new project and begin by selecting the body tube for your rocket. Add components like the nose cone, fins, and engine mount.

## 3. Run Simulations:

Once your design is complete, you can run simulations. Adjust variables such as engine type, launch angle, and weather conditions to see how they affect your rocket's performance.

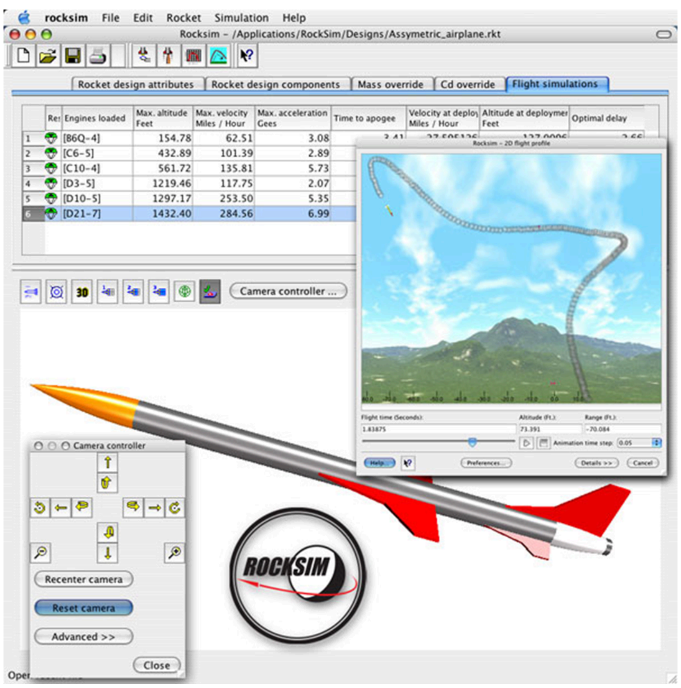
## 4. Analyze Results:

Review the simulation results to see predictions for altitude, velocity, and stability. Make adjustments to your design as needed and run additional simulations.



# What is RockSim?

RockSim is a commercial rocket design and simulation software that offers advanced features for serious rocketry enthusiasts. It is widely used by hobbyists, educators, and professionals. RockSim has features such as launch simulations and can overlay simulated flights in Google Earth.




## Features of RockSim:

**Detailed Design Tools:**

RockSim provides extensive tools for creating detailed rocket designs, including custom parts and complex configurations.

**Advanced Simulations:**

It offers more sophisticated simulation capabilities, including multi-stage rockets and clustered engines.

**Educational Resources:**

RockSim includes tutorials and educational materials to help users learn about rocketry principles and simulation techniques.

**Thrust Curve Analysis:**

The software allows for detailed thrust curve analysis, helping you choose the right engine for your rocket.

# Getting Started with RockSim:

## 1. Purchase and Install:

RockSim is a commercial product, so you will need to purchase a license. After purchasing, download and install the software from the Apogee Components website. https://www.rocksim.com/

## 2. Design Your Rocket:

Use the design tools to create a detailed model of your rocket. You can customize every component to match your specifications.

## 3. Simulate Flights:

Run simulations to test your design under various conditions. RockSim can simulate complex scenarios, such as rockets with multiple stages or clustered engines.

## 4. Optimize Your Design:

Use the simulation results to optimize your rocket's performance. Experiment with different configurations and components to achieve the best results.

# Why Use Simulation Software?

Simulation software like OpenRocket and RockSim offers several benefits:

**Safety**

By predicting how your rocket will perform, you can make sure it is stable and safe to fly before launching.

**Cost-Effective**

Virtual testing reduces the need for physical prototypes, saving time and money.

**Educational**

These tools help you understand the principles of rocketry, aerodynamics, and physics.

**Performance Optimization**

Fine-tune your rocket designs for maximum performance, ensuring successful and impressive launches.

Whether you're a beginner using OpenRocket or an advanced user with RockSim, simulation software is an invaluable tool in model rocketry. It allows you to design, test, and optimize your rockets with precision, ensuring safe and successful flights every time. Explore these tools and take your rocketry skills to new heights!

# Activity One: Engine Test

**Skill Level**

Intermediate (Ages 11-13)

**Suggested Group Size:**

Any

**Life Skills**

Critical thinking, learning to learn

**Space**

Check the launch site dimensions required for the engines you will use.

**Tags**

model, rocket, model rocketry, science, altitude

## Materials List:

- Model Rocket
- Two engines of differing powers (ex: one A and one B engine. Ensure both engines are listed as recommended engines for the chosen rocket.)
- Launch system
- Observation chart
- Writing utensil

Time Needed: 20-30 minutes

**Learner Outcomes:** Participants will identify how different engines affect the flight of their rocket.

**MS-PS2-2 Motion and Stability: Forces and Interactions**
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

**MS-PS3-5 Energy**
Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

**Success Indicators:**
Explain the purpose of using different sized engines.

# Activity One: Engine Test

## Introduction:

Understanding how engine size impacts the model rocket's flight will help participants select the appropriate engine for various situations.

## Opening Questions:

What is total impulse?
What is engine propellant?
What do the parts of an engine code mean?

## Background information:

Participants should have read through "Introduction to Model Rocket Motor Performance" in the Unit 3 Manual.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)

  If it has been a while since they have read "Introduction to Model Rocket Motor Performance" review this section with the participants. Answer any questions they may have about engines (also called motors).

## Let's Do It!

- Review the observation chart so that participants understand what they will be looking for as they launch the rockets.
- Launch the rocket with the first engine and have participants record their observations in the chart on the handout.
- Launch the rocket with the second engine and have participants record their observations in the chart on the handout.
- Review what they noticed about the two launches and discuss the pros and cons of using each engine using the question prompts below. Have them record these pros and cons on the bottom of the handout.

# Activity One: Engine Test

## Term and Concept Discovery:

**Total Impulse:**
The total amount of force from a rocket engine; determined by multiplying the average thrust by the burning time.

**Recommended Engines:**
Engines listed in the instructions that will give a safe and stable flight with the chosen rocket.

**Average Thrust:**
The total impulse of the engine divided by the time during which the engine produces thrust.

**Delay:**
Number of seconds between engine burnout and ejection charge

## Talk It Over:

**Share:** With the group or individual, discuss what happened during each flight.

**Reflect:** Ask the group or individual to explain the pros and cons of using the first engine versus the second.

**Generalize:** Discuss how this activity relates to choosing appropriate motors for various situations such as a launch competition versus launching with family and friends.

## Apply

Why would understanding total impulse, average thrust, and delay help someone select the correct engine for different situations?

# Activity One: Engine Test

## Variations:

If participants have access to an altimeter, they could use that to determine the exact altitude achieved for each launch. Depending on the amount of space available, participants could continue with the activity by observing a third or fourth recommended engine. If supplies are not readily available, participants could also build a rocket in OpenRocket with the same specifications as a model rocket kit and run the simulation for each of the recommended flight engines to see the difference in motor performance.

## Did You Know?

Did you know that in 2023, a team of students from Embry-Riddle Aeronautical University set a new record by launching an amateur rocket to an altitude of 47,732 feet? That's about 1.6 times higher than Mount Everest! By understanding and applying principles like total impulse and average thrust, they achieved this incredible milestone. Just imagine—your model rocket experiments today use the same basic science that helped the Cygnus team reach these incredible heights!

Bergin, C. (2024, June 24). Record-breaking amateur rocket flight goes higher than Mount Everest. Space.com. https://www.space.com/record-breaking-amateur-rocket-flight-higher-mount-everest

# Activity One: Engine Test

## Observation Chart

| | | |
|---|---|---|
| **Which engine sent the rocket higher?** | | |
| **Which rocket landed closest to the launch pad?** | | |
| **Did anything unusual happen? (e.x. Large gust of wind)** | | |
| **Additional Observations** | | |

Which engine worked better for your rocket and why?

Which engine sent your rocket the highest?

Which engine were you using when the rocket landed closest to the launch pad?

Why did this motor have that outcome?

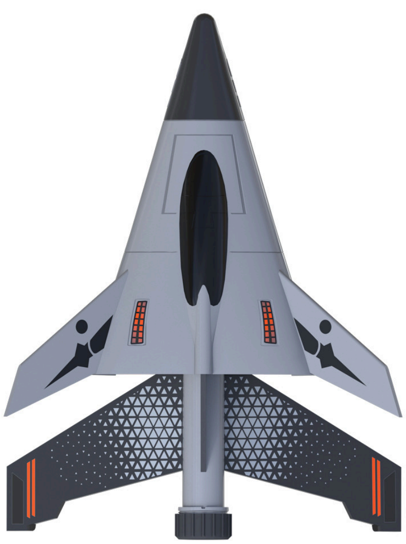
# CHAPTER 2

# Introduction to Model Rocket Motor Performance

## The Motor and Its Purpose

Take a C6-5 engine and use it as an example. The C tells that the total impulse must be between 1.12- and 2.24-pound seconds (5.00 and 10.00 newton-seconds); 6 indicates that the average thrust is 6 newtons (1.35 pounds); 5 tells that there is a 5-second delay before ejection charge is ignited. The retainer cap is to retain ejection charge until ignited. Ejection charge provides a fixed amount of gas to activate the recovery system. Delay train is a slow-burning mixture producing smoke, which allows the rocket to reach its peak altitude before igniting the ejection charge and gives a smoke trail for tracking.

The propellant of an engine is a chemical composite that produces the reaction products by a self sustaining combustion process. The nozzle (called the De Laval nozzle) converts the pressure (thermal) energy of reaction products into velocity (motion) energy of reaction products at the nozzle exit.



## Typical Characteristics of Propellants

The most important characteristic of the propellant is its burning rate. Other characteristics are: specific impulse, density, exhaust velocity, specific heat ratio, temperature of combustion, pressure and temperature requirements for ignition, composition of reaction products, resistance to damage from handling or storage and possible toxicity. Specific impulse is defined as the total impulse if you fired an engine containing one pound of propellant. The other characteristics mentioned are too complex to discuss here.

## Bonus Fun Fact: How the Roman Empire Influenced Modern Rocketry

Did you know that the design of the Solid Rocket Boosters (SRBs) on the Space Shuttle and the Space Launch System can be traced back to the Roman Empire?

The SRBs are designed to be 12.17 feet in diameter. But why this specific size? The answer lies in their transportation method. These boosters, manufactured by Thiokol in Utah, must be shipped by train to launch facilities. The boosters need to fit through train tunnels, which are sized according to the width of American train tracks: 4 feet, 8.5 inches apart. This specific track width originated from the width of covered wagon wheels built in Europe. These wagons had wheels spaced 4 feet, 8.5 inches apart to fit the ruts in long dirt roads, which were made by Roman war chariots. The chariots were designed to accommodate the width of two horses walking side by side.

In summary, the dimensions of modern SRBs are indirectly influenced by the width of Roman chariots, which were built to match the size of two horses. So, in a way, the size of a horse's rear end determined the design of one of the most advanced vehicles ever made!

## Black Powder vs. Composite Model Rocket Motors

Model rockets commonly employ two primary types of solid rocket motors: black powder and composite motors. Both types have unique characteristics that make them suitable for different applications within the hobby. Understanding the differences between them can help you choose the right motor for your model rocket project. Black powder engines, like those made by Estes, are safe, affordable, and readily found while composite motors are becoming more available and offer unique performance characteristics.

"Figure 1. AI-generated image by Gemini. This image depicts a Roman chariot, a train, and a Space Shuttle launch vehicle, symbolizing the evolution of transportation throughout history. This image was created using Gemini 2.0 Flash, a large language model developed by Google AI.

# Black Powder Motors

## Composition and Construction:

**Material:** Black powder engines are made from a simple mixture of potassium nitrate, charcoal, and sulfur.

**Design**: They are typically encased in a cardboard tube with a clay nozzle and a clay retainer cap.

## Performance:

**Thrust Profile:** Black powder engines produce a quick, high-thrust burn. They are ideal for launching lighter rockets.

**Ease of Use:** These motors are easy to ignite and use, making them suitable for beginners and educational purposes.

**Availability:** Black powder engines are widely available and are often the first type of motor new rocketeers use.

## Safety and Handling:

**Storage:** They are sensitive to humidity and need to be stored in a dry environment to prevent degradation.

**Ignition:** Black powder engines ignite easily, which is convenient but make sure to always handle them carefully for a safe and successful launch.

## Fun Fact: Solid Rocket Boosters

The Space Shuttle Discovery and its seven-member STS-120 crew head toward Earth-orbit and a scheduled link-up with the International Space Station. Liftoff from Kennedy Space Center's launch pad 39A occurred at 11:38:19 a.m. (EDT). Onboard are astronauts Pam Melroy, commander; George Zamka, pilot; Scott Parazynski, Stephanie Wilson, Doug Wheelock, European Space Agency's (ESA) Paolo Nespoli and Daniel Tani, all mission specialists.

NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test, Wednesday, Nov. 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center in Florida. NASA's Artemis I mission is the first integrated flight test of the agency's deep space exploration systems: the Orion spacecraft, Space Launch System (SLS) rocket, and ground systems. SLS and Orion launched at 1:47 a.m. EST, from Launch Pad 39B at the Kennedy Space Center. Photo Credit: (NASA/Joel Kowsky)
Photo, Nasa Hq. "Artemis I Launch (NHQ202211160017)." Flickr, Yahoo!, 17 June 2024, www.flickr.com/photos/nasahqphoto/52504616014/in/photostream/.

# Composite Motors

## Composition and Construction:

**Material:** Composite motors use a mixture of ammonium perchlorate and a rubbery binder known as HTPB (hydroxyl-terminated polybutadiene)

**Design**: These motors are housed in stronger casings, often made of phenolic resin or fiberglass.

## Performance:

**Thrust Profile:** Composite motors provide a longer, more consistent thrust compared to black powder motors. This makes them suitable for heavier rockets and more advanced flights.

**Efficiency:** They have a higher specific impulse, meaning they produce more thrust per unit of propellant.

**Variety:** Composite motors come in a wide range of sizes and power levels, offering more options for different rocket designs and missions.

### Safety and Handling:

**Storage:** Composite motors are less sensitive to environmental conditions, making them easier to store over long periods.

**Ignition:** They require a more powerful ignition source, which can be a bit more complex but also reduces the risk of accidental ignition.

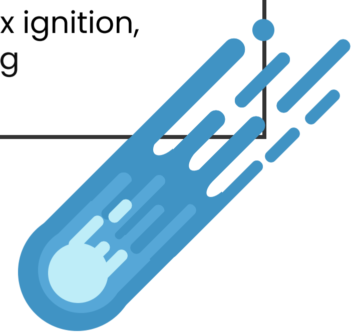
## Fun Fact: Solid Rocket Boosters

The SRB or Solid Rocket Boosters found on the side of the Space Shuttle and the new Space Launch System for the Orion Space Capsule and Artemis Missions to the Moon are huge Composite Rocket motors and are made with the same basic Ammonium perchlorate formulation found in model rocket motors.

NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test, Wednesday, Nov. 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center in Florida. NASA's Artemis I mission is the first integrated flight test of the agency's deep space exploration systems: the Orion spacecraft, Space Launch System (SLS) rocket, and ground systems. SLS and Orion launched at 1:47 a.m. EST, from Launch Pad 39B at the Kennedy Space Center. Photo Credit: (NASA/Joel Kowsky)
Photo, Nasa Hq. "Artemis I Launch (NHQ202211160017)." Flickr, Yahoo!, 17 June 2024, www.flickr.com/photos/nasahqphoto/52504616014/in/photostream/.

# Comparison Summary

| Feature | Black Powder Motors | Composite Motors |
|---|---|---|
| Material | Potassium nitrate, charcoal, sulfur | Ammonium perchlorate, HTPB |
| Casing | Cardboard, clay nozzle, clay retainer cap | Phenolic resin, fiberglass |
| Thrust Profile | Quick, high-thrust burn | Long, consistent thrust |
| Ease of Use | Easy to ignite, beginner-friendly | Requires powerful ignition source, more advanced |
| Availability | Widely available, common for beginners | Wide range of sizes and power levels |
| Storage | Sensitive to humidity, needs dry storage | Less sensitive, easier to store |
| Ignition | Simple ignition, requires careful handling | More complex ignition, safer handling |



## Safety Check!

While these motors appear simple, you should never attempt to make your own or modify commercially purchased motors as the risk of fire and explosions that can cause serious injury is possible. Handling commercially made model rocket motors are generally safe following the safety guidelines.

Choosing the right motor depends on your specific needs and experience level. Black powder engines are perfect for beginners and simple rocket designs, while composite motors are better suited for advanced rocketeers looking for higher performance and more variety in their rocketry projects.

# The Systems of Rocket Propulsion

There are two types of rocket propulsion systems: liquid and solid propellants. Liquid propellant rockets are or were the most difficult to develop because they require exceptional engineering and manufacturing. In larger missiles, the fuel and oxidizer tanks are the main structure of a rocket. Tank size will vary according to the propellant and fuel oxidizer ratio needed for maximum power efficiency. These liquid propellant rockets are generally started by a gas generator. Some of the liquid propellants are hypergolic; they ignite immediately upon contact in the thrust chamber.

Solid propellants are a mixture of fuel and oxidizer joined by a binder in a solid state. They are mixed to obtain the desired physical and chemical characteristics. Below are some of the advantages or characteristics that a solid propellant should possess:


- Easily manufactured
- Easily handled with safety
- Stable and easily stored
- Burns uniformly and ignites easily
- Burning surface can be maintained
- Will not absorb water vapor easily
- Smokeless and flashless

The burning rate is measured in inches per second. Most motors have a nozzle at the end of the propellant with the design contingent on the propellant used.

## Function of the Nozzle

Most model rocket engines use the De Laval nozzles, which consist of three sections: convergent section, a throat section and a divergent section. The convergent section works much the same way as water does when it speeds up as it goes through a narrow channel of a stream. (It forces reaction products to increase velocity as they pass through the throat section.) The divergent section is a little more complicated to explain. At ground level a weather balloon is slack and loose. As the balloon rises above the ground, the balloon begins to expand because the pressure inside remains the same while the air pressure outside is reduced. This is why the balloon expands. If the pressure in the balloon expands beyond the outside pressure, it will burst. The throat section works much the same way as the nozzle on a water hose. As the hole is made smaller, the water pressure becomes greater. The larger the hole, the less the pressure, although the amount of water coming out remains the same.

## Design of the Propellant Grain

The main guiding purpose of varying propellant grain design (grain geometry) is to give the burning area necessary time to produce desired chamber pressure. Grain design most commonly found in model rocket engines is a combination of core burning and end burning. Core burning is commonly known as progressive burning since it increases the burning area with time; end burning is normally called neutral burning since the area burning remains constant.

## Manufacturer Testing

Every manufacturer uses very sophisticated equipment to test engines for thrust levels and impulse total. The goal is not only to meet the standards set by N.A.R., but to exceed these standards. Approximately three out of 100 engines are static tested to ensure that the standards are met. The equipment automatically performs various physical tests such as correct amount of propellant, delay, etc. All of these tests are essential to the manufacturers and model rocketeers.

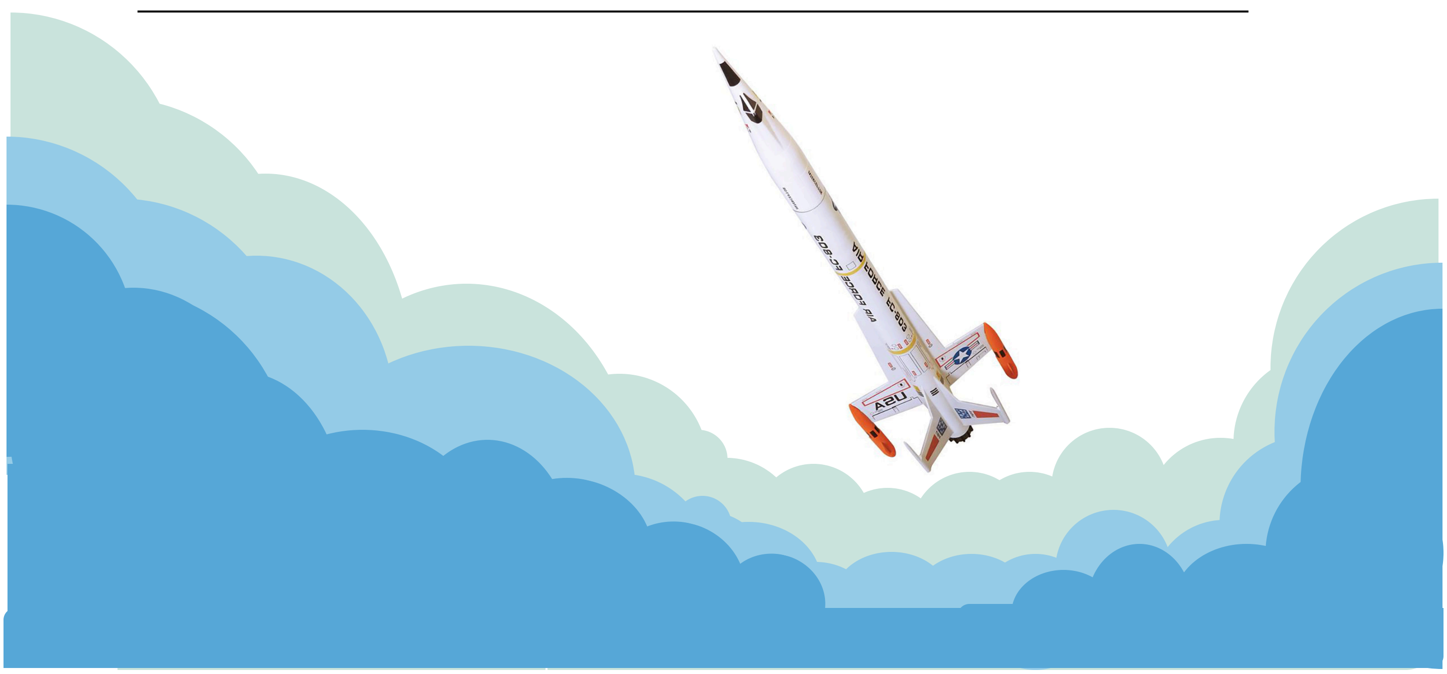
# Knowledge Check on Model Rocket Motor Performance

1. Which engine has a higher total impulse, an A8-3 or B4-4?

2. What is the purpose of the retainer cap?

3. What is the most basic type of propulsion?

4. What is the most important characteristic of an engine propellant?



# CHAPTER 3

# All About Multi-Stage Rockets

## Definition of Multi-Staging

Staging is one of the prominent characteristics of rocketry. Staging in model rocketry refers to using multiple rocket engines to propel a rocket higher and faster. This method is used with solid and liquid propellant rockets, and can be used in rockets less than one foot tall to well over 100 feet. The main advantage of multi-staging is doing away with unnecessary weight later in the rocket's flight. The young rocketeer who masters the principles of multi-staging is gaining knowledge that will be useful in the future.

# Direct and Indirect Staging in Model Rocketry

There are two primary types of staging: direct staging and indirect staging. Each method has its own mechanics and advantages.

## Direct Staging

**Definition:** Direct staging, also known as traditional or serial staging, involves stacking rocket stages on top of one another. Each stage contains its own engine, fuel, and sometimes its own guidance system. Once the lower stage has burned out, it is jettisoned (detached), and the next stage ignites.

### Advantages:

**Efficiency:** By discarding used stages, the rocket becomes lighter, which increases the efficiency of the remaining stages.

**Altitude:** Direct staging allows the rocket to reach higher altitudes as each new stage provides fresh thrust.

**Example:** Multi-Stage Rockets
A common example of direct staging in model rocketry is a two-stage rocket, where the first stage boosts the rocket to a certain altitude, and the second stage ignites to propel it even further.

### How It Works:

1. **Launch**

   The rocket is launched with the first stage engine providing the initial thrust.

2. **Stage Separation**

   After the first stage burns out, it is detached or jettisoned.

3. **Second State Ignition**

   The second stage engine ignites, taking over the propulsion of the rocket.

4. **Continued Flight**

   This process can repeat for additional stages, with each stage igniting after the previous one is discarded.

# Direct and Indirect Staging in Model Rocketry

## Indirect Staging

**Definition:** Indirect staging involves using booster engines that are attached to the side of the rocket. These boosters provide additional thrust during the initial phase of the flight and are jettisoned once they burn out.

## Advantages:

**Increased Thrust:** The initial thrust provided by the boosters helps the rocket achieve higher speeds and altitudes quickly.

**Simplicity:** The core engine continues to operate, simplifying the transition between stages.

**Example:** Clustered Boosters. In some advanced model rockets, side boosters are used in conjunction with a central core engine. This setup is similar to how real-life rockets like the SLS use solid rocket boosters to aid the main engines during launch.

### How It Works:

1. **Launch**

   The rocket launches with both the core engine and the booster engines igniting simultaneously.

2. **Boost Phase:**

   The boosters provide additional thrust, helping the rocket accelerate faster and gain more altitude quickly.

3. **Booster Separation:**

   Once the boosters burn out, they are jettisoned from the main rocket.

4. **Continued Flight**

   The core engine continues to burn, propelling the rocket to higher altitudes.

## Comparison Summary

| Feature | Direct Staging | Indirect Staging |
|---|---|---|
| Stage Configuration | Stages stacked vertically | Boosters attached to the sides |
| Ignition Sequence | Each stage ignites after the previous one is jettisoned | Boosters and core engine ignite simultaneously |
| Stage Separation | Sequential, after each stage burns out | Boosters jettison after burnout, core engine continues |
| Efficiency | Higher efficiency due to weight reduction after each stage | High initial thrust, simpler transition |
| Typical Use | Multi-stage rockets for higher altitude | Rockets needing additional thrust at launch |

## Multi-Staging Motor Types

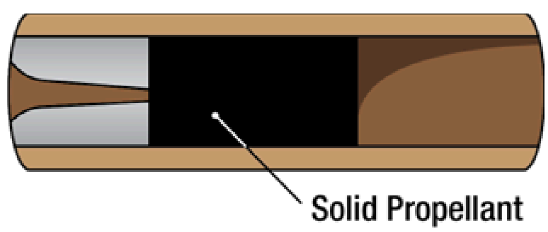
Booster and intermediate stages use an engine that has no delay and tracking charge and no ejection charge. Selection of your booster motor will depend upon several factors: rocket stability, weight, launch rod length and weather conditions. Wind has a definite effect on how your multi-stage rocket will perform. Rockets have a tendency to flop in the slightest breeze. In the upper stage, you should use an engine with a four-second or more delay because the speed of the rocket might tear apart your parachute.

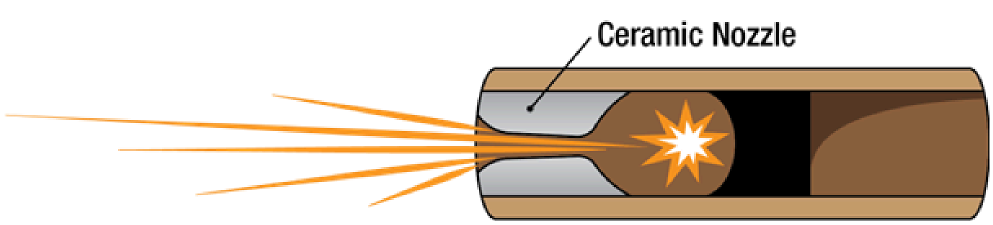
# Multi-Staging Ignition

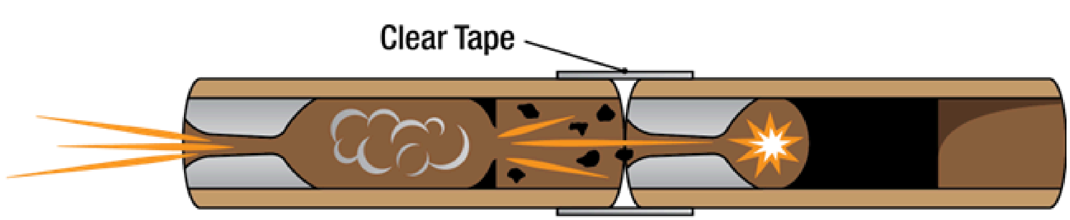
The first or lower stage is ignited by standard electrical means. Second stage ignition is automatically accomplished upon burnout of the first stage. The booster or first stage engine has no delay or ejection charge. This is necessary to assure instant ignition of the next stage upon burnout. As the propellant burns, it leaves a large combustion chamber. As it continues to burn, the walls become thinner until it is too thin to withstand the pressure in the combustion chamber. At this time, the propellant wall ruptures, letting the high pressure exhaust forward into or toward the nozzle of the next stage, carrying hot gasses and pieces of propellant into the nozzle of the second stage engine.

If the upper stage engine is placed ahead of the booster engine so the two can separate easily, ignition reliability will be as low as 40 percent, depending upon booster engine used (except when a Series II engine is used in the upper stage, which increases reliability to about 80 percent).

The simplest and most reliable method of joining stages tightly is cellophane tape. By wrapping one layer of tape around the joint between the two engines and recessing this joint 1/2 inch toward the rear of the booster body tube, reliability jumps to almost 100 percent. Coupling is the most important part in multi-stage ignition reliability.



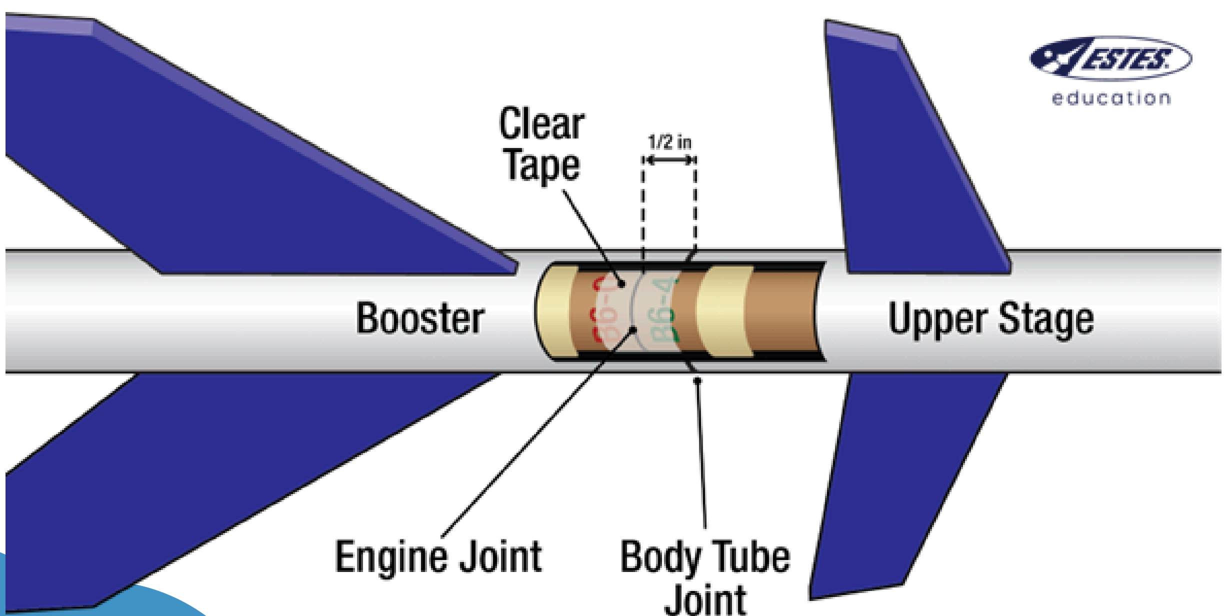



# Multi-Stage Coupling and Safety

"Multi-stage coupling" refers to the mechanism or connection point between two or more rocket stages in a multi-stage rocket design, allowing them to be stacked together during flight and then separate cleanly once the lower stage's engine burns out, enabling the next stage to ignite and continue the ascent to a higher altitude. A common method of coupling is to wrap a single layer of 1/2 inch tape (cellophane) tightly around the joint between the two engines. (See Figure 1.)

Then, by grasping each engine firmly, pull them apart. Repeat this process a few more times until you develop a feel for stage coupling, which will prove valuable when you build and fly multi-stage rockets. The proper procedure for coupling will depend on the size of the body tube. With a body tube size of 3/4 inch, the upper stage engine must project at least 1/2 inch rearward into the booster body tube to ensure a straight line separation. Make sure the engines are taped together before insertion into the rocket.

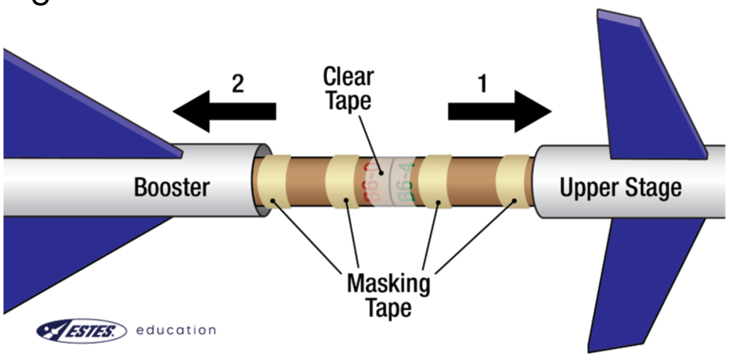
Figure 1:



# Multi-Stage Coupling and Safety

Always check before and after taping to be sure the engines are in proper positions (nozzle of upper stage engine against top of booster engine). If you forget to check carefully, it can be very embarrassing as well as do damage to your rocket. Wrap masking tape around top and rear to give it a tight fit in the body and push it into place (upper stage). Repeat the process for the booster stage, then push the booster into place. (See Figure 2.)

Figure 2:




The best method of mounting engines in rockets that have a large diameter tube involves correct positioning of the upper stage holder to extend 1/4 inch rearward from the end of the main body tube and, also, position of the engine block so engine extends 1/4 inch rearward from the end. Engine mounting in the booster must leave space for this engine mounting. If proper care is not taken, almost anything can happen.

## To ensure a successful and safe launch, here are some aspects to consider:

- Ensure each stage is securely connected yet can separate easily upon burnout.

- Use appropriate couplers or stage connectors designed for reliable separation.

- Ensure engines in each stage are properly aligned to avoid instability.

- Secure the engines firmly in their mounts to prevent movement during flight.

- Multiple Recovery Systems: Consider separate recovery systems for each stage or a combined system for the entire rocket.

- Ensure reliable deployment mechanisms, such as ejection charges or timers, to deploy parachutes or streamers.

- Appropriate Engines: Choose engines that provide adequate thrust for each stage. Typically, lower stages use more powerful engines, while upper stages use smaller ones.

- Ensure correct delay times between stage ignition to avoid premature separation or ignition to ensure the upper stage is not pointed sideways or down when it is ignited.

## Multi-Stage Recovery and Flying Considerations

Multi-Stage Rockets are a blast, but the extra altitude and speed require some special considerations. Almost every experienced model rocket enthusiast has launched a multi-stage rocket to never see the booster stage again! Many multi-stage model kits use one of the simplest recovery methods, which is the tumbling method that is effective but often hard to see without a nice brightly colored parachute. It is also difficult to track the booster as it falls while the upper stage is still accelerating into the sky. The booster stage should be painted a very bright color if you expect to keep track of it and use it again.

# Knowledge Check for Multi-Stage Rockets

1. In what type of rocket is multi-staging used?

2. How is the lower stage ignited, and how is the upper stage ignited?

3. Why is it important to check the motors before and after taping?

4. What is the simplest and most reliable method of joining stages?

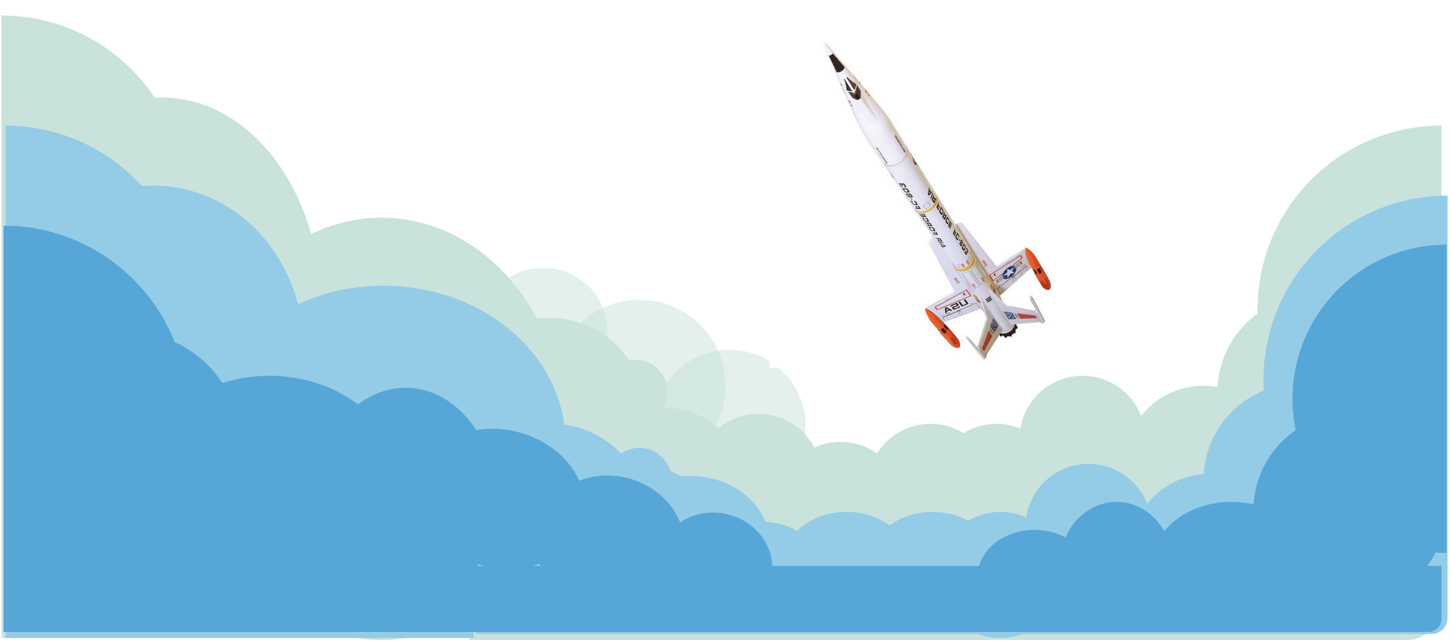
5. What type of recovery is used in the booster stage?

6. What engines are used in the lower stage?

# Knowledge Check for Multi-Stage Rockets

**7** Complete the missing spaces in the chart.

| Feature | Direct Staging | Indirect Staging |
|---|---|---|
| Stage Configuration | | Boosters attached to the sides |
| Ignition Sequence | Each stage ignites after the previous one is jettisoned | |
| | Sequential, after each stage burns out | Boosters jettison after burnout, core engine continues |
| Efficiency | | High initial thrust, simpler transition |
| Typical Use | Multi-stage rockets for higher altitude | |



# Activity Two:Understanding Multi-Stage Rockets

**Skill Level**

Intermediate (Ages 11-13)

**Suggested Group Size:**

One or more

**Life Skills**

Critical thinking, learning to learn

**Space**

A long room or hallway

**Tags**

model, rocket, model rocketry, multi-stage

## Materials List:

- Scissors
- Two modeling balloons (long skinny balloons used to make balloon animals)
- Two milkshake straws
- A small ring cut from a paper towel tube
- Two large binder clips
- Tape
- Fishing line or smooth string
- A balloon pump

Time Needed:
20-30 minutes

**Learner Outcomes:**
Participants will be able to explain how a multi-stage rocket works.

**Education Standard(s):**
**MS-PS2-2 Motion and Stability: Forces and Interactions**
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

**MS-PS3-5 Energy:**
Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

**Success Indicators:**
Explain how multi stage rockets work.

# Activity Two:Understanding Multi-Stage Rockets

## Introduction:

This activity is an opportunity for participants to see how a multi-stage rocket works up close.

## Opening Questions:

What is a multi-stage rocket and how does it work?

## Background information:

Participants should have read through "All About Multi-Stage Rockets" in the Unit 3 Manual.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)
  If it has been a while since they have read "All About Multi-Stage Rockets" review this section with the participants. Answer any questions they may have.

## Let's Do It!

- Thread the fishing line through both straws, and then tie both ends off to sturdy objects on either side of the room or hallway. Make sure that the string is pulled tight and there is no slack.
- Prestretch the balloons to make them easier to inflate, then use the balloon pump to inflate one of them about half or three quarters of the way full. Use a binder clip to hold the opening of the balloon closed.
- Pull the nozzle and binder clip of the inflated balloon through the ring cut out from a paper towel roll.
- Stick the closed end of the second balloon about half way through the ring and begin inflating.
- Continue blowing up the second balloon until it presses up against the inside of the cardboard ring and pinches the opening of the first balloon shut.
- You should be able to remove the binder clip on the first balloon and have it stay inflated. If it does not, try twisting the first balloon a few times or adding a little more air into the second balloon until it does.
- Use another binder clip to hold the opening of the second balloon closed.
- Tape the balloons to the straws doing your best to make sure they stay pointed in a straight line. Do not tape the balloons together as this will prevent the two stages from separating.
- Pull the balloons to one end of your string and remove the binder clip from the second balloon.

# Activity Two:Understanding Multi-Stage Rockets

## Term and Concept Discovery:

**Multi-Staging:**
A multi-stage model rocket consists of two or more rocket stages, stacked on top of each other. Each stage has its own engine and ignites in sequence.

**Direct Staging:**
Method of stacking stages, each with their own motor, fuel, and potentially a guidance system.

**Indirect Staging:**
Uses booster engines that are attached to the side of the rocket to provide additional thrust.

**Multi-Stage Coupling:**
The joint that allows one stage to detach from the next stage during a staged flight.

## Talk It Over:

**Share:**
Have the group or individual explain what happened in this activity.

**Reflect:**
Ask participants to explain the similarities and differences between this activity and the launch of multi-stage model rockets.

**Generalize:**
Ask the group how this activity went and if there were any ways to improve the process.

## Apply

Ask the group to explain how a multistage rocket works and how using this model has helped their understanding.

# Activity Two:Understanding Multi-Stage Rockets

## Variations:

If you have the time and resources, have participants launch a multistage model rocket. This can be used in conjunction with or instead of the balloon activity.

## Future Learning:

Want to see a multistage rocket in action? Check out videos of NASA's Artemis missions, which aim to return humans to the Moon and eventually send astronauts to Mars. These missions use advanced multistage rockets that build on the technology of the Saturn V. Understanding these concepts now could inspire you to be part of the next generation of space explorers!

## Did You Know?

Did you know that the Saturn V rocket, which took astronauts to the Moon during the Apollo missions, was a multistage rocket? This powerful rocket had three stages, each designed to propel the spacecraft further into space after the previous stage was dropped away. The principles you're learning about with your balloon rockets are the same ones that helped humanity reach the Moon!

Source: NASA. (n.d.). What was the Saturn V? (Grades 5-8). NASA. https://www.nasa.gov/learning-resources/for-kids-and-students/what-was-the-saturn-v-grades-5-8/#:~:text=The%20Saturn%20V%20rockets%20used,rocket%20would%20continue%20into%20space

# CHAPTER 4

# Launch Systems and Electrical Circuits

# Setting Up a Launch Field and Safety Guidelines

The National Association of Rocketry (NAR) provides comprehensive safety guidelines to ensure the safe and successful launch of model rockets. Here's a step-by-step guide to setting up a launch field and following safety guidelines based on NAR standards:

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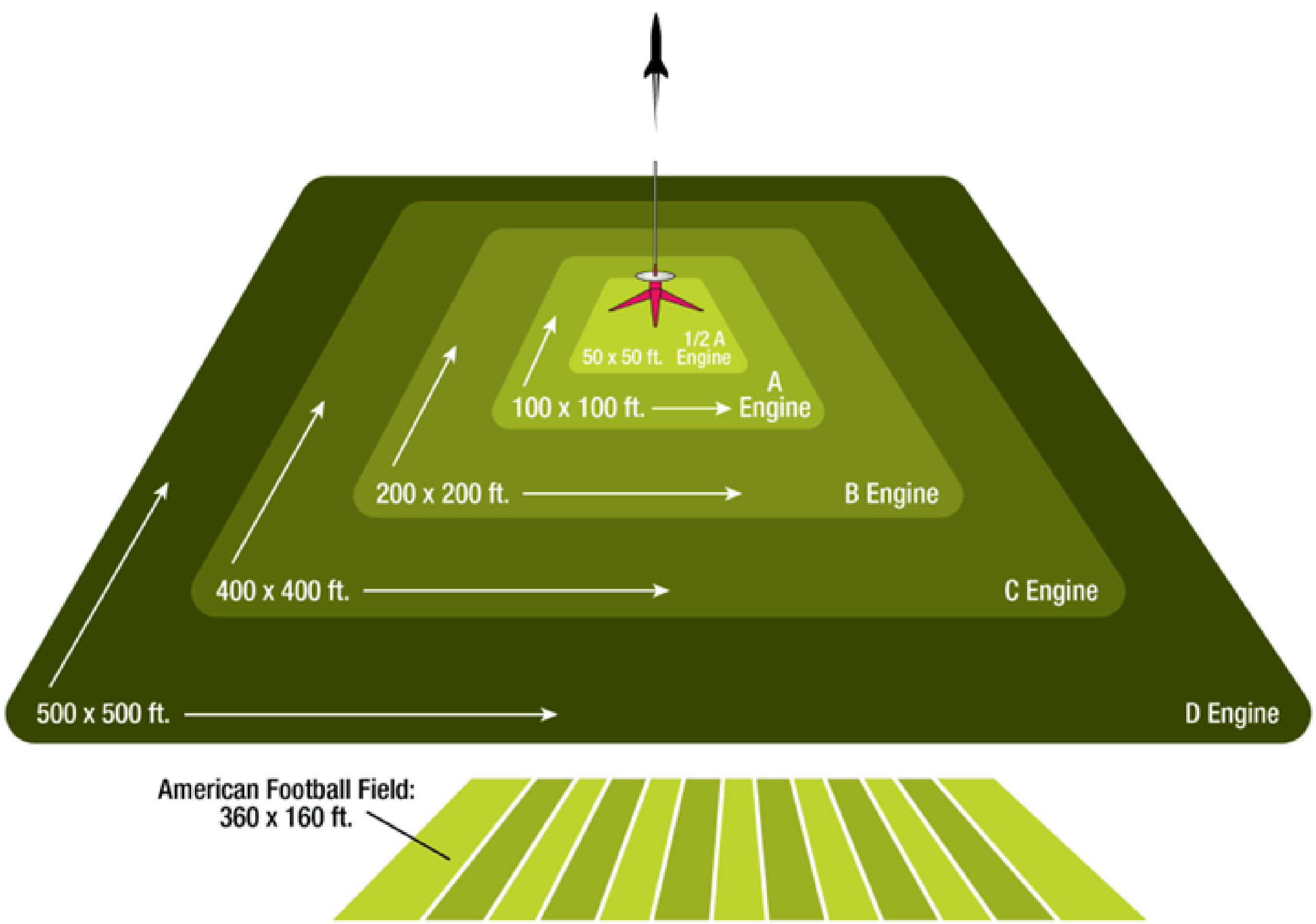
## LAUNCH SITE DIMENSIONS

| INSTALLED TOTAL IMPULSE (N-SEC) | EQUIVALENT MOTOR TYPE | MINIMUM LAUNCH SITE DIMENSIONS |
|---|---|---|
| 0.00 - 1.25 | 1/4 A, 1/2 A | 50 x 50 ft. |
| 1.26 - 2.50 | A | 100 x 100 ft. |
| 2.51 - 5.00 | B | 200 x 200 ft. |
| 5.01 - 10.00 | C | 400 x 400 ft. |
| 10.01 - 20.00 | D | 500 x 500 ft. |
| 20.01 - 40.00 | E | 1,000 x 1,000 ft. |
| 40.01 - 80.00 | F | 1,000 x 1,000 ft. |



## Selecting a Launch Field

**Field Size:**

**Minimum Distance**: Choose a large open field with sufficient distance from the launch pad to spectators, buildings, and other obstacles. The minimum distance should be based on the engine size and the expected altitude.

**Clear Area:** Ensure the area is clear of dry vegetation, power lines, trees, and other obstructions

**Surface:**

**Flat Terrain:** A flat, level surface helps ensure a stable launch pad setup.

**Non-Flammable:** Avoid launching on surfaces that could catch fire, such as dry grass.

## Setting Up the Launch Area

**Launch Pad:**

**Stable Platform:** Use a stable launch pad that can support the rocket and withstand the forces during launch.

**Launch Rod/Rail:** Ensure the launch pad has a guide rod or rail to help the rocket ascend straight.

**Safety Perimeter:**

**Safe Distance:** Establish a safety perimeter around the launch pad, ensuring spectators and participants are at a safe distance (at least 15 feet away for motors D and smaller, and 30 feet away for larger motors).

**Barriers:** Use barriers such as cones or flags to mark the safety perimeter.

**Equipment:**

**Fire Extinguisher:** Have a fire extinguisher or water source nearby in case of fire.

**First Aid Kit:** Keep a first aid kit on hand for any minor injuries.

## Launch Safety Guidelines

**Preparation:**

**Inspect Rocket:** Thoroughly inspect the rocket for damage or loose parts before launch.

**Check Engines:** Verify that engines are securely installed and igniters are properly connected.

**Wind Conditions:** Avoid launching in strong winds (no greater than 20 mph) or adverse weather conditions.

**Launch Control:**

**Launch Controller:** Use an electrical launch controller with a safety key to ensure controlled and safe ignition.

**Countdown:** Perform a loud and clear countdown to alert everyone of the imminent launch.

**During Launch:**

**Safe Distance:** Ensure all participants are outside of the safety perimeter.

**No Fly Zone:** Confirm there are no aircraft or obstacles in the flight path.

**Post-Launch:**

**Recovery:** Track the rocket's descent and ensure it lands safely. Do not attempt to recover from trees, power lines, or other dangerous locations.

**Inspection:** Inspect the rocket after recovery for any damage or issues that need addressing.

# Model Rocket Launch Systems

There are three main types of launch systems. The first launch system uses a launch rod (such as a Porta Pad); second is a launch rail, which its name implies. It uses a device similar to a square metal tube with the center of one side cut out so that a T-shape or T-bar is attached to the rocket instead of a launch lug. The third system is the launch tower, which is very much like that used with real rockets at Cape Canaveral.

One system not mentioned yet is a self-contained launch system, which is called Electro-Launch. The base contains eight 1.5-volt batteries (in plastic case), a blast shield and launch rod. The launch rod on the Electro-Launch serves the same purpose as other launch rods: it guides it during the first few feet of flight. The electric current is adequate to heat the igniter (use "D" size photocell dry cells), which causes the propellant to ignite. The blast deflector helps protect the plastic base of the Electro-Launch from the heat of the rocket's exhaust.

These launch systems are paired with controllers that use electrical ignition systems to launch rockets. It is therefore important to have a basic understanding of electricity and circuits, especially when advancing to multiple launch systems, as will be covered in subsequent sections.

## Symbols Used in Electrical Circuits

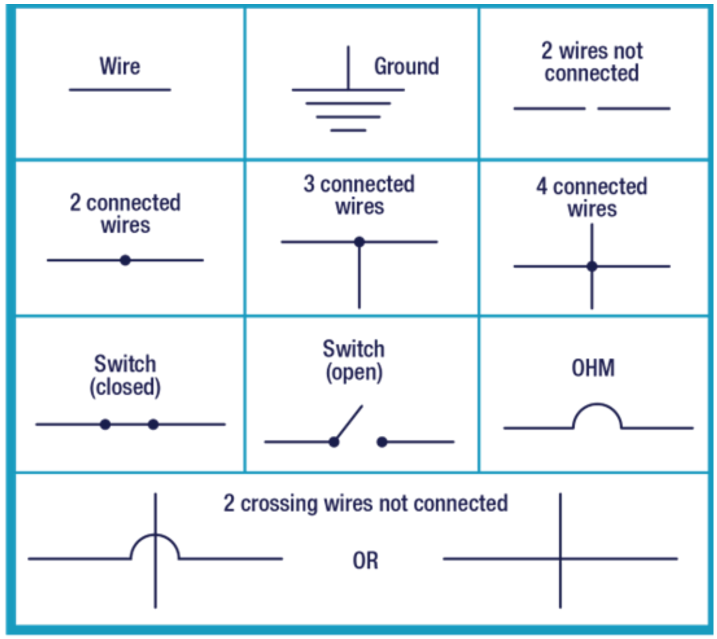
The following symbols are used to describe electrical circuits:

- Wire
- Ground
- Two wires not connected
- Two connected wires
- Three connected wires
- Four connected wires
- Switch (closed)
- Switch (open)
- OHM
- Two crossing wires not connected

## Principles of Electrical Circuits

An electrical current is the flow of electrons. A circuit is the path the electric current takes or follows. Electrons will only flow when a circuit is complete.

In a sense, electricity must come from a source and have somewhere to go. Whenever there is an interruption in the circuit, the electrons will not flow from the negative terminal of a power source, through the circuit and to the source through its positive terminal.

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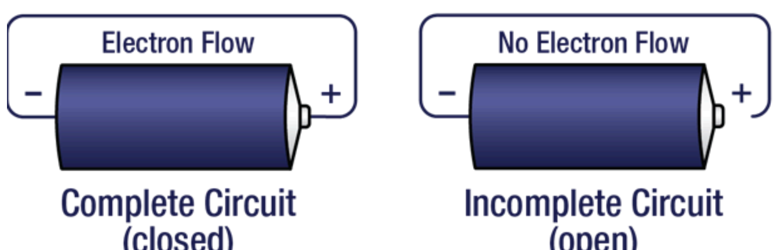


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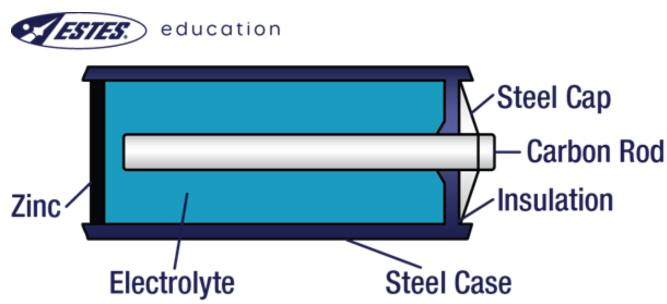
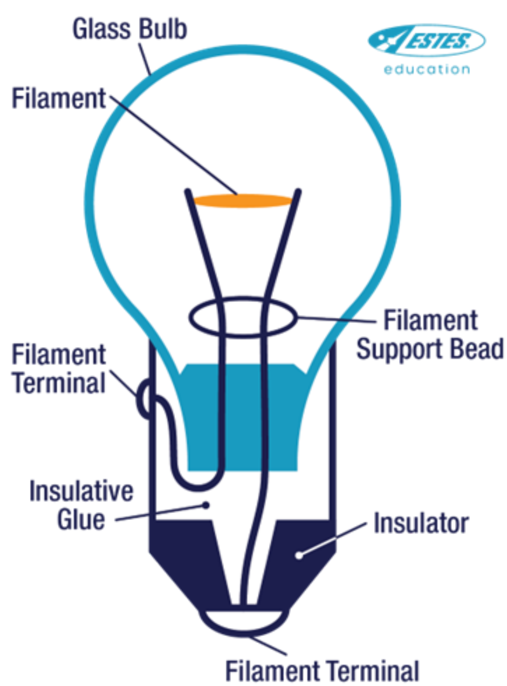
## Principles of Electrical Circuits

A battery works by converting stored chemical energy into electrical energy. Inside the battery, a chemical reaction creates a flow of electrons from the negative terminal (anode) to the positive terminal (cathode) through a circuit. In a model rocket ignition system, the battery supplies electrical energy to an igniter—a small wire coated in a special pyrogen (a flammable compound). When the launch controller is activated, electricity flows through the igniter, heating it up until it glows red-hot. This heat ignites the pyrogen, which then ignites the rocket motor's propellant, launching the rocket into the sky. Using a fresh battery ensures a strong and reliable ignition for a successful launch!

As in any other circuit, an electric bulb will not light unless the electricity flows through it. The electron may enter through either terminal and exit through the other terminal. The most common failure occurs when the filament melts or breaks in an electrical bulb. A sealed bulb contains nitrogen or an inert gas that does not react with the hot filament.

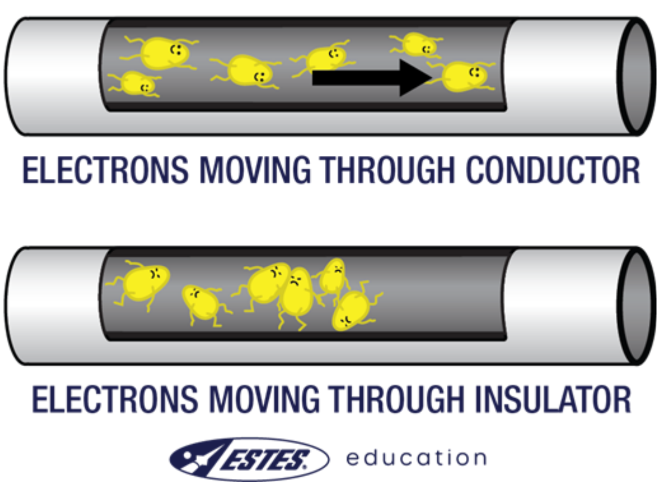


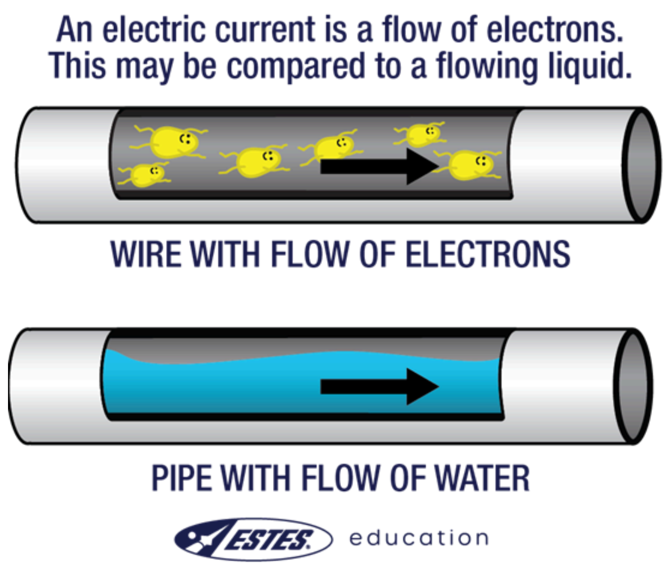
# Mathematics of Electrical Circuits

The amount of electrical current that flows is determined by the number of electrons going through the conductor. The unit used to measure this flow of current is a coulomb. (A coulomb is equal to about 6,250,000,000,000,000,000 electrons.) When one coulomb goes through a wire in one second, the current is flowing at a rate of one ampere. An ampere is a unit used to measure the rate at which electricity is flowing, hence, the ampere is equal to one coulomb per second.

The pressure pushing the electrons may also be measured. Electrons try to move from where they are crowded to places they are not. This tendency of electrons produces electrical pressure. This pressure or force is called electromotive force. A volt is the unit used to measure this force. It is also called electrical potential. The greater the pressure, the greater the voltage in the circuit.




The power of the electricity flowing in circuit is determined by how many amperes of electricity are flowing and by the voltage pushing them. This total amount of electricity with which to do work is measured in watts.




When electricity flows in only one direction, we call this flow direct current. When electricity flows rapidly back and forth, this motion or flow is called alternating current. When a substance presents very little resistance to the flow of electricity, this process is called conducting or conductors of electricity.

When an object presents a high resistance to the passage of electricity, it is called an insulator.

When an object presents a high resistance to the passage of electricity, it is called an insulator.

Units used to measure the amount of electrical resistance are called ohms. We need to know several things to determine the amount of current that will flow from a given power supply through a specific object. The amount of current that will flow may be determined by dividing the voltage by the resistance in ohms. This formula is called Ohm's law.

$$I = E/R \quad \text{Current} = \frac{\text{Electromotive force}}{\text{Resistance}}$$

I = Amperes of current flowing in the circuit
E = Electromotive force in volts
R = Resistance in ohms

The number of amperes that will flow in a circuit may be determined by dividing the voltage of the power supply by the resistance (in ohms) of the circuit.

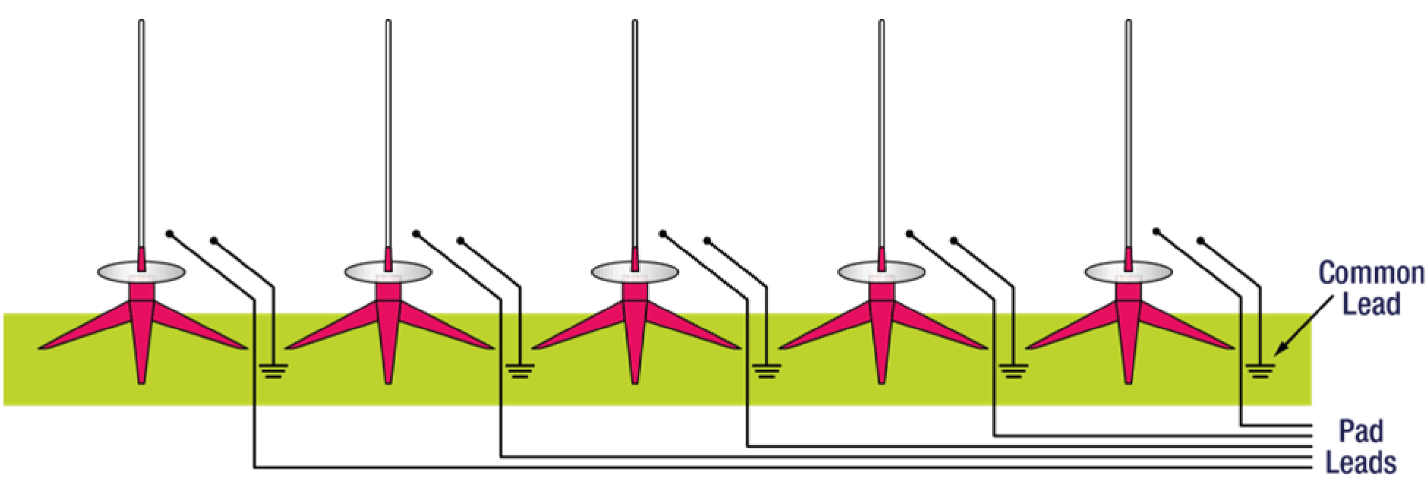
## Single Launcher Systems

A single rocket launch system is designed to safely and reliably ignite a model rocket motor and send the rocket into flight. The main components include a launch controller, launch pad, ignition system, and power source (usually a battery). The launch pad provides a stable base and includes a launch rod or rail to guide the rocket at liftoff. The launch controller is a handheld device with a safety key and a launch button, ensuring the rocket ignites only when intended. The ignition system consists of electrical leads and an igniter that heats up to ignite the rocket motor when the launch button is pressed. Many commercially available launch systems, such as the Estes Electron Beam and Estes Pro Series II controllers, are designed for beginner and advanced rocketeers, offering features like long safety leads and LED continuity indicators.

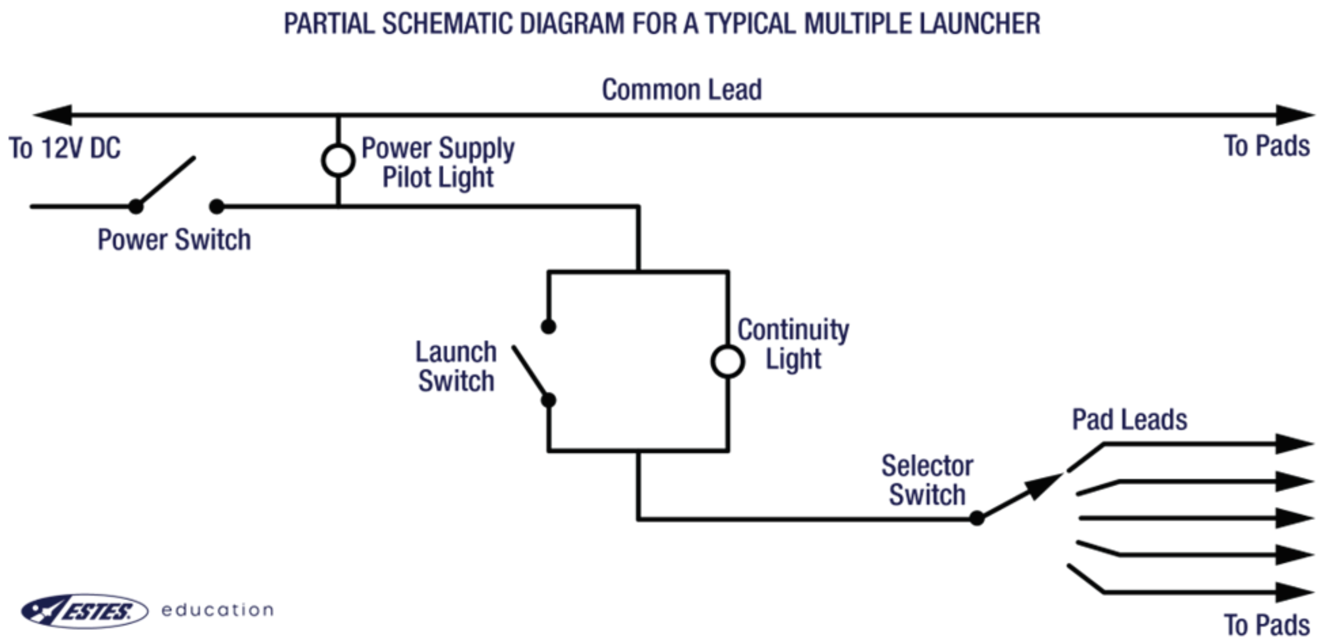
More advanced systems, like the Aerotech Interlock Controller, provide higher power for mid-power rockets. Choosing the right launch system depends on the type of rocket being launched and the level of automation or safety features desired.

## Multiple Launcher Circuits

A launcher with several launch pads provides a convenient device for flying many model rockets in rapid sequence. A multi-pad unit or system provides a number of launcher set-ups attached to one power supply and control unit. Electrical power is usually supplied by a separate wire to each launch pad with a common return or ground wire. The control panel usually incorporates a key-operated power supply switch, a power supply pilot bulb, a rotary selector switch, a continuity light and a launch switch.




A TYPICAL MULTIPLE LAUNCHER




The electrical power supply to the micro-clips is usually a separate wire to each launch pad to carry the electrical current to that pad and a common (shared) return or ground wire.

The control panel for a multiple launcher usually incorporates a key-operated power supply switch (to turn power supply off and on), a power supply pilot bulb (to indicate when the power supply is on), a rotary selector switch (to direct current to the pad in use only), a continuity light to indicate if the electrical circuit through the igniter is complete, and a launch switch.

A multiple launcher can be easily built. It is very handy for contests and demonstration launches.

# Knowledge Check for Launch Systems and Electrical Circuits

1. What are the three main types of launch systems?

   ______________________________

   ______________________________

   ______________________________

2. List four symbols used in electrical circuits.

   ______________________________

   ______________________________

   ______________________________

3. What is an electrical current?

   ______________________________

   ______________________________

   ______________________________

4. What is a coulomb?

   ______________________________

   ______________________________

   ______________________________

# Knowledge Check for Launch Systems and Electrical Circuits

5. What is an ampere?

6. Describe direct current and alternating current.

7. What is the difference between a conductor and an insulator?

8. What is an ohm?

# Activity Three: Create a Launch System

**Skill Level**

Intermediate (Ages 11-13)

**Suggested Group Size:**

One or more students

**Life Skills**

Critical thinking, decision making

**Space**

Table

**Tags**

model, rocket, model rocketry, electricity, circuits

**Materials List:**

- Blank paper
- Writing utensil

Time Needed:
20-30 minutes

**Learner Outcomes:**
Participants will be able to explain how launch systems work and identify basic electrical symbols.

**Education Standard(s):**
**MS-PS2-2 Motion and Stability: Forces and Interactions**
Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

**MS-ETS1-1 Engineering Design:**
Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

**MS-ETS1-2 Engineering Design:**
Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

**Success Indicators:**
Explain how launch systems work.

# Activity Three: Create a Launch System

## Introduction:

Understanding how launch systems work will help participants identify and troubleshoot potential problems when launching model rockets.

## Opening Questions:

What are the pieces of a single launcher system? What is different about multiple launcher circuits?

## Background information:

Participants should have read through "Launch Systems and Electrical Circuits" in the Unit 3 Manual.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)
  If it has been a while since they have read "Launch Systems and Electrical Circuits" review this section with the participants. Answer any questions they may have.

## Let's Do It!

- Talk with the group about the difference between single launcher systems and multiple launcher systems and the important components of each. Then have participants select one type to design.

- Give youth some time to draw out a launch system on their paper and have them list any supplies they would need to build it on the side.

- Once everyone has finished, have each participant show their drawing and identify each of the parts. If they are missing any components of the circuit, explain what they are missing and why it is an important part.

# Activity Three: Create a Launch System

## Term and Concept Discovery:

**Multi-Staging:**
A multi-stage model rocket consists of two or more rocket stages, stacked on top of each other. Each stage has its own engine and ignites in sequence.

**Direct Staging:**
Method of stacking stages, each with their own motor, fuel, and potentially a guidance system.

**Indirect Staging:**
Uses booster engines that are attached to the side of the rocket to provide additional thrust.

**Multi-Stage Coupling:**
The joint that allows one stage to detach from the next stage during a staged flight.

## Talk It Over:

**Share:** With the group or individual, discuss their launch system designs and whether or not they have all of the important pieces.

**Reflect:** Discuss the differences between both types of launch systems.

**Generalize:** Ask the group to explain which type of launch system they are most likely to use and why.

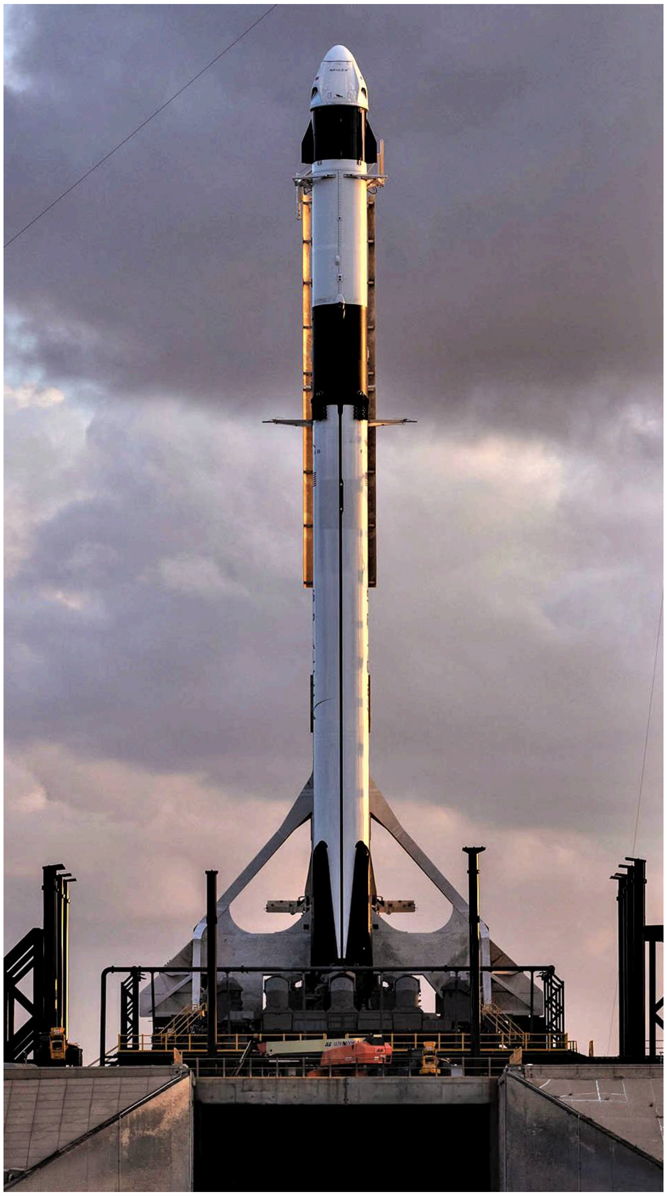
## Apply

Ask the group to explain how a multistage rocket works and how using this model has helped their understanding.

# Activity Three: Create a Launch System

## Variations:

If you have the time and resources, participants may actually design and build a launch system. Talk with them about which type of system would be most beneficial to them or your group and have them select which type they would like to build.



## Did You Know?

Did you know that SpaceX's Falcon 9 rocket uses a sophisticated launch system that allows it to be reused multiple times? This innovative technology involves advanced electrical circuits and sensors to control the rocket's launch and landing, significantly reducing the cost of space travel.

In 2015, SpaceX successfully landed the first stage of its Falcon 9 rocket back on Earth, marking the first time an orbital rocket had been recovered intact. This was achieved through precise control of the rocket's launch and descent using advanced electrical and computer systems—similar to the concepts you're learning about with your launch system designs!

# CHAPTER 5

## Launch Considerations

## Facilities and Equipment Requirements

Launching a model rocket requires a safe and open area free from buildings, trees, and power lines. The National Association of Rocketry (NAR) provides guidelines on minimum launch site sizes based on the motor’s total impulse. Essential equipment includes a sturdy launch pad with a guide rod or rail, a reliable ignition system, and a launch controller with a safety key. Fire safety is also critical—having water, sand, or a fire extinguisher nearby is a good precaution. Additionally, all launches should follow local laws and regulations regarding rocketry.

## Atmosphere Effects

The atmosphere plays a significant role in a rocket's performance and stability. Factors such as air pressure, temperature, humidity, and wind speed can influence a rocket’s flight path, altitude, and recovery system deployment. Understanding these variables helps rocketeers make informed launch decisions to improve performance and safety.

## Pressure

Air pressure decreases with altitude, meaning a rocket experiences less aerodynamic drag the higher it climbs. However, lower pressure can also affect ejection systems, as some rely on pressure changes to deploy parachutes. When launching at higher elevations, it’s important to test recovery systems to ensure they function properly under reduced atmospheric pressure.

## Temperature

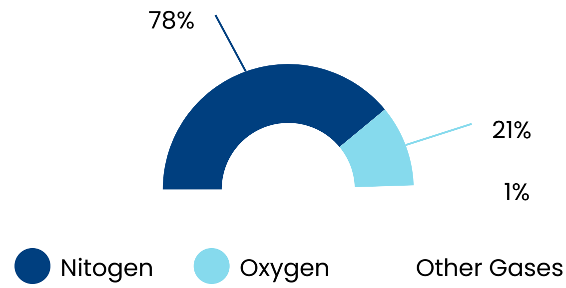
Temperature affects both rocket motors and electronics. In colder temperatures, solid rocket propellant may burn less efficiently, leading to reduced thrust. High temperatures can weaken plastic parts or cause adhesives to fail, potentially affecting fins or recovery systems. Rocketeers should store motors at room temperature before launch to ensure consistent performance.

## Wind Conditions

Wind is one of the most critical environmental factors for rocketry. Strong winds can cause a rocket to tilt (weathercock) during ascent, reducing altitude and increasing the risk of landing far from the launch site. Moderate winds may still be manageable with proper launch angles, but rocketeers should avoid launching in excessive wind conditions. Wind limits are often set based on rocket size and weight, with smaller rockets being more affected by strong gusts.

## Composition

Earth's atmosphere is made up of 78% nitrogen, 21% oxygen, and trace amounts of other gases. As a rocket ascends, air composition remains fairly constant, but the thinning atmosphere reduces aerodynamic forces, which can affect stability and parachute deployment. This is important when launching high-altitude rockets, as recovery systems rely on air resistance to slow descent.




## Density

Air density influences both thrust efficiency and aerodynamic drag. Denser air provides more resistance, which can slow a rocket but also improve stability. In contrast, launching in thin air at high altitudes allows for higher speeds but can make a rocket more susceptible to instability or weathercocking (unwanted turning into the wind)..

## Guidance Systems and Flight Controls

Model rockets rely on passive stability for guidance, meaning fins and aerodynamic design keep the rocket on its intended path. More advanced rocketry systems use gyroscopes, accelerometers, or onboard flight computers to actively adjust flight paths. Some larger model rockets may even incorporate control surfaces or thrust vectoring systems to maintain stability.

## Single-Station and Two-Station Tracking

Tracking a rocket's flight helps gather altitude, velocity, and trajectory data. A single-station tracking system typically uses a ground observer or an altimeter inside the rocket to measure height. A two-station tracking system, used in more advanced launches, involves two separate observers at known distances using triangulation to determine precise altitude and flight path. Modern tracking tools, such as GPS-based systems, provide even more accurate flight data for analysis.

## Humidity

Humidity can impact the ignition process and rocket materials. High moisture levels may cause igniters to absorb water, making them harder to ignite. Additionally, paper-based rockets or parachutes may become weakened or soggy, leading to potential failures. It's best to store rockets and launch equipment in a dry location before use.

## Thermals and Their Effects

Air pressure decreases with altitude, meaning a rocket experiences less aerodynamic drag the higher it climbs. However, lower pressure can also affect ejection systems, as some rely on pressure changes to deploy parachutes. When launching at higher elevations, it's important to test recovery systems to ensure they function properly under reduced atmospheric pressure.

# Knowledge Check for Launch Considerations

1. What is the purpose of the National Association of Rocketry (NAR)?

______________________________________________________________

______________________________________________________________

______________________________________________________________

2. Essential equipment includes a sturdy launch pad with a ____________________ or rail, a reliable ____________________, and a ______________________________ with a safety key.

3. What is one step you could take at your launch site to minimize one of the atmospheric effects mentioned in this chapter? Name the effect and how you would mitigate it.

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

# CHAPTER 6

# Predicting and Determining Altitude

# Single-Station Method of Tracking

Single-station tracking is one of the simplest and most inaccurate systems used. The only way of measuring accurately is with optical equipment. This requires some knowledge of mathematics. The basics of this math can be applied by any rocketeer to help in tracking. The two types of data needed to obtain altitude are angles and distances. In trigonometry, capital letters represent an angle and small case letters designate a side. Small "a" represents the side opposite angle A; the same applies to "b" and "c". Two capital letters represent a distance. BC designates the relative distance from angle B to angle C, or side "a". (See Figure 1.)

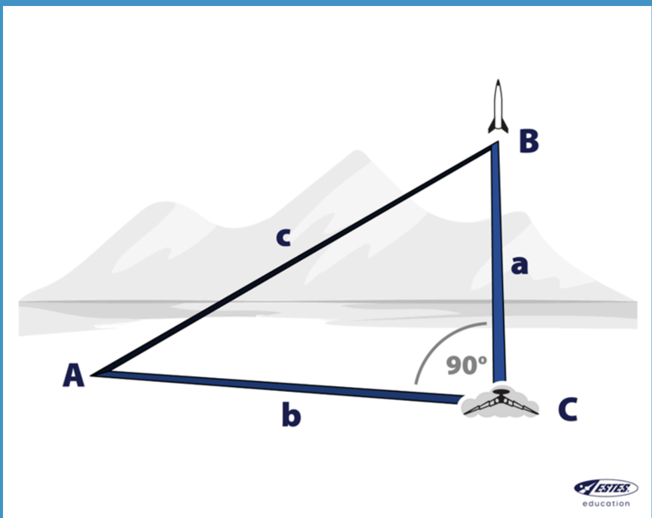



Figure 1

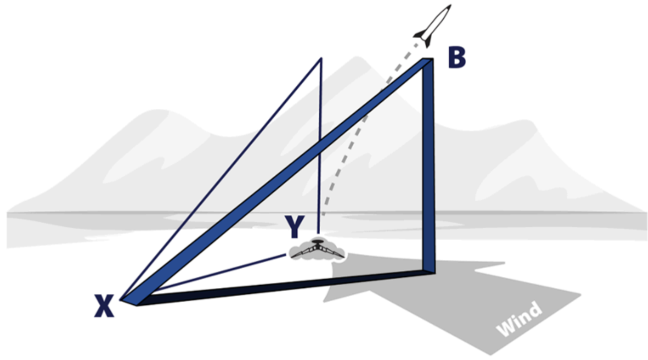



Figure 2

When firing your rocket, A is found when you lock your scope at the peak altitude of the rocket. With only one tracker, you have the disadvantage of knowing only one side and angle and will not have enough information to solve the other sides and angles of the triangle. You must guess at the unknown angle or angles, and by this method only have an approximation of the height.

When using only one tracker, it is a good idea to set up the station at a right angle.to the wind. This is so the error rate is less than it could be. If you track downwind or upwind you will get too much error in elevation readings due to the weather cocking of the rocket. However, the closer the rocket is to vertical, the more accurate the figures obtained. (See Figure 2.)

The following method will be used by a single tracker. Assume that the rocket goes up vertically or near a vertical altitude. Call the angle C the right angle and work from there. (See Figure 1).

In this case, angle B[1] is equal to 90 degrees minus A. (The sum of the angles in a triangle is 180 degrees, half of this or 90 degrees is taken by angle C).

**Height of the rocket:**

Base (distance from tracker to launcher) = 250 feet
Tan = (see table of sines and tangents)
Angle A = 62 degrees
Height = (Tan Angle A) (Base) = 1.88 x 250 = 470 feet

If your tracking device measures an angle that falls between two whole numbers, you can estimate the rocket's height by averaging the tangent values of the two closest angles. For example, if the measured angle is 63.5 degrees, find the tangent values for 63 and 64 degrees and take the difference. Divide this difference by two and add it to the height calculated for 63 degrees to get a more precise estimate. This method helps improve accuracy, especially when small angle changes can significantly affect height calculations.

## ESTES SINES AND TANGENTS

| ANGLE | SIN | TAN | ANGLE | SIN | TAN | ANGLE | SIN | TAN | ANGLE | SIN | TAN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .02 | .02 | 19 | .33 | .34 | 37 | .60 | .75 | 55 | .82 | 1.43 |
| 2 | .03 | .03 | 20 | .34 | .36 | 38 | .62 | .78 | 56 | .83 | 1.48 |
| 3 | .05 | .05 | 21 | .36 | .38 | 39 | .63 | .81 | 57 | .84 | 1.54 |
| 4 | .07 | .07 | 22 | .37 | .40 | 40 | .64 | .84 | 58 | .85 | 1.60 |
| 5 | .09 | .09 | 23 | .39 | .42 | 41 | .66 | .87 | 59 | .86 | 1.66 |
| 6 | .10 | .11 | 24 | .41 | .45 | 42 | .67 | .90 | 60 | .87 | 1.73 |
| 7 | .12 | .12 | 25 | .42 | .47 | 43 | .68 | .93 | 61 | .87 | 1.80 |
| 8 | .14 | .14 | 26 | .44 | .49 | 44 | .69 | .97 | 62 | .88 | 1.88 |
| 9 | .16 | .16 | 27 | .45 | .51 | 45 | .71 | 1.00 | 63 | .89 | 1.96 |
| 10 | .17 | .18 | 28 | .47 | .53 | 46 | .72 | 1.04 | 64 | .90 | 2.05 |
| 11 | .19 | .19 | 29 | .48 | .55 | 47 | .73 | 1.07 | 65 | .91 | 2.14 |
| 12 | .21 | .21 | 30 | .50 | .58 | 48 | .74 | 1.11 | 66 | .91 | 2.25 |
| 13 | .22 | .23 | 31 | .52 | .60 | 49 | .75 | 1.15 | 67 | .92 | 2.36 |
| 14 | .24 | .25 | 32 | .53 | .62 | 50 | .77 | 1.19 | 68 | .93 | 2.48 |
| 15 | .26 | .27 | 33 | .54 | .65 | 51 | .78 | 1.23 | 69 | .93 | 2.61 |
| 16 | .28 | .29 | 34 | .56 | .67 | 52 | .79 | 1.28 | 70 | .94 | 2.75 |
| 17 | .29 | .31 | 35 | .57 | .70 | 53 | .80 | 1.33 | 71 | .95 | 2.90 |
| 18 | .31 | .32 | 36 | .59 | .73 | 54 | .81 | 1.38 | 72 | .95 | 3.08 |
| 73 | .96 | 3.27 | 75 | .97 | 3.73 | 77 | .97 | 4.33 | 79 | .98 | 5.14 |
| 74 | .96 | 3.49 | 76 | .97 | 4.01 | 78 | .98 | 4.70 | 80 | .98 | 5.67 |

ESTES education

## Two-Station Way of Tracking

When using two-station tracking, a higher degree of accuracy is possible. When the azimuth angles are not used, the trackers must be on opposite sides of the launcher. It will depend on the wind whether they are north and south or east and west. They must be in line with the wind. They should be equal distances apart from the launcher. Here the sine will be used not the tangent.

# Knowledge Check for Predicting and Determining Altitude

1. What is the simplest method of tracking?

2. What do capital and small letters mean in trigonometry?

3. At what distance should a single tracker be located?

4. Is two-station tracking more accurate than single-station? Why or Why not?

5. Is the tangent used in two-station tracking? Why or why not?

# Activity Four: Altitude Testing in OpenRocket

**Skill Level**

Intermediate (Ages 11-13)

**Suggested Group Size:**

Any

**Life Skills**

Critical thinking, learning to learn

**Space**

Table or desk

**Tags**

model, rocket, model rocketry, science, math, altitude

## Materials List:

- Simulation data
- Sheet for graphing
- Writing utensil

Time Needed:
20-30 minutes

**Learner Outcomes:**
Participants will investigate the impact of engine type on model rocket flight using simulation-based data.

**Education Standard(s):**
**MS-PS2-2 Motion and Stability: Forces and Interactions**
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

**MS-PS3-1 Energy:**
Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

**MS-ETS1-2 Engineering Design:**
Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

**Success Indicators:**
Create a bar graph that shows how engine choice affects altitude.

# Activity Four: Altitude Testing in OpenRocket

## Introduction:

Using simulation data to understand how engine size impacts the model rocket's flight will help participants see the importance of running simulations before an actual rocket launch, especially if they choose to make a scratch-built rocket.

## Opening Questions:

**What** is a rocket simulation?
**What** change might occur to the simulation if you were to use a different engine?
**What** are the advantages of using a rocket simulation before launching the actual rocket?

## Background information:

Participants should have read through "Introduction to Model Rocket Motor Performance" in the Unit 3 Manual.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)
  If it has been a while since they have read "Introduction to Model Rocket Motor Performance" review this section with the participants. Answer any questions they may have about engines (also called motors).

## Let's Do It!

- Review the simulation data.
- Create a bar graph that shows the change in altitude for each of the three engine types.

# Activity Four: Altitude Testing in OpenRocket

## Term and Concept Discovery:

**Simulation:**
A model of a real activity, created for training purposes or to solve a problem.

**Apogee:**
The peak altitude or highest point of a rocket's flight.

**Velocity:**
The rate of motion or speed of an object in a given direction.

**Acceleration:**
The rate at which an object changes its velocity.

## Talk It Over:

**Share:** With the group or individual, discuss what happened during each simulation.

**Reflect:** Ask the group or individual to explain the pros and cons of using a rocket simulation before launching the real rocket. How could a simulation have more importance with a scratch-built rocket? What are some factors that could affect the launch that might not be shown in a simulation?

**Generalize:** Discuss how this activity relates to choosing appropriate engines for different launch targets, such as a particular altitude or flight time.

## Apply

Why would someone use a rocket simulation before or instead of launching an actual rocket?

# Activity Four: Altitude Testing in OpenRocket

## Variations:

If participants have access to the Cosmic Cargo model rocket and launch supplies, they could use the previously mentioned engines and see how close the simulation data is to their real rocket launches.

Access the OpenRocket Simulator at https://openrocket.info/. If they have a different model rocket, they can build one in OpenRocket to test the simulation with that version.

## Did You Know?

Aftershock II, a rocket built by students at the University of Southern California, is currently the highest and fastest amateur rocket, reaching an altitude of 470,000 ft (90 miles). This showcases the incredible potential of student-led rocketry projects.

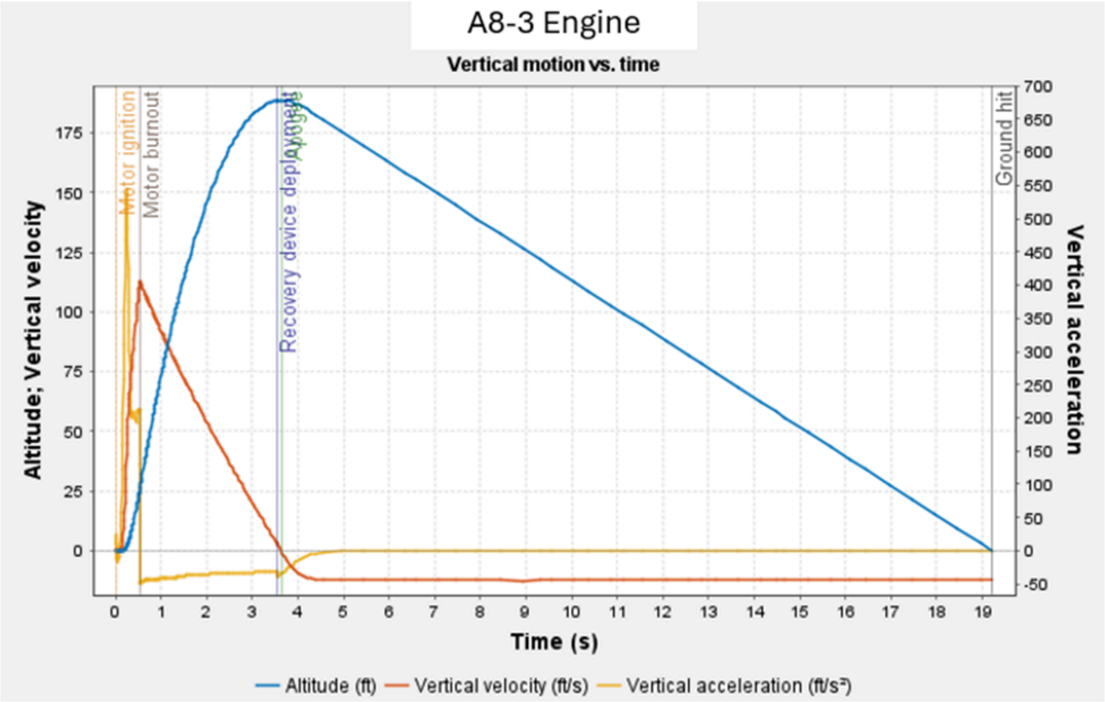
## Simulation Analysis

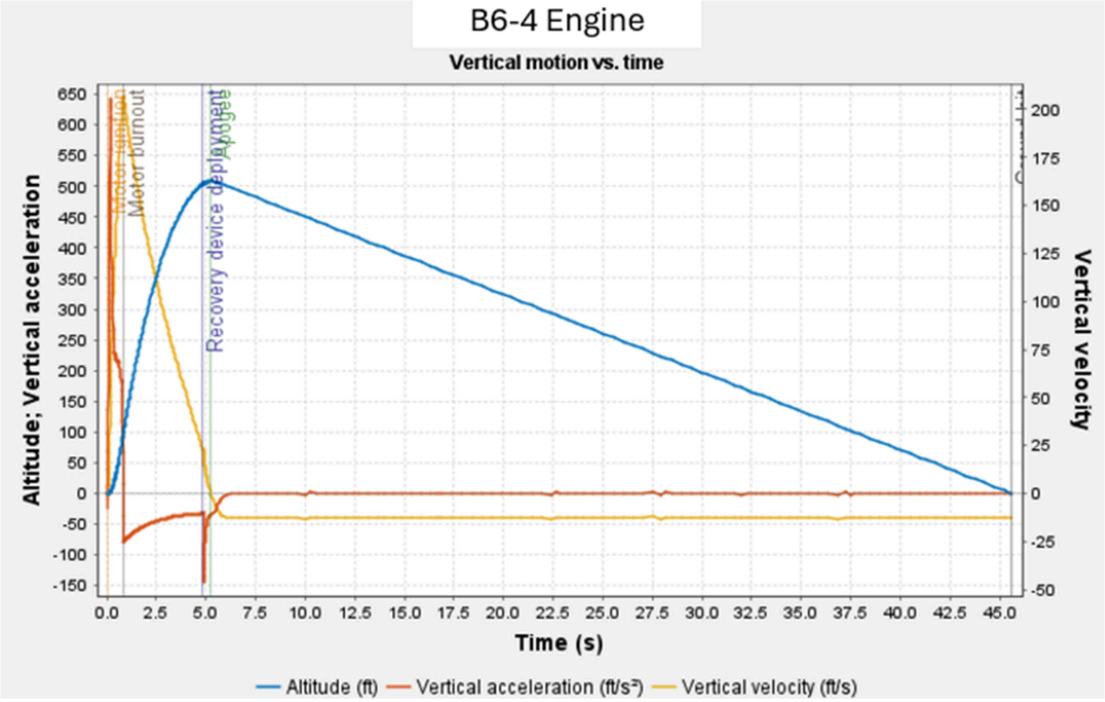
In the table below, you see data from a model rocket computer simulation predicting the apogee, maximum velocity, maximum acceleration and flight time for the model rocket (Cosmic Cargo) with three different engines: A8-3, B6-4, and C6-5.

| OpenRocket Simulations | Apogee (m) | Max V (m/s) | Max A (m/s2) | Flight Time (s) |
|---|---|---|---|---|
| 1. Rocket with A8-3 engine | 57.6 | 336 | 544 | 19.2 |
| 2. Rocket with B6-4 engine | 154.8 | 207 | 644 | 45.6 |
| 3. Rocket with C6-5 engine | 331.3 | 113 | 683 | 93.4 |

# Activity Four: Altitude Testing in OpenRocket

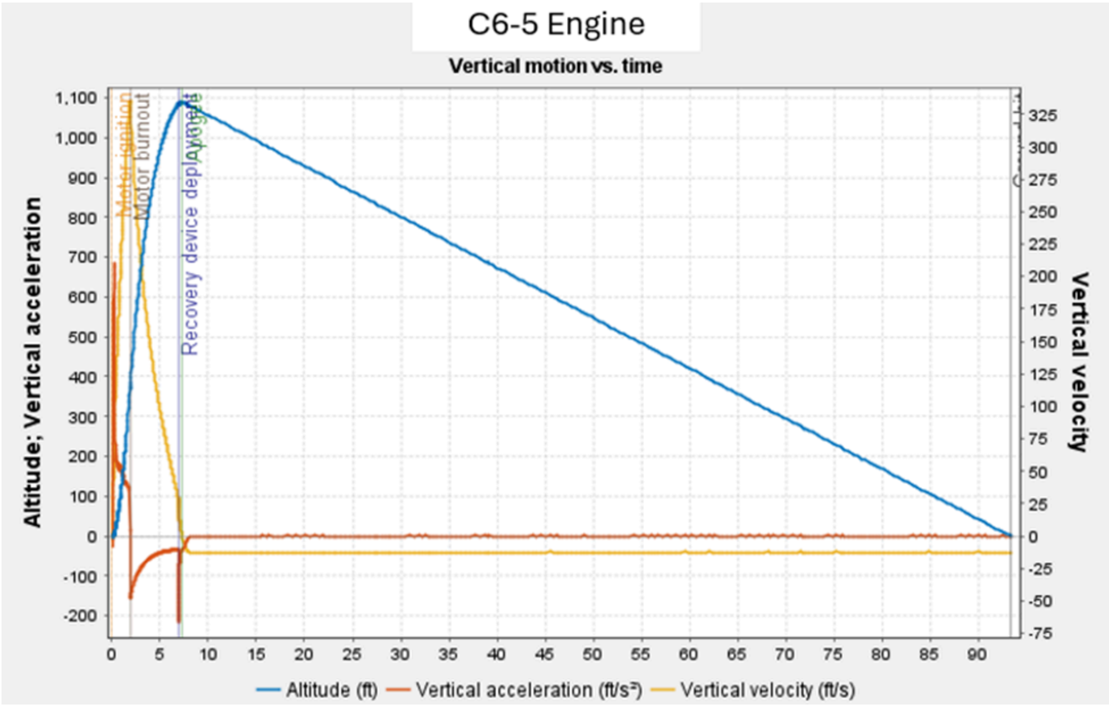
Review the following images of each simulation. Note the measurement differences in the x-axis and y-axis of each one. (Images from Cosmic Cargo Simulation in Open Rocket at https://openrocket.info/.)



# Activity Four: Altitude Testing in OpenRocket

Review the following images of each simulation. Note the measurement differences in the x-axis and y-axis of each one. (Images from Cosmic Cargo Simulation in Open Rocket at https://openrocket.info/.)




Create a bar graph that shows the difference in altitude for the three different engines.

# CHAPTER 7

# Recovery Systems

## How Big is That Parachute?

The main function of any recovery system is to return the rocket that was sent aloft safely to the ground. The parachute is the most popular form of recovery system. The other recovery systems were discussed in Unit 2. The main purpose is to create more drag, which naturally slows down the model rocket. If the rocket "free falls," it will be damaged by the fall, as any object falling attains a velocity or acceleration of 32 feet per second. It means that an object will fall 32 feet per second faster at the end of each second than it was falling at the start of that second. The maximum speed an object can reach is called its terminal velocity.


If you create too much drag, a good wind or breeze could cause an object to drift a great distance before it returns to the ground. Naturally, the higher the rocket is, the longer it will take to come down. If rockets go very high each time and you live in a very windy area, a large parachute can be a big problem. One way to reduce the drag on the chute is to "reef in" the shroud lines by shortening the shroud lines with masking tape or a piece of string. Another is by cutting a very small hole to start with and, experimenting by the time test (using a stopwatch and dropping the weighted parachute from a known height), increase the hole accordingly, so the chute does not drift too far. When cutting a hole in the chute, be careful that the hole is always round and has no sharp corners because the shock of the opening could tear the chute to pieces. Another alternative to the hole is to use a smaller chute. Streamers can be used in very lightweight models in place of the chute.

## Helicopter Recovery

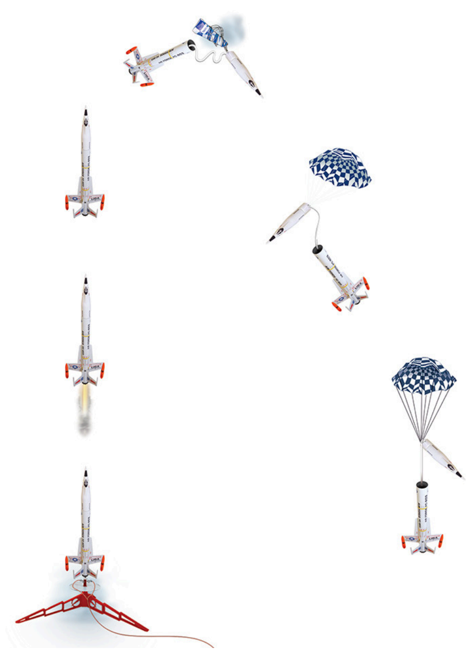
Helicopter recovery uses spinning blades or fins to slow the rocket's descent by creating lift, much like a helicopter. This system works by deploying vanes or rotating fins when the ejection charge fires, allowing the rocket to spin and descend slowly. Some designs have blades that fold against the body during ascent and deploy at apogee using elastic bands or hinges. This method provides a unique and stable descent, often reducing drift while keeping recovery gentle.

## Aerobrake Recovery

Aerobrake recovery slows the rocket's descent using air resistance instead of a separate parachute or streamer. Some designs achieve this by deploying flaps, fins, or expanding surfaces at apogee to increase drag and slow the rocket. Another approach is designing a wider rocket body that naturally slows down as it falls. This method works well for short, sturdy rockets and avoids the need for recovery wadding or parachute packing.

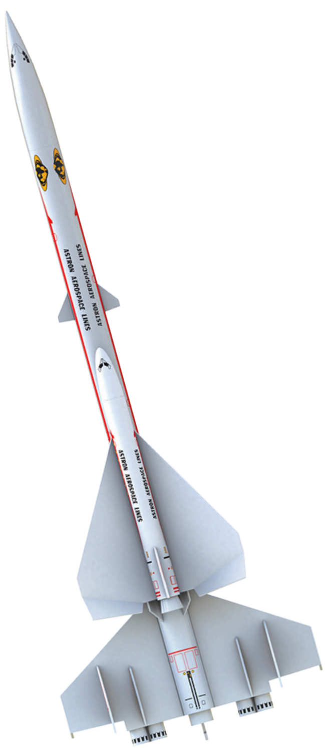
## Parachute Modifications

Modifying a parachute can help balance descent speed and drift distance. Cutting a vent hole, adjusting shroud lines, or switching to a different material can affect how the parachute behaves. Some rocketeers experiment with semi-spherical chutes, spill holes, or reefing techniques to optimize performance. Testing different modifications by timing descent speed from a fixed height can help determine the best setup for different weather conditions and rocket types.



## Streamers

Streamers provide an alternative recovery method for lightweight rockets. They consist of long, ribbon-like material that flutters in the air, creating enough drag to slow the rocket's fall without causing excessive drift. Streamers are often used in small, competition, or high-altitude rockets where parachutes might be too slow or allow too much drift. The wider and longer the streamer, the more drag it generates, but too much can cause unstable descent. Material choice also matters—thin plastic or crepe paper works well, while heavier materials can drop too fast.



## Glider

In glider recovery, the rocket transforms into a glider after reaching its peak altitude, allowing it to return smoothly to the ground. Some rockets have wings that deploy at apogee, while others are designed as rocket-powered gliders from the start. Gliders can be boost-gliders (which separate from the engine section) or rocket gliders (which remain intact). Proper wing shape and balance are important to ensure a stable glide instead of an uncontrolled fall. Glider recovery is fun for competition flying and requires careful trimming for the best results.

## Others?

Beyond parachutes, streamers, helicopters, aerobrakes, and gliders, other creative recovery methods exist. Some model rockets use balloon recovery, where an inflatable balloon deploys to slow descent. Others use rotary parachutes that spin like a maple seed. Experimental designs even include retractable wings or drone-assisted guidance for precision landings. Each system has advantages and is suited to different rocket sizes, altitudes, and weather conditions.

# Recovery Supplies

The following are just for general knowledge, as the choice of recovery supplies is left up to you.

**Quick Change Swivels**

Allows recovery systems to be swapped easily, reducing tangling.

**Parachute Kits for Every Purpose**

Pre-packaged kits with the right size chute for your rocket.

**Safety Streamers**

Fast and effective recovery for lightweight rockets.

**Recovery Wadding**

Protects the parachute from the heat of the ejection charge.

**Shock Cords**

Absorbs the shock of parachute deployment and prevents recovery system loss.

**Tape Discs**

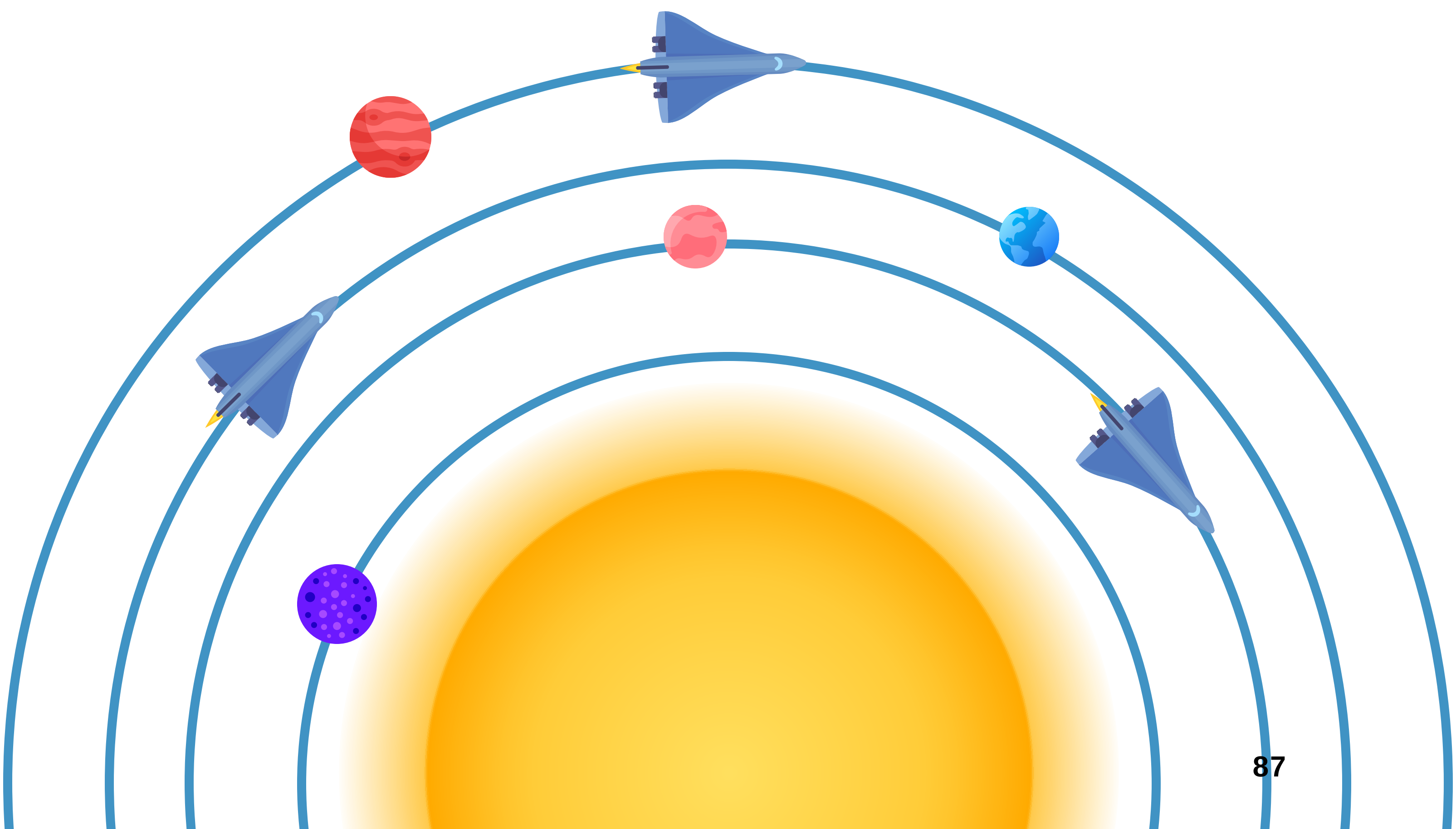
Used to attach shroud lines to parachutes securely.

**Do-It-Yourself Parachute Material**

Custom parachute-making material, including aluminized options.

**Shroud Lines**

Strong cords that attach the parachute to the rocket.



# Activity Five:
# Forces of Flight

**Skill Level**

Intermediate (Ages 11-13)

**Suggested Group Size:**

Any

**Life Skills**

Critical thinking, learning to learn, problem solving

**Space**

A long room or hallway

**Tags**

model, glider, model rocketry, science, force

**Materials List:**

- Tape
- Empty bottle (approx 400-800 ml)
- 4 plastic bottle caps
- Nail
- 2 straws
- Scissors
- Balloon
- Wood skewer
- Nose Cone & Wing Template
- Pens to decorate

Time Needed:
20-30 minutes

**Learner Outcomes:** Understand Free Body Diagrams to represent forces acting on an object in both horizontal (aviation) and vertical (rocket) flight and explain and apply the concepts of Thrust, Lift, Gravity, and Drag in the context of aviation flight

**Education Standard(s):**
**MS-PS2-2 Motion and Stability: Forces and Interactions**
Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

**MS-ETS1-2 Engineering Design**
Evaluate competing design solutions based on jointly developed and agreed-upon design criteria using a systematic process to determine how well they meet the criteria and constraints of the problem.

**MS-ETS 1-3 Engineering Design**
Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

**Success Indicators:**
Explain the main four forces in aviation flight.

# Activity Five: Forces of Flight

## Introduction:

Understanding that free body diagrams show the differences in key forces for aviation and rocket flights.

## Opening Questions:

What are the four main forces in model rocketry?
Are the forces the same in aviation?
Are there any differences?

## Background information:

Participants should have read through "Introduction to Model Rocket Motor Performance" in the Unit 3 Manual.

Free Body Diagrams (FBDs) are graphical illustrations that are used to visualize and analyze the forces acting upon an object. They are invaluable tools in physics and engineering as they simplify complex real-world situations into more manageable theoretical models.
A typical FBD consists of a simple outline or a dot that represents the object under consideration, and vectors (arrows) that represent the different forces acting on it. Each force's magnitude and direction can be visually understood by the arrow's length and the way it points.

Watch this video for clear build instructions and make each group a copy of the Nose Cone and Wing Template.

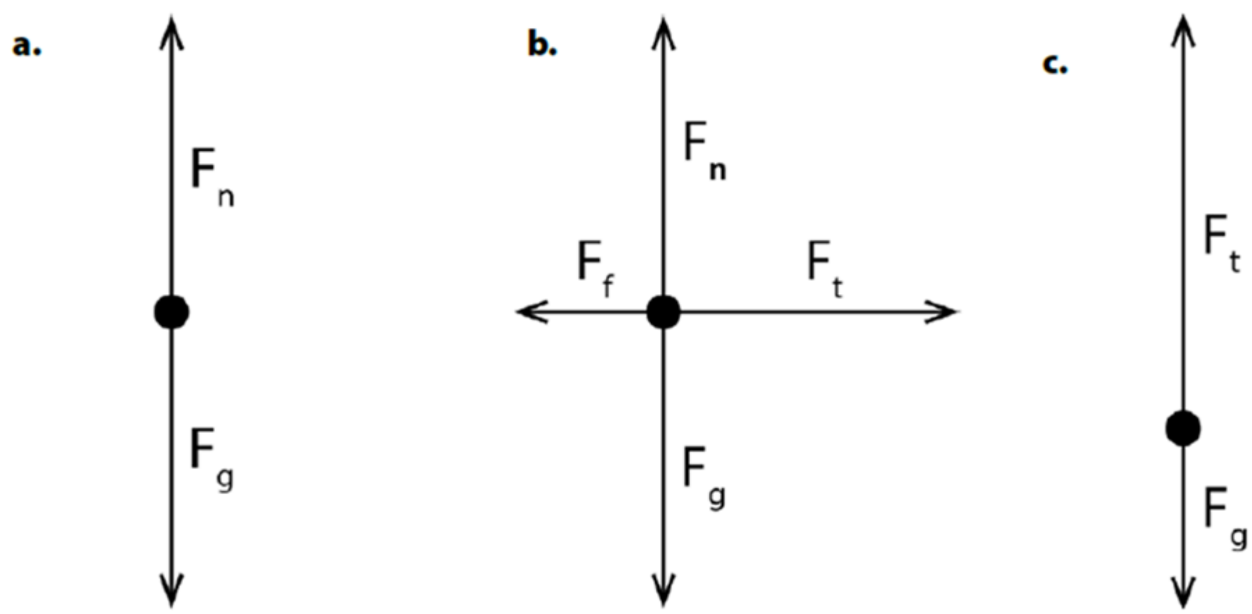
# Activity Five: Forces of Flight

## Background information:

Below are 3 FBDs. Notice in a, Fg=Fn, so this is an object with zero acceleration, perhaps a book resting on a table. In b, an object has an Ft (Tension or Thrust) to the right, and a frictional drag to the left (Ff), while Fg=Fn, so this is an object accelerating toward the right along a surface. Perhaps this is a toy car being pulled to the right by a rope. In c, we see an object with a larger Ft upwards than Fg downward, so this object is accelerating upwards.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)
  - If it has been a while since they have read "Glider" in Chapter 7 of the manual, review this section with the participants.
  - Complete Horizontal Flight: Glider questions
  - Watch this video for clear build instructions



# Activity Five: Forces of Flight

## Let's Do It!

Cut skewer and 1 straw in half.  (Do not cut the other straw)

Tape straw pieces to the bottle.

Make holes in the center of each bottle cap with the nail.

Put skewers through straws and press on bottle cap wheels.

Tape the balloon securely onto the end of the complete straw.

Make a hole on top of the bottle (opposite the wheels) near the bottle opening (where cap screws on).

Run straw through the top and out the opening.

Tape cone on closed end of bottle (what was the bottom is now the front) and wings on top.

Inflate the balloon, hold the opening closed until ready, and test on a flat floor.

# Activity Five: Forces of Flight

## Term and Concept Discovery:

●**Free Body Diagrams:** graphical illustrations used to visualize the forces acting on an object. In a free body diagram, the object is typically represented by a dot, and the forces are represented by arrows pointing in the direction of the force. The length of the arrow can be used to represent the magnitude of the force.

●**Thrust:** a force (push or pull) that moves an object forward. In physics, it's usually talked about in the context of propulsion systems, like a jet engine or a rocket, which use thrust to move an object through a fluid (like air or water).

●**Lift:** an aerodynamic force that is perpendicular to the direction of flight. For a plane this force is directed up and opposes the weight of the aircraft, for a rocket this is the restoring force that fins exert when a rocket is at a non-zero angle of attack.

●**Gravity:** a force of attraction that exists between any two masses, any two bodies, and any two particles. In the context of Earth, it's the force that pulls objects downwards towards the center of Earth. The Earth exerts a gravitational force on objects, pulling them towards it, and this is what gives objects weight.

## Talk It Over:

**Share:** With the group or individual, discuss what happened during each trial.

**Reflect:** Ask the group or individual to describe any modifications they made for a more successful experiment.

**Generalize:** Discuss how this activity might relate to other recovery systems and brainstorm how the Free Body Diagrams for those might look different (helicopter, streamer, parachutes, etc.)

●**Drag:** a force that opposes an object's motion through a fluid (like air or water). It's caused by friction and differences in air pressure. Drag is the air resistance that an airplane or a rocket encounters as it moves through the air.

●**Normal Force:** the support force exerted upon an object that is in contact with another stable object. For example, if a book is resting on a surface, then the surface is exerting an upward force to support the weight of the book. This is the normal force.

# Activity Five: Forces of Flight

## Apply

Why would understanding the four forces of flight help someone decide which recovery system to use?

## Variations:

Encourage students to use vocabulary and relative magnitude while discussing and drawing out their FBDs.

## Did You Know?

Not only was NASA's space shuttle the world's first reusable spacecraft, it was also a glider! The space shuttle was a groundbreaking vehicle that combined the power of a rocket with the flight characteristics of a glider. After launching into orbit atop powerful solid rocket boosters and a massive external fuel tank, the shuttle orbiter returned to Earth unpowered and glided through the atmosphere, then landed like an airplane on a long runway. The space shuttle's ability to glide and land was critical for bringing astronauts home safely, and its innovative design allowed it to complete complex missions such as servicing the Hubble Space Telescope and helping build the International Space Station.

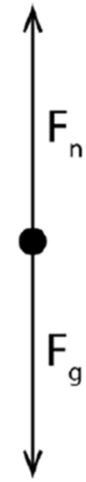
## Horizontal Flight: Glider

Free Body Diagrams (FBDs) are graphical illustrations that are used to visualize and analyze the forces acting upon an object. They are invaluable tools in physics and engineering as they simplify complex real-world situations into more manageable theoretical models.

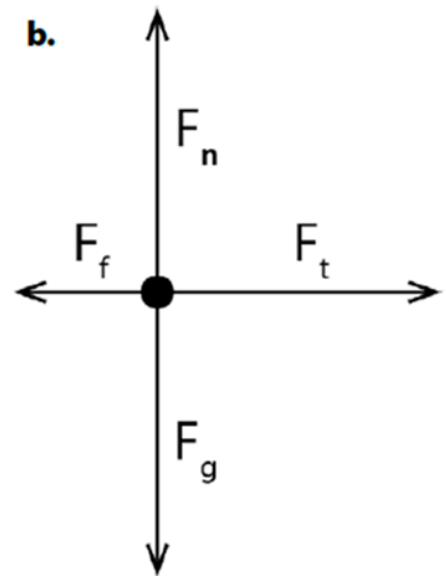
A typical FBD consists of a simple outline or a dot that represents the object under consideration, and vectors (arrows) that represent the different forces acting on it. Each force's magnitude and direction can be visually understood by the arrow's length and the way it points.

Here are 3 FBDs. Notice in a, Fg=Fn, so this is an object with zero acceleration, perhaps a book resting on a table. In b, an object has an Ft (Tension or Thrust) to the right, and a frictional drag to the left (Ff), while Fg=Fn, so this is an object accelerating toward the right along a surface. Perhaps this is a toy car being pulled to the right by a rope. In c, we see an object with a larger Ft upwards than Fg downward, so this object is accelerating upwards.

a.

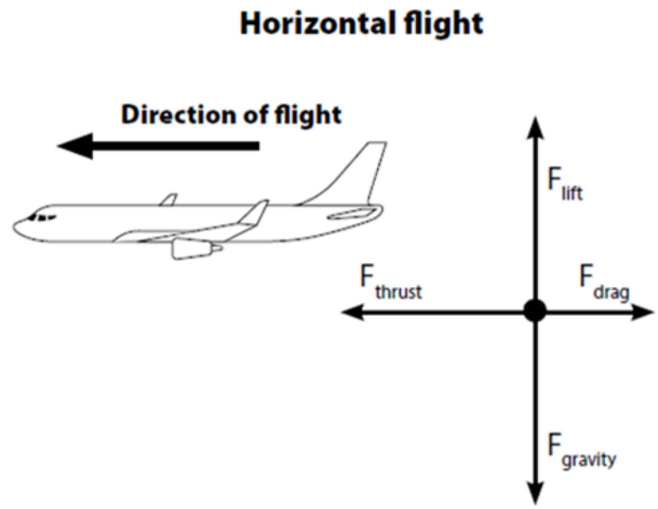



b.




c.

# Key Forces in Horizontal Flight: Aviation

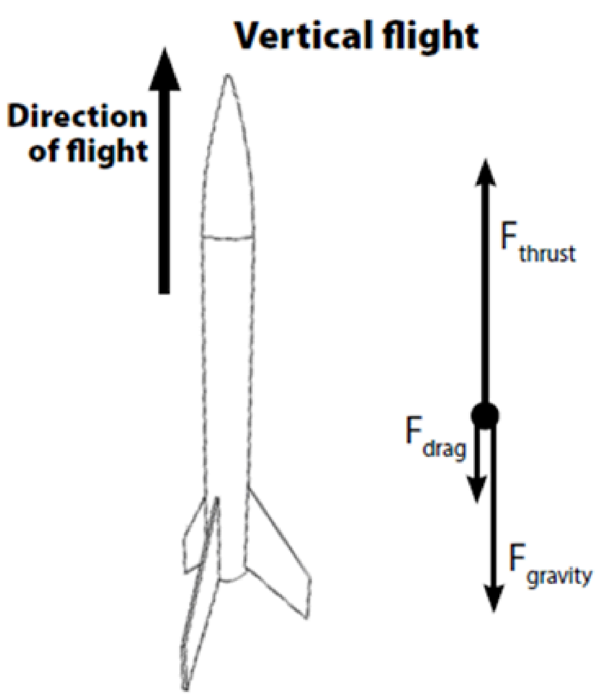



## Thrust

For an airplane, thrust is typically provided by jet engines or propellers, which use the principle of "action and reaction" (Newton's 3rd Law) to push air backward and cause the airplane to move forward.

## Lift

For an airplane, lift is crucial. The wings of an airplane are designed in a specific shape - flat at the bottom and curved on the top - to make air travel faster over the top than the bottom, thus creating higher pressure beneath the wings than above, causing the plane to lift.




## Gravity

Airplanes have to overcome the force of gravity to get off the ground. This force constantly pulls them downward, towards the center of the Earth.  This force is what vehicles must overcome in order to take off and stay in the air or space. For an airplane operating within the Earth's atmosphere, the gravitational force stays roughly constant. Fg = m*ag

## Drag

Drag is the air resistance that an airplane encounters as it moves through the air. The drag force opposes the motion of the object, so for an airplane moving forward, the drag force is backward.

For an airplane, a free body diagram might include forces such as lift (upwards), gravity (downwards), thrust (forward), and drag (backward).

# Clarify the sources of the main forces acting on gliders during flight:

**Thrust, Lift, Gravity, Drag**

1. Glider wing configuration is mostly responsible for

______________________________

2. The body shape of the glider moving through air is mostly responsible for

______________________________

3. The earth's mass acting on the glider's mass is responsible for

______________________________

4. Which Forces always oppose each other in horizontal flight?

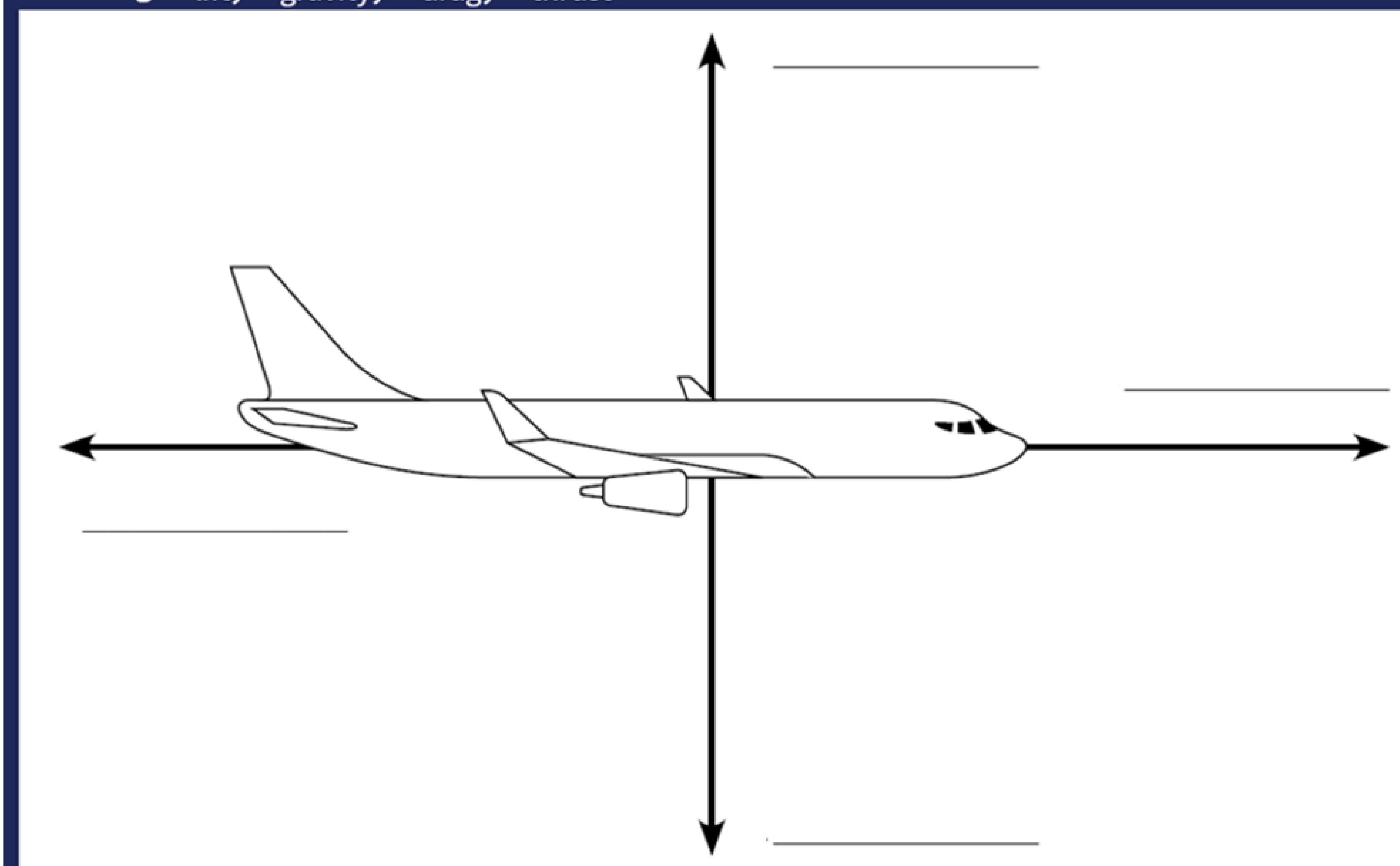
Flift opposes ______________

Fgravity opposes ______________

Fdrag opposes ______________

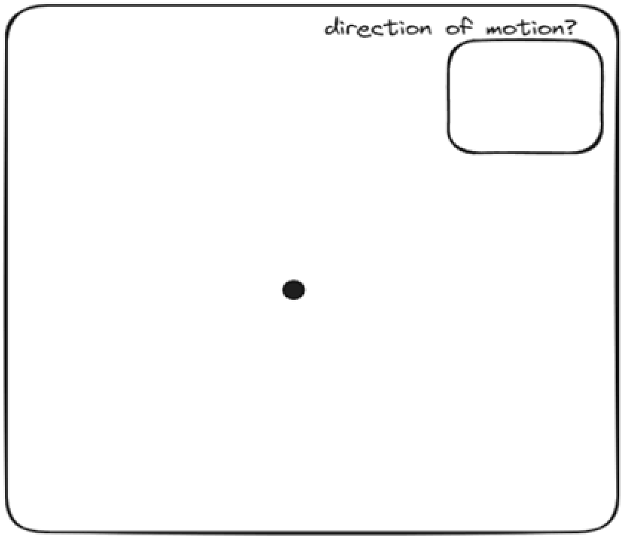
Fthrust opposes ______________

**A glider is flying toward the right as in the picture below. Label each arrow with one of the following:** $F_{lift}$, $F_{gravity}$, $F_{drag}$, $F_{thrust}$

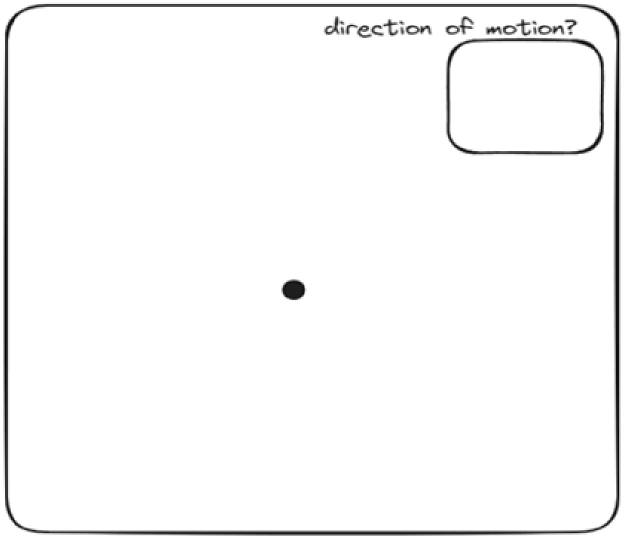


# Activity Five: Forces of Flight

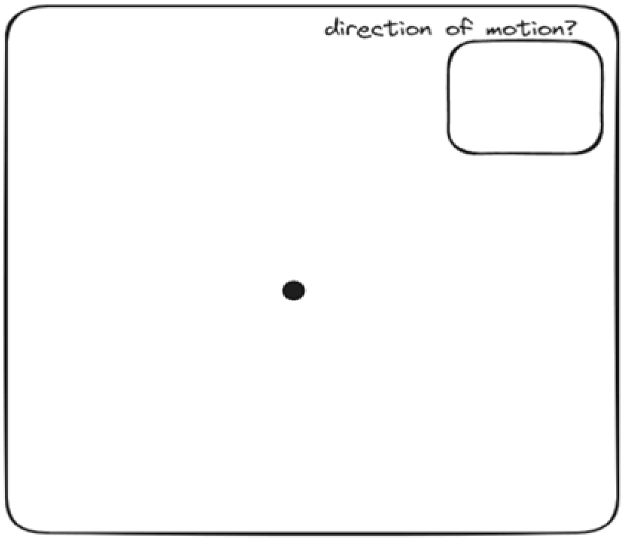
Flying from left to right



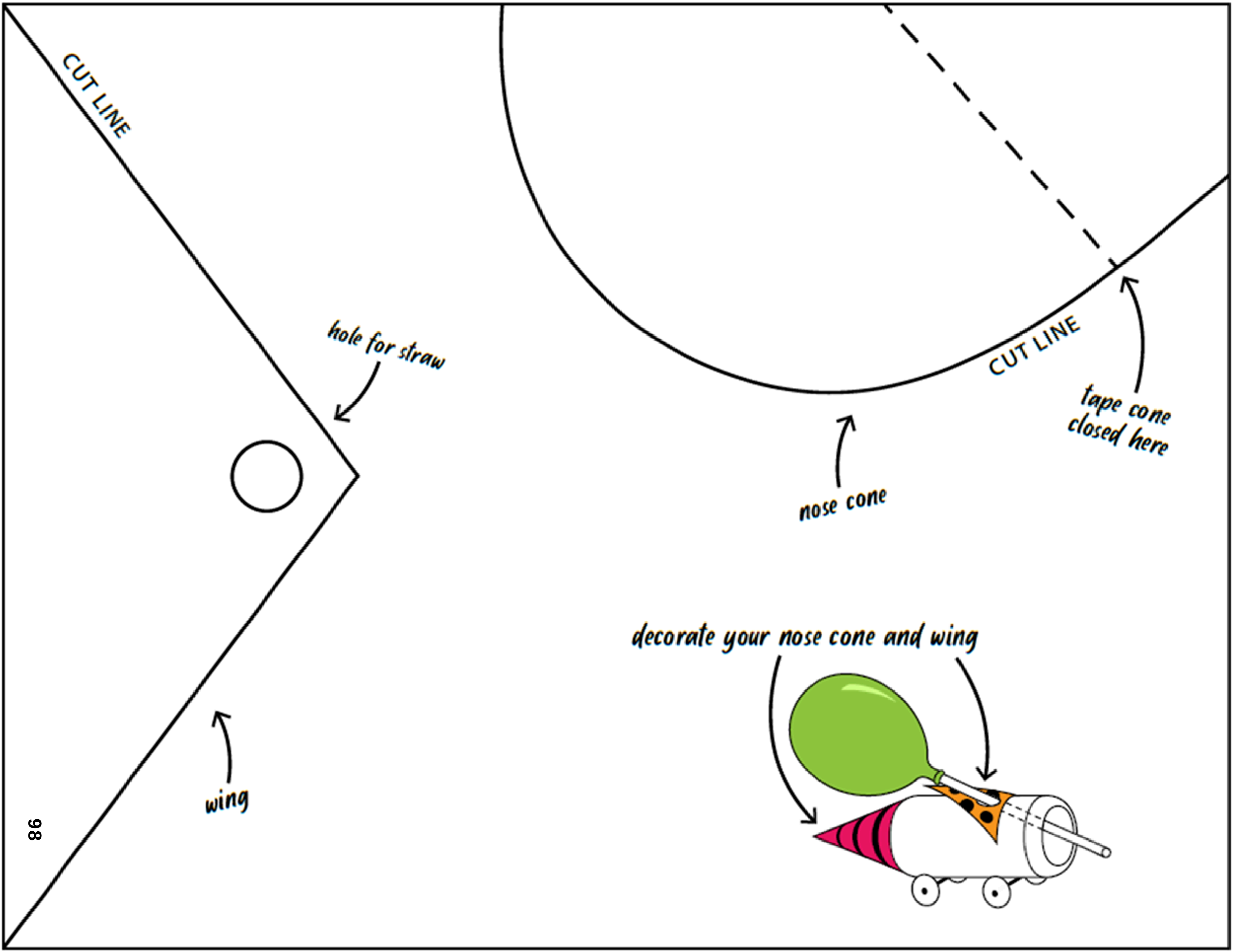

Slowing as it flies from left to right




Not moving on a surface




Experiment with your shuttle and have it travel from left to right. Draw and label Free Body Diagrams for the following three points in time during your experiment. Indicate direction of motion.


CUT LINE
hole for straw
wing
CUT LINE
nose cone
tape cone closed here
decorate your nose cone and wing

# CHAPTER 8

## Answer Keys

# Knowledge Check on Motor Types and Classification Answer Key

1. What does the color code indicate?

   The color indicates the recommended use of the engine: green indicates use for single stage rockets, purple is to be used in top stage and multi-stage rockets, blue is for plugged engines, and red is for booster and intermediate stages of multi-stage models.

2. What does A8-3 on a motor tell you?

A= Total impulse or power produced is 2.50 newton seconds

8= Motors average thrust is 8 Newtons

3= Delay between burnout and ejection charge is 3 seconds

3. What are units called that measure total impulse?

   Pound-seconds or Newton-seconds are the units of measure for total impulse.

4. List two motors and their pound-seconds and newton-seconds (refer to Total Impulse Classification).

   Copy the chart on page 9 with the code, pound-seconds, and newton-seconds for each motor.

5. What are clustered motors?

   In cluster motors, multiple rocket engines are used together in a single launch vehicle. They utilize two or more engines igniting simultaneously to provide greater thrust and improve rocket performance.

# Activity One: Engine Test

## Observation Chart Answer Key

| | First Flight Engine | Second Flight Engine |
|---|---|---|
| **Which engine sent the rocket higher?** | | |
| **Which rocket landed closest to the launch pad?** | | |
| **Did anything unusual happen? (e.x. Large gust of wind)** | | |
| **Additional Observations** | | |

Responses in the chart will vary depending on model rocket, motor types selected, and other variables such as weather. All answers will be found in the observation chart and should relate back to the codes on the motors used (total impulse, average thrust, and delay.) or external variables such as wind.

Which engine worked better for your rocket and why?

Which engine sent your rocket the highest?

Which engine were you using when the rocket landed closest to the launch pad?

Why did this motor have that outcome?

# Knowledge Check on Model Rocket Motor Performance Answer Key

1. Which engine has a higher total impulse, an A8-3 or B4-4?

   The B4-4 has a higher total impulse because A indicates a lower total impulse than B.

2. What is the purpose of the retainer cap?

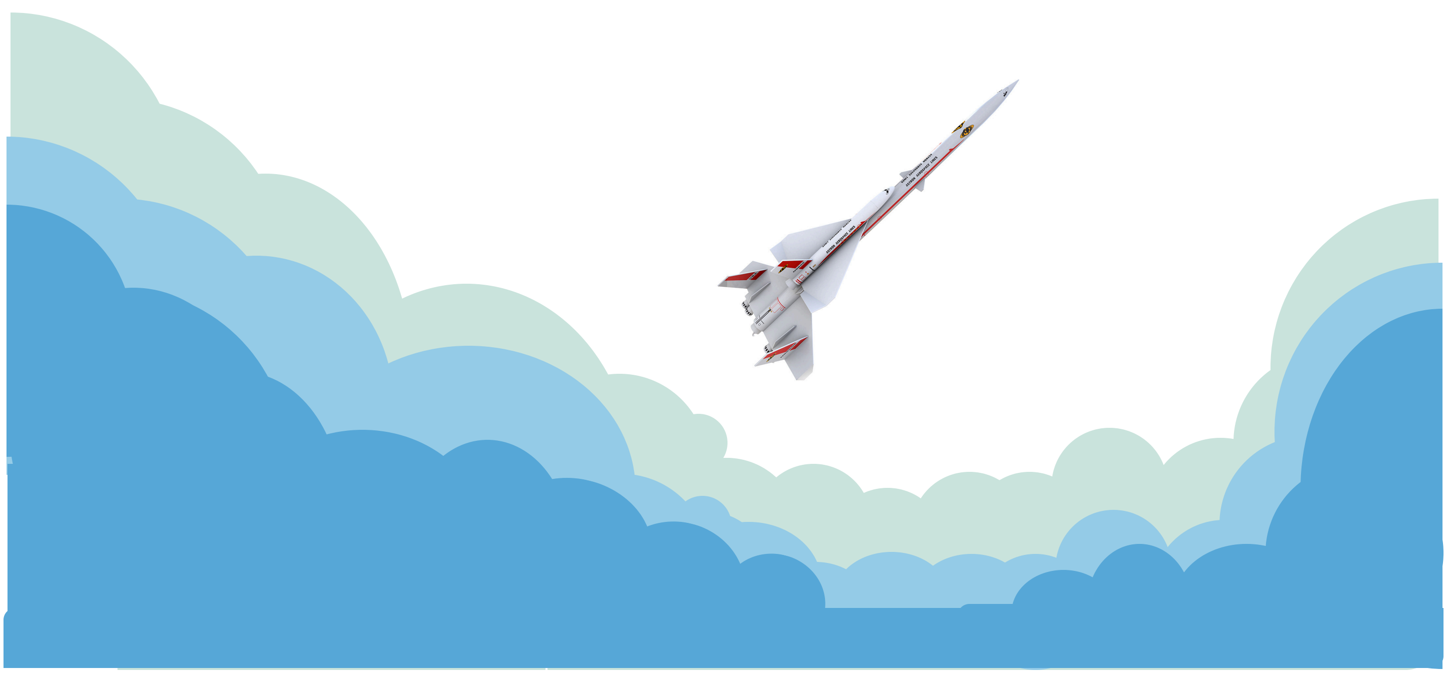
   To retain the ejection charge until it is ignited. They are used in place of an engine clip to hold the motor inside the rocket, preventing it from being pushed out of the rocket during ejection charge.

3. What is the most basic type of propulsion?

   Liquid propulsion was more difficult to develop. Solid propulsion is more basic / the most basic.

4. What is the most important characteristic of an engine propellant?

   The most important characteristic of the propellant is its burning rate.



# Knowledge Check for Multi-Stage Rockets Answer Key

1. In what type of rocket is multi-staging used?

   Multi-staging is used on multi-stage rockets

2. How is the lower stage ignited, and how is the upper stage ignited?

   The lower stage is ignited by standard electrical means. The upper stage is ignited automatically upon burnout of the first stage when propellant wall ruptures causing directing the high pressure, hot gasses from the first stage contact the nozzle of the upper stage.

3. Why is it important to check the motors before and after taping?

   Always check motors before use to make sure that they are in good condition and safe. Then, you must ensure that motors are taped together in the correct order to ensure that they work together properly (igniting the second stage when it is time for it to) to prevent damage to your rocket.

4. What is the simplest and most reliable method of joining stages?

   The simplest and most reliable method of joining stages is cellophane tape.

5. What type of recovery is used in the booster stage?

   The booster stage recovery method is the tumbling method.

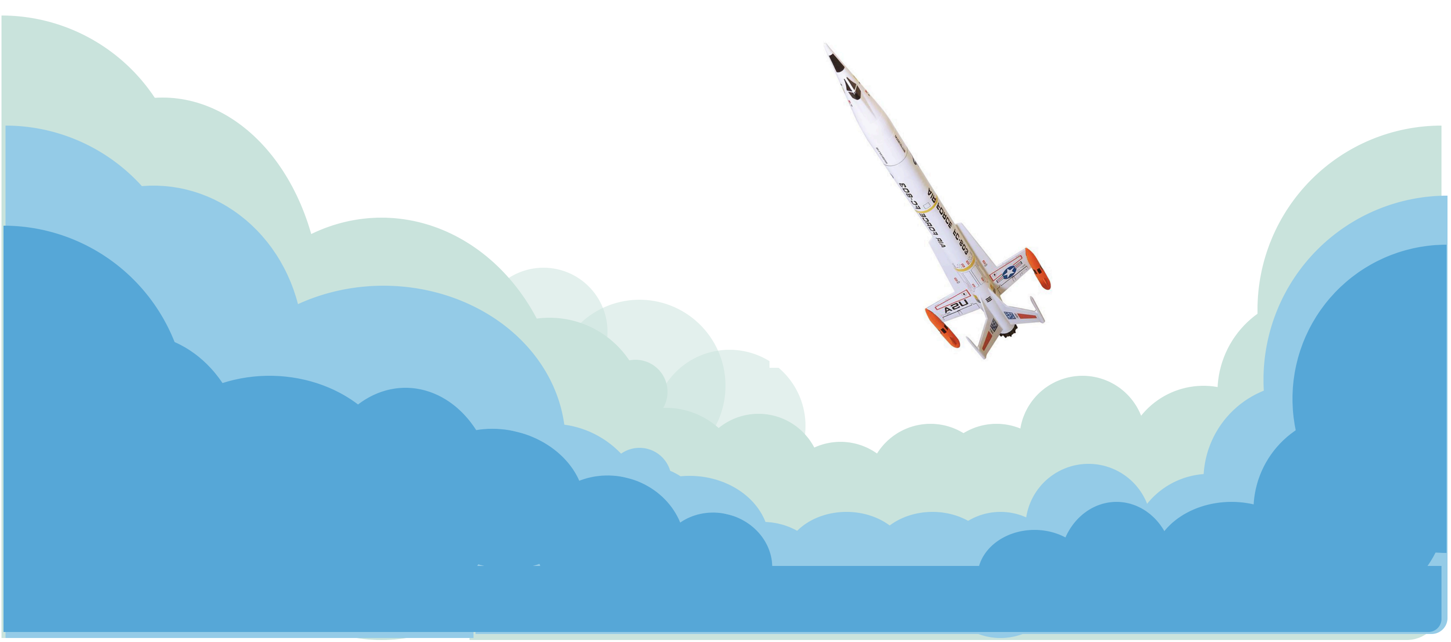
6. What engines are used in the lower stage?

   Lower stage engines should have no delay and tracking charge and no ejection charge.

# Knowledge Check for Multi-Stage Rockets Answer Key

**7** Complete the missing spaces in the chart.

| Feature | Direct Staging | Indirect Staging |
|---|---|---|
| Stage Configuration | Stages stacked vertically | Boosters attached to the sides |
| Ignition Sequence | Each stage ignites after the previous one is jettisoned | Boosters and core engine ignite simultaneously |
| Stage Separation | Sequential, after each stage burns out | Boosters jettison after burnout, core engine continues |
| Efficiency | Higher efficiency due to weight reduction after each stage | High initial thrust, simpler transition |
| Typical Use | Multi-stage rockets for higher altitude | Rockets needing additional thrust at launch |



# Activity Two: Understanding Multi-Stage Rockets Answer Key

## Term and Concept Discovery:

**Multi-Staging:**
A multi-stage model rocket consists of two or more rocket stages, stacked on top of each other. Each stage has its own engine and ignites in sequence.

**Direct Staging:**
Method of stacking stages, each with their own motor, fuel, and potentially a guidance system.

**Indirect Staging:**
Uses booster engines that are attached to the side of the rocket to provide additional thrust.

**Multi-Stage Coupling:**
The joint that allows one stage to detach from the next stage during a staged flight.

## Apply

Ask the group to explain how a multistage rocket works and how using this model has helped their understanding.

## Talk It Over:

**Share:**
Have the group or individual explain what happened in this activity.

**Reflect:**
Ask participants to explain the similarities and differences between this activity and the launch of multi-stage model rockets.

**Generalize:**
Ask the group how this activity went and if there were any ways to improve the process.

**Share:**
Participants should identify that the first balloon represents the lower stage, where it propels forward and then when it runs out of thrust, sets off the second balloon, representing the upper stage.

# Knowledge Check for Launch Systems and Electrical Circuits Answer Key

1. What are the three main types of launch systems?

   The three main types of launch systems are a launch rod, a launch rail, and a launch tower.

2. List four symbols used in electrical circuits.

   Copy the top image from page 53. List: wire, ground, two wires not connected, two connected wires, three connected wires, four connected wires, switch closed, switch open, OHM, and two crossing wires not connected.

3. What is an electrical current?

   An electrical current is the flow of electrons.

4. What is a coulomb?

   A coulomb is the unit used to measure the flow of a current.

# Knowledge Check for Launch Systems and Electrical Circuits Answer Key

5. What is an ampere?

   An ampere is a unit used to measure the rate at which electricity is flowing per second.

6. Describe direct current and alternating current.

   Direct current is when electricity is flowing in only one direction. When electricity flows rapidly back and forth, this motion is called alternating current.

7. What is the difference between a conductor and an insulator?

   A conductor presents very little resistance to the flow of electricity while an insulator is an object that presents a high resistance to the passage of electricity.

8. What is an ohm?

   An ohm is the unit used to measure the amount of electrical resistance.

# Activity Three: Create a Launch System Answer Key

## Introduction:

Understanding how launch systems work will help participants identify and troubleshoot potential problems when launching model rockets.

## Opening Questions:

What are the pieces of a single launcher system?
What is different about multiple launcher circuits?

## Background information:

Participants should have read through "Launch Systems and Electrical Circuits" in the Unit 3 Manual.

**Experience:** Follow the experiential learning cycle by explaining the following:

- Before the Activity (steps facilitator must take prior to the activity)
  If it has been a while since they have read "Launch Systems and Electrical Circuits" review this section with the participants. Answer any questions they may have.

## Let's Do It!

- Talk with the group about the difference between single launcher systems and multiple launcher systems and the important components of each. Then have participants select one type to design.
- Give youth some time to draw out a launch system on their paper and have them list any supplies they would need to build it on the side.
- Once everyone has finished, have each participant show their drawing and identify each of the parts. If they are missing any components of the circuit, explain what they are missing and why it is an important part.

**Individual diagrams may differ a little, but should look similar to the diagrams on pages 57 and 58.**

# Knowledge Check for Launch Considerations Answer key

1. What is the purpose of the National Association of Rocketry (NAR)?

   The National Association of Rocketry (NAR) provides guidelines on minimum launch sizes based on the motor’s total impulse and other safety standards.

2. Essential Equipment includes a sturdy launch pad with a guide rod or rail, a reliable ignition system and a launch controller with a safety key.

3. What is one step you could take at your launch site to minimize one of the atmospheric effects mentioned in this chapter? Name the effect and how you would mitigate it.

   Wind conditions would be the easiest atmospheric effect to mitigate at the launch site. Counteract moderate winds by aiming the launch rod slightly into the wind.

# Knowledge Check for Predicting and Determining Altitude Answer Key

1. What is the simplest method of tracking?

   Single-station tracking is one of the simplest and most inaccurate systems used.

2. What do capital and small letters mean in trigonometry?

   In trigonometry, capital letters represent and angle and lower case letters designate a side.

3. At what distance should a single tracker be located?

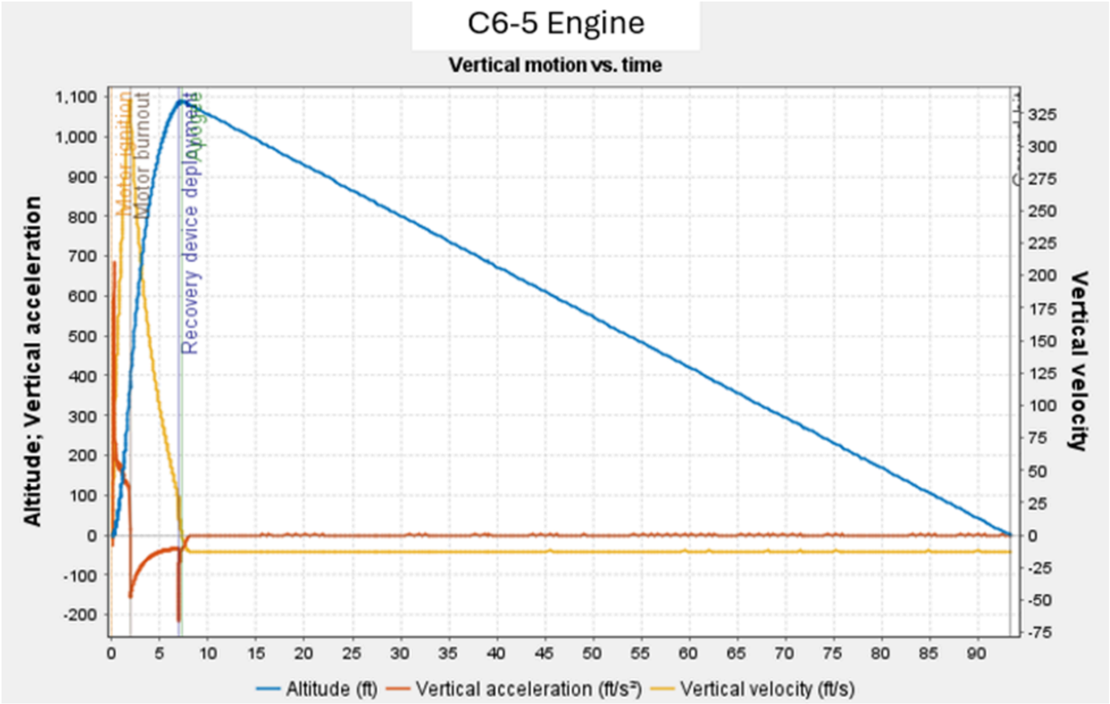
   A single tracker should be located 250 feet from the launcher.

4. Is two-station tracking more accurate than single-station? Why or Why not?

   Two-station tracking is more accurate than single-station because there are two sets of data to more accurately identify the altitude.

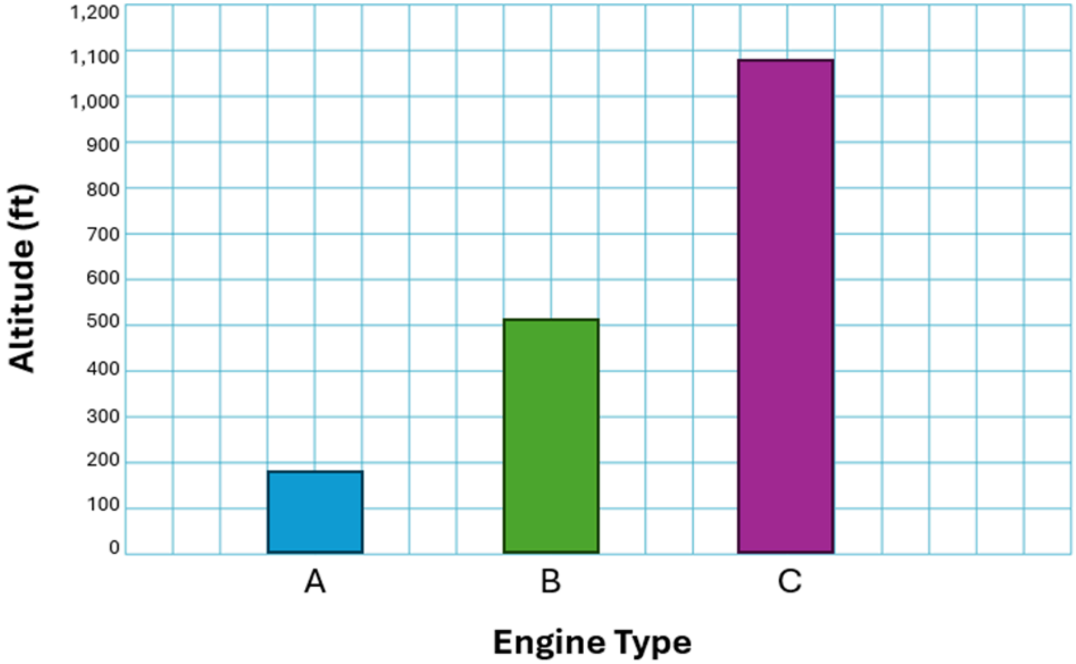
# Activity Four: Altitude Testing in OpenRocket

Review the following images of each simulation. Note the measurement differences in the x-axis and y-axis of each one. (Images from Cosmic Cargo Simulation in Open Rocket at https://openrocket.info/.)




Answers will vary depending on the rocket and motors that they use. A sample of what to do is included in the manual.

**Sample Graph:**



# Clarify the sources of the main forces acting on gliders during flight Answer Key:

**Thrust, Lift, Gravity, Drag**

1. Glider wing configuration is mostly responsible for

   Glider wing configuration is mostly responsible for making air travel faster over the top than the bottom, creating higher pressure beneath the wings than above generating lift.

2. The body shape of the glider moving through air is mostly responsible for

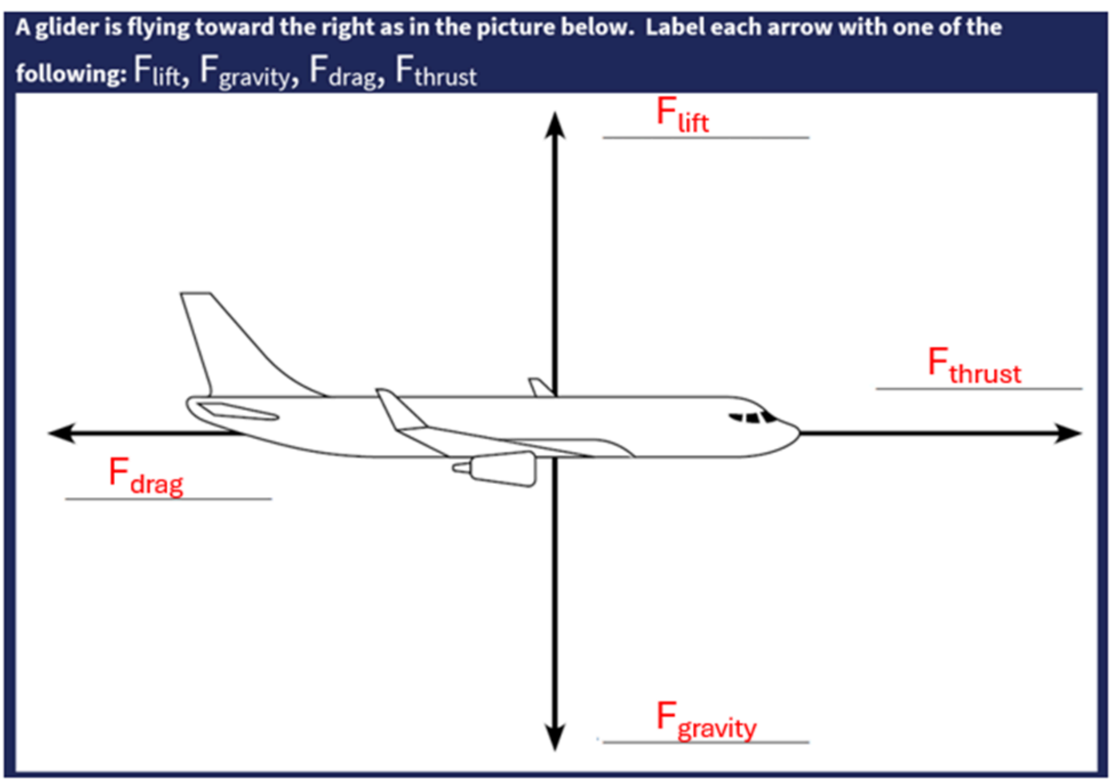
   The body shape of the glider is mostly responsible for drag.

3. The earth's mass acting on the glider's mass is responsible for

   The earth's mass acting on the glider's mass is responsible for gravity.

4. Which Forces always oppose each other in horizontal flight?

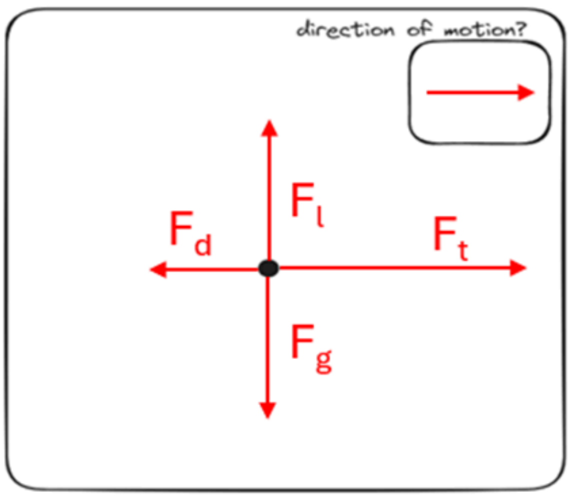
   Flift opposes Fgravity
   Fgravity opposes Flift
   Fdrag opposes Fthrust
   Fthrust opposes Drag



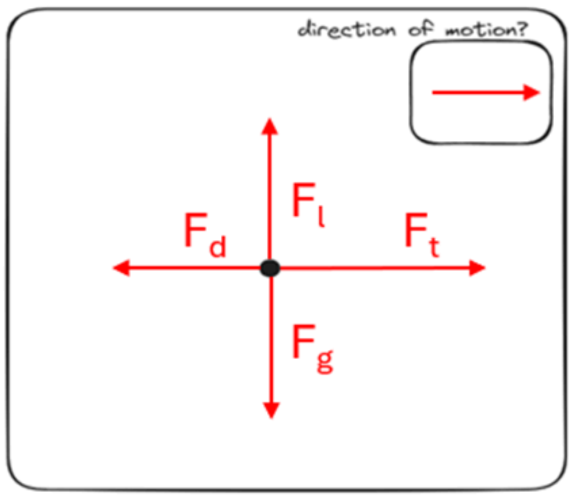
# Activity Five: Forces of Flight

## Answer Key

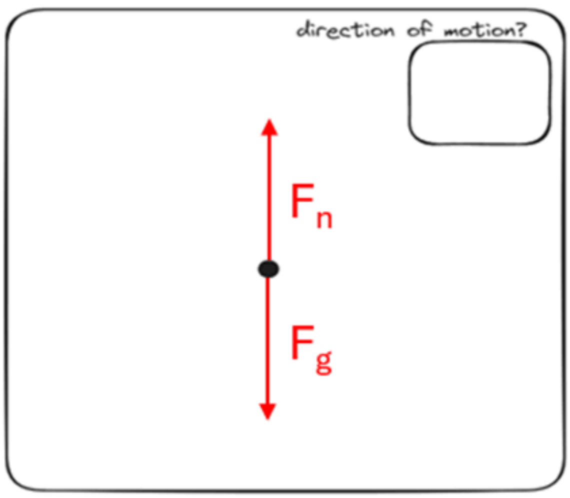
Flying from left to right




Slowing as it flies from left to right




Not moving on a surface



# 4-H Pledge

I pledge.....
My head to clearer thinking,
My heart to greater loyalty,
My hands to larger service,
My health to better living
for my club, my community,
my country and my world.