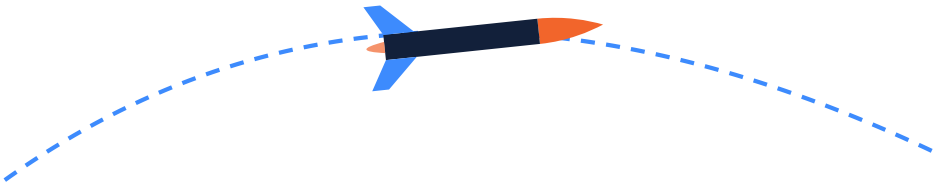
MIDDLE SCHOOL · GRADES 6–8 · 9 LESSONS

Rockets & Model Rocketry

Worksheets, data sheets, the inclinometer template, the flight log and the mission report planner. Goes with **Rocket Builder by Quiver Design Works**, a free app at rocket.quiverdesignworks.net. Lesson plans: rocket.quiverdesignworks.net/learn/middle.



	Page	Use in	Who
M	My rocket journey (unit map)	Lesson 1	Everyone
W1	Balloon rocket data	Lesson 1	Everyone
W2	Forces and launch angles	Lesson 2	Everyone
W3	Swing test	Lesson 3	Everyone
W4	Drag test	Lesson 4	Everyone
W5	Motor codes and impulse	Lesson 5	Everyone
W5b	Thrust curve	Lesson 5	Extension
W6	Design log	Lesson 6	Everyone
W7	Parachutes and landing energy	Lesson 7	Everyone
W8	Altitude tracking	Lesson 8	Everyone
T	Inclinometer template	Lesson 8	Everyone
W8b	Safety rules	Lesson 8	Everyone
W8c	Launch checklists	Lesson 8	Everyone
W9	Graph your data	Lesson 9	Everyone
F	Flight log (printed rocket)	Lesson 9	12+ (adult launches)
C	Mission report planner and rubric	Lesson 9	Everyone
Q	Quick checks, Lessons 1–9	Any lesson	Everyone
K	Answer keys	Teachers	Teachers

Printing: US Letter, portrait, scale 100% ("actual size"), so the inclinometer comes out the right size. Turn on "background graphics" for the coloured bands. Print the answer keys for the teacher only.

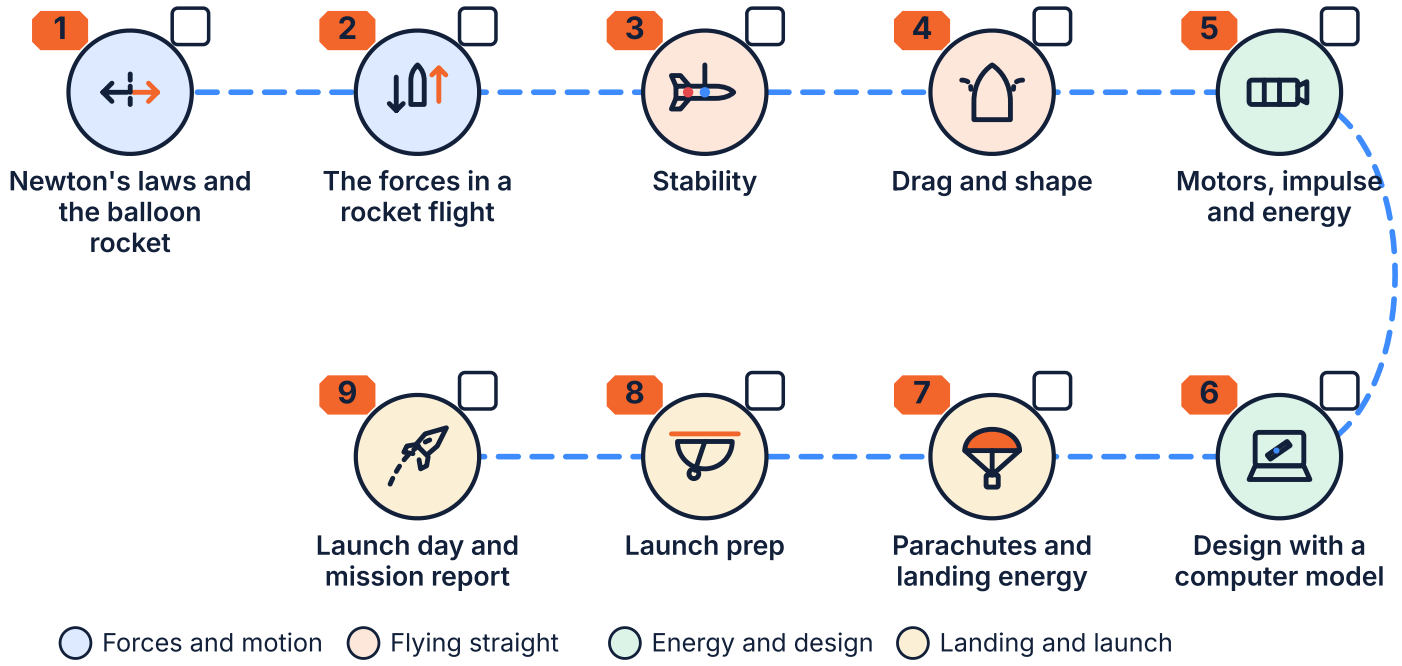
Standards: Washington State K–12 Science Learning Standards (NGSS): MS-PS2-1, MS-PS2-2, MS-PS2-4, MS-PS3-1, MS-PS3-2, MS-PS3-5, MS-ETS1-1 to 4. The lesson plans list the standards for each page.

Safety: model rocket motors and kits are rated 12+, and adults handle all motors and igniters. Students under 12 do every page and take launch-day jobs away from the pad. Glasses on for straw and stomp rockets. Follow the NAR Model Rocket Safety Code.

Name _____ Date _____

M My rocket journey

Tick each stop when you finish it. Motors and launches are always run by an adult.

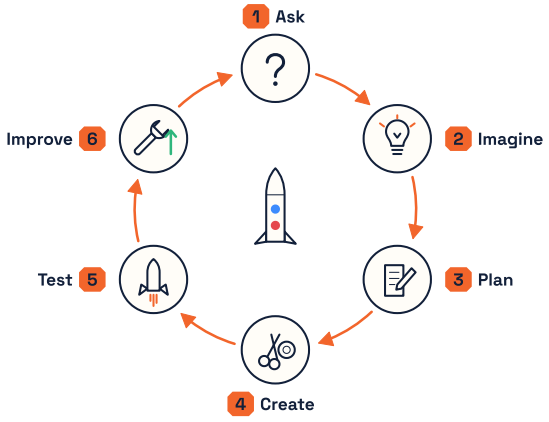


The big parts

- **Forces and motion**: Lessons 1–2
- **Flying straight**: Lessons 3–4
- **Energy and design**: Lessons 5–6
- **Landing and launch**: Lessons 7–9

Adult: plan ahead

- **By Lesson 1:** Order the pad, controller, wadding and motors
- **By Lesson 5:** Find a field or a NAR club launch
- **By Lesson 6:** Start printing (hours per part)
- **By Lesson 7:** Assemble with an adult
- **By Lesson 8:** Pick a backup launch day



Engineers go round this loop again and again: you will too.

Name _____ Date _____

W1 Balloon rocket data

Lesson 1 · Newton's three laws

Words: force · mass · inertia · acceleration · action and reaction · thrust

Question: Does more air make it go further? Does more weight make it go less far?

My guess: _____

Part A: more air (same mass)

Balloon size	Circumference (cm)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
Small					
Medium					
Large					

Part B: more mass (same air)

Paper clips	Circumference (cm)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0					
5					
10					

Mean = (trial 1 + trial 2 + trial 3) ÷ 3. Only the mass changes in Part B: that makes it a fair test.

Think about it

1. Newton's **third** law: the balloon pushes air out the back. What pushes the balloon forward?

2. Newton's **second** law: in Part B, the push was the same. What happened when you added paper clips? Why?

3. Newton's **first** law: why did the straw stay still until you let go? Why did it stop at the end?

4. Rocket Builder: press ▶ **Watch it launch**. Write three things you noticed.

Extension: a balloon pushes with 0.1 N on a 10 g (0.010 kg) rocket. Ignoring friction, a = F ÷ m = _____ m/s². With 10 g of paper clips added: a = _____ m/s².

Name _____ Date _____

W2 Forces and launch angles

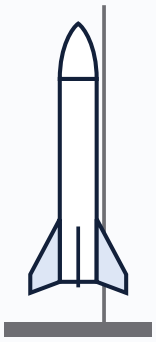
Lesson 2 · The forces in a rocket flight

Words: thrust · weight · drag · lift · balanced · unbalanced · apogee

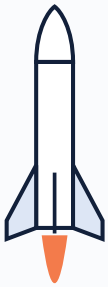
Part 1: draw the forces

Draw an arrow for each force on the rocket and label it: **thrust**, **weight**, **drag**. Make bigger forces longer arrows.

1. On the pad



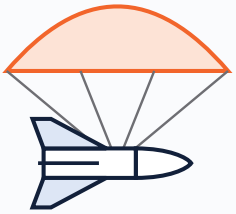
2. Boost (motor on)



3. Coast (motor off)



4. Under the parachute

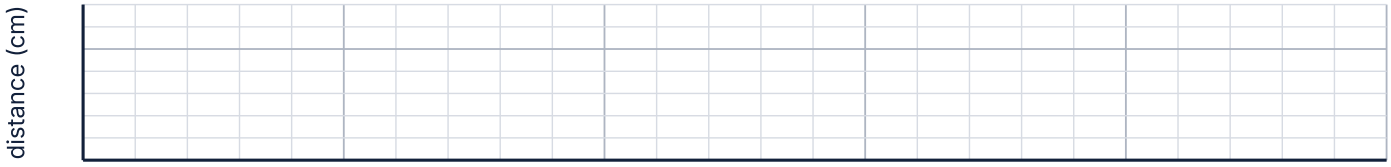


Which pictures show **balanced** forces? _____ Which show **unbalanced**? _____

Part 2: launch-angle test (straw rockets)

Angle	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
15°				
30°				
45°				
60°				
75°				

Bar graph: _____



1. Which angle went furthest? Why do you think so?

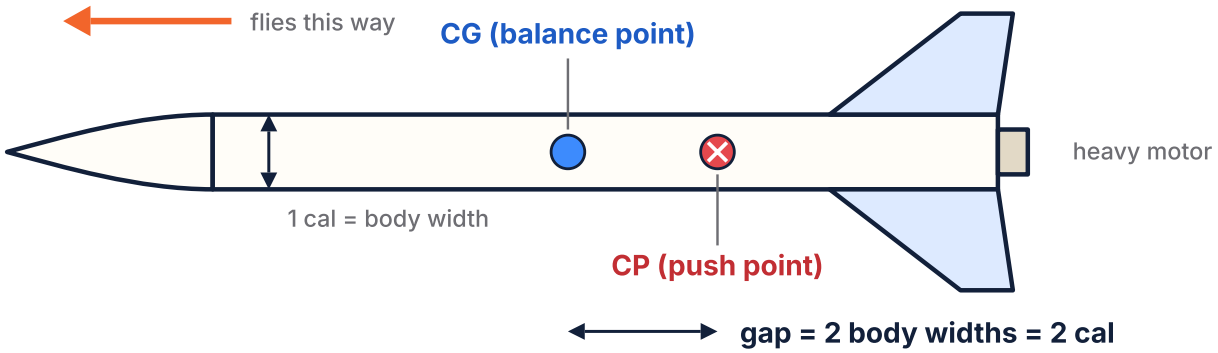
2. Rocket Builder: press ▶ **Watch it launch**. Number these in the order you see them: ___ coast ___ liftoff ___ parachute ___ top (apogee) ___ boost
3. The **power** bar (thrust ÷ weight) for my rocket says _____ ×. Is it 5× or more? _____

Name _____ Date _____

W3 Swing test

Lesson 3 · Stability: balance point and push point

Words: stable · unstable · balance point (CG) · push point (CP) · caliber · stability score



The blue dot (balance point) must be **in front of** the red dot (push point). Score (cal) = (push point distance − balance point distance) ÷ body width. 1–2 cal is just right.

Body width of my test rocket: _____ cm (= 1 cal)

Version	Change	Balance point from tip (cm)	Push point from tip (cm)	Gap (cm)	Score (cal)	Swing test: stable, wobbly or tumbles?
A	no fins, no clay					
B	fins, no clay					
C	fins + clay in nose					
D	fins + clay at tail					

1. Which version was the most stable? Use your scores to explain.

2. Why did clay in the nose help, but clay at the tail hurt?

3. A rocket is 3 cm wide. Its push point is 4.5 cm behind its balance point. Score = _____ cal. Is that just right, wobbly, or too stable? _____
4. In Rocket Builder, my rocket's score is _____ cal. The fins are _____ shaped.

Name _____ Date _____

W4 Drag test

Lesson 4 · Drag and shape

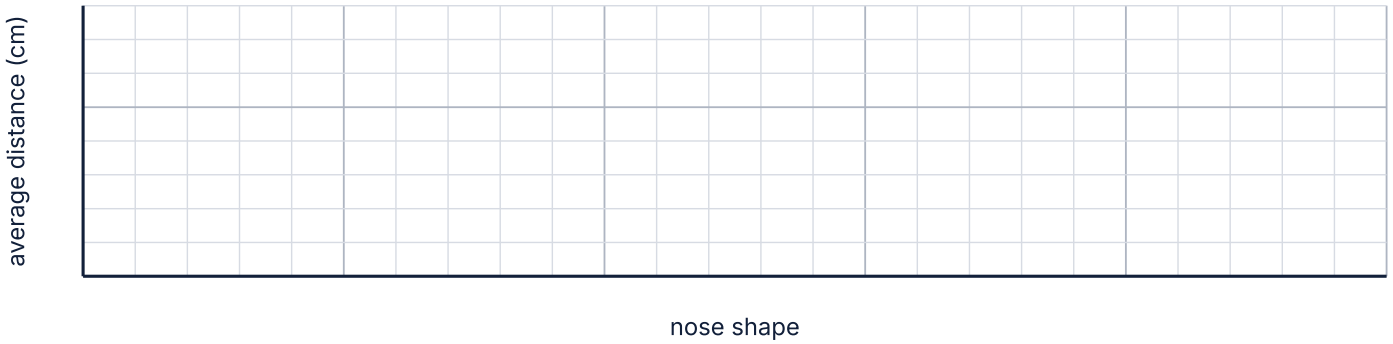
Words: drag · streamlined · frontal area · drag coefficient · variable · fair test · trade-off

The variable I'm changing: nose shape. **Things I keep the same:** _____

Test 1: nose shapes (launch angle: _____°)

Nose	Mass (g, optional)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
Flat					
Cone					
Round					

Bar graph: _____



Test 2: fins

Fins	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)	Straight or wobbly?
None					
3 small					
3 medium					
4 large					

1. Which nose had the least drag? How do you know?

2. Was the difference big, or could it be luck? What would make you more sure?

3. Explain the fin trade-off using your data.

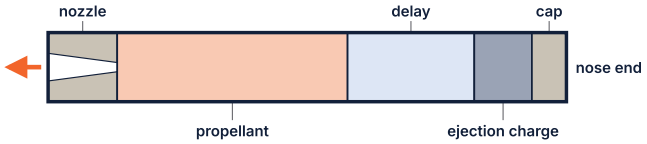
Extension (Advanced mode): drag = ½ × 1.2 × speed² × Cd × area. A rocket with area 0.00071 m² and Cd 0.65 at 40 m/s: drag ≈ _____ N. In Rocket Builder (Advanced → Flight → Advanced), predicted altitude with Cd 0.5: _____ m; Cd 0.8: _____ m.

Name _____ Date _____

W5 Motor codes and impulse

Lesson 5 · Motors, impulse and energy

Words: propellant · nozzle · delay · ejection charge · igniter · total impulse · impulse class · thrust-to-weight



hot gas rushes out of the nozzle, so the rocket is pushed the other way: toward the nose

Motor rockets are 12+, and only adults handle motors and igniters. This drawing shows the inside of a motor. Never open one.

Class	1/4A	1/2A	A	B	C	D	E	F
Total impulse up to (N·s)	0.625	1.25	2.5	5	10	20	40	80
Smallest field (NAR)	15 m	15 m	30 m	60 m	120 m	150 m	300 m	300 m

1. Decode the motor codes

Code	Impulse class	Average thrust (N)	Delay (s)	Smallest field
A8-3				
B6-4				
C6-5				
D12-5				

2. Impulse = average thrust × burn time

Motor	Average thrust (N)	Burn time (s)	Total impulse (N·s)	Class
a	3	0.8		
b	5	0.9		
c	10	1.7		
d	15	3.4		

3. Rocket Builder: How high will it go?

The best motor for my design is _____. It should reach _____ m, at a top speed of about _____ m/s.

4. Thrust-to-weight (it must be 5 or more)

100 g weighs about 1 N. So a rocket of 80 g weighs about 0.8 N.

1. Rocket + motor = 80 g. Motor average thrust = 5 N. Weight = _____ N. Thrust ÷ weight = _____. Pass? _____
2. Rocket + motor = 120 g. Motor average thrust = 4.7 N. Weight = _____ N. Thrust ÷ weight = _____. Pass? _____

5. Where is the energy?

Write the energy at each point: **stored (propellant)**, **kinetic (motion)**, **potential (height)**, **heat (drag)**. On the pad: _____ Boost: _____ Apogee: _____

Name _____ Date _____

W5b Thrust curve

Extension

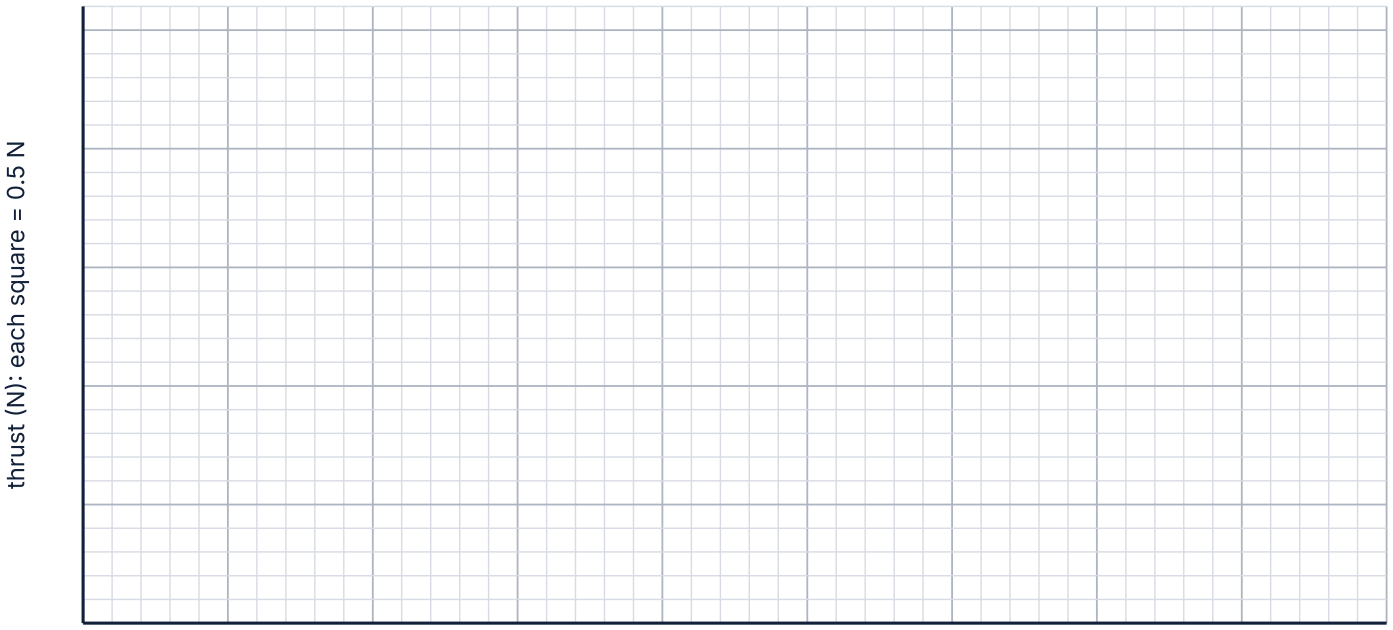
Lesson 5 · Extension: impulse is the area under the thrust curve

This table is a **thrust curve** for a B motor, rounded from a measured one. Thrust is how hard the motor pushes at each moment.

Time (s)	0	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.9
Thrust (N)	0	12	9.5	5	4	4	4	4	4	4	4	0

1. Plot the points on the grid and join them with straight lines. Time along the bottom (each small square = 0.02 s), thrust up the side (each small square = 0.5 N).

Thrust curve, B motor _____



2. What is the **peak** (highest) thrust? _____ N. When? _____ s
3. The **area under the curve** is the total impulse. Find it by splitting the shape into triangles and rectangles (or count squares: each small square = 0.02 × 0.5 = 0.01 N·s). Total impulse ≈ _____ N·s. Class: _____
4. Average thrust = total impulse ÷ burn time (0.86 s) = _____ N. Why is the code's middle number a little different?

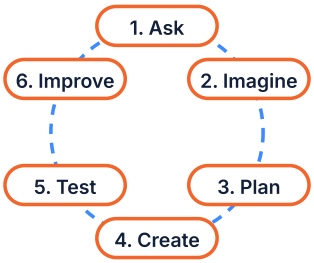
5. **F = m × a at liftoff.** Rocket + C6 motor: mass 0.086 kg, measured average thrust 4.7 N. Weight = 0.086 × 9.8 = _____ N. Net force = _____ N. Acceleration = _____ m/s².

Name _____ Date _____

W6 Design log

Lesson 6 · Design with a computer model

Words: criteria · constraints · iteration · prototype · trend · model

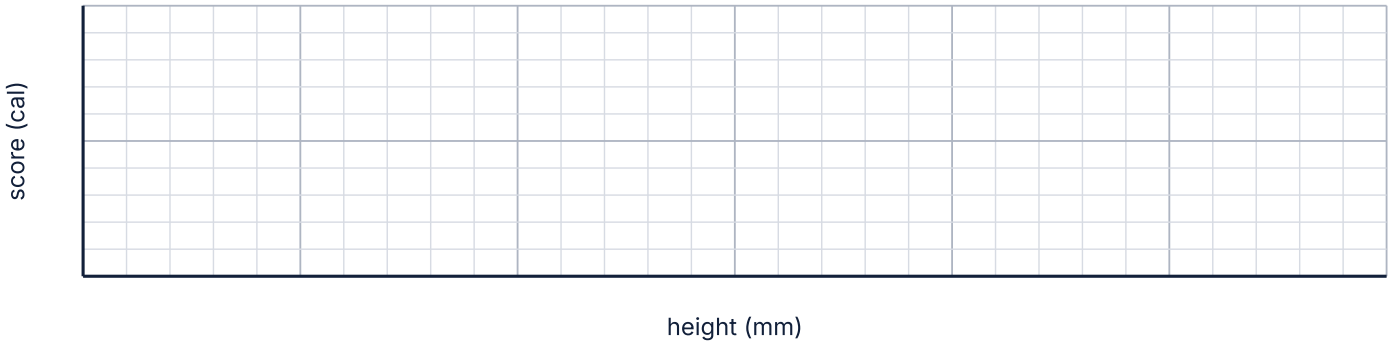


Criteria (what it must do): score 1–2 cal (2–3 OK) · a motor gets ✓ Good · height fits our field · _____

Constraints (limits): printer height _____ mm · field size _____ m · safety and environment: _____

#	Height (mm)	Fin shape	Nose	Score (cal)	Fins grew? ✓	Best motor	Altitude (m)	Power (×)	Off rod (m/s)
1									
2									
3									
4									
5									
6									
7									
8									

Line graph: height vs score _____



The trend: as the height went up, the score _____

Decision table: score each design 1 (poor) to 3 (great)

Design #	Stability (1–2 cal is best)	Altitude fits our field	Looks	Print time	Total

I chose design # _____ because _____

Advanced (custom fins): span 15 mm _____ cal · 20 mm _____ · 25 mm _____ · 30 mm _____. The score crosses 1.0 at about _____ mm.

▶ **Watch it launch:** it went up about _____ m and landed about _____ m from the pad.

Name _____ Date _____

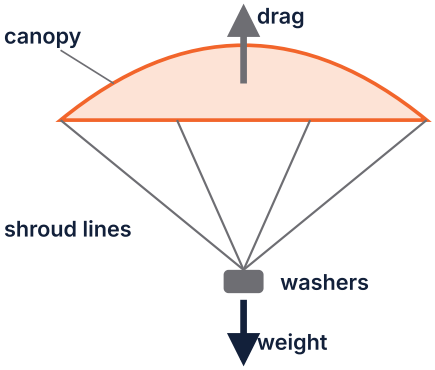
W7 Parachutes and landing energy

Lesson 7 · Parachutes and landing energy

Words: recovery · canopy · shroud lines · descent rate · terminal speed · drift

Drop height: _____ m **Weight on each parachute:** _____

Descent rate (m/s) = drop height ÷ average time



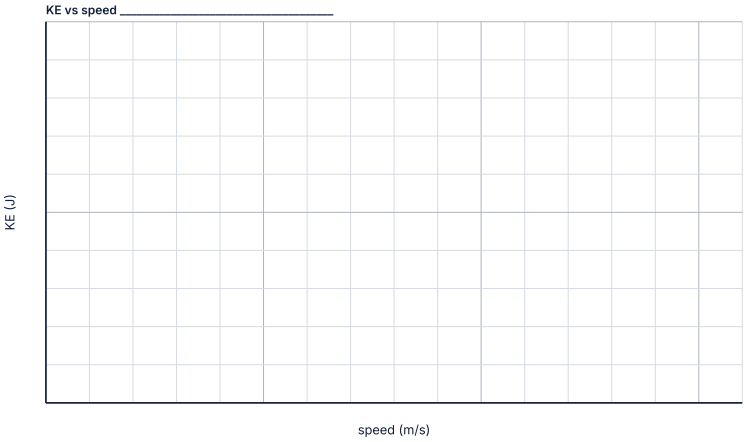
Parachute	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Average time (s)	Descent rate (m/s)
No parachute					
20 cm					
30 cm					
40 cm					

Landing energy: KE = ½ × mass × speed²

Speed (m/s)	2	4	8	16
KE of 0.08 kg (J)				

Mass (g)	40	80	160
KE at 4 m/s (J)			

Plot KE (up) against speed (along). Which graph would be a straight line: KE vs speed, or KE vs mass?



Your rocket's parachute (Rocket Builder)

Parachute size: _____ inches. Descent speed: _____ m/s. Predicted altitude: _____ m.

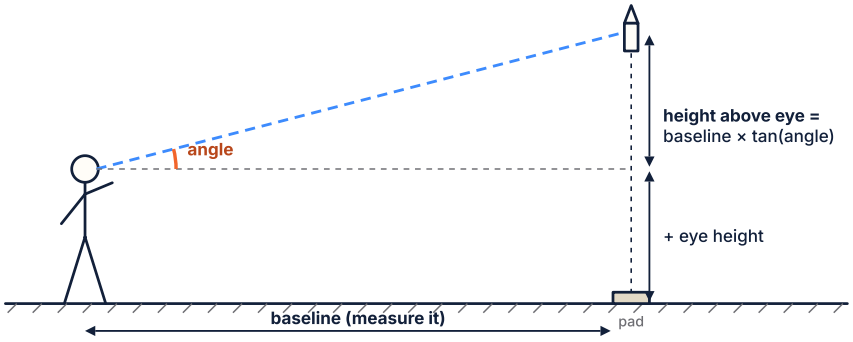
Time to come down = altitude ÷ descent speed = _____ s. Drift in a 10 mph (4.5 m/s) breeze = time × 4.5 = _____ m.

1. Practice: a rocket reaches 120 m and falls at 4 m/s. Time = _____ s. Drift = _____ m. Is a 60 m field big enough? _____
2. Why not just use the biggest parachute you can find?

Name _____ Date _____

W8 Altitude tracking

Lesson 8 · Measuring height with angles



Angle	Multiplier	Angle	Multiplier
5°	0.09	45°	1.00
10°	0.18	50°	1.19
15°	0.27	55°	1.43
20°	0.36	60°	1.73
25°	0.47	65°	2.14
30°	0.58	70°	2.75
35°	0.70	75°	3.73
40°	0.84	80°	5.67

height = baseline × multiplier + eye height

1. How tall is it? (tree, flagpole or house)

Object	Baseline (m)	Angle 1	Angle 2	Angle 3	Average angle	Multiplier	Eye height (m)	Height (m)

2. Practice

1. Baseline 25 m, angle 40°, eye height 1.3 m. Height = _____ m.
2. Baseline 80 m, angle 55°, eye height 1.5 m. Height = _____ m.
3. Scale drawing: on the back, draw a baseline of 10 squares (1 square = 2 m). Draw a 35° angle at one end and a line straight up at the other. How many squares tall? _____ = _____ m.

3. Track a stomp rocket

Launch	Tracker	Baseline (m)	Angle	Multiplier	Height (m)	Average of trackers (m)
1						
1						
2						
2						

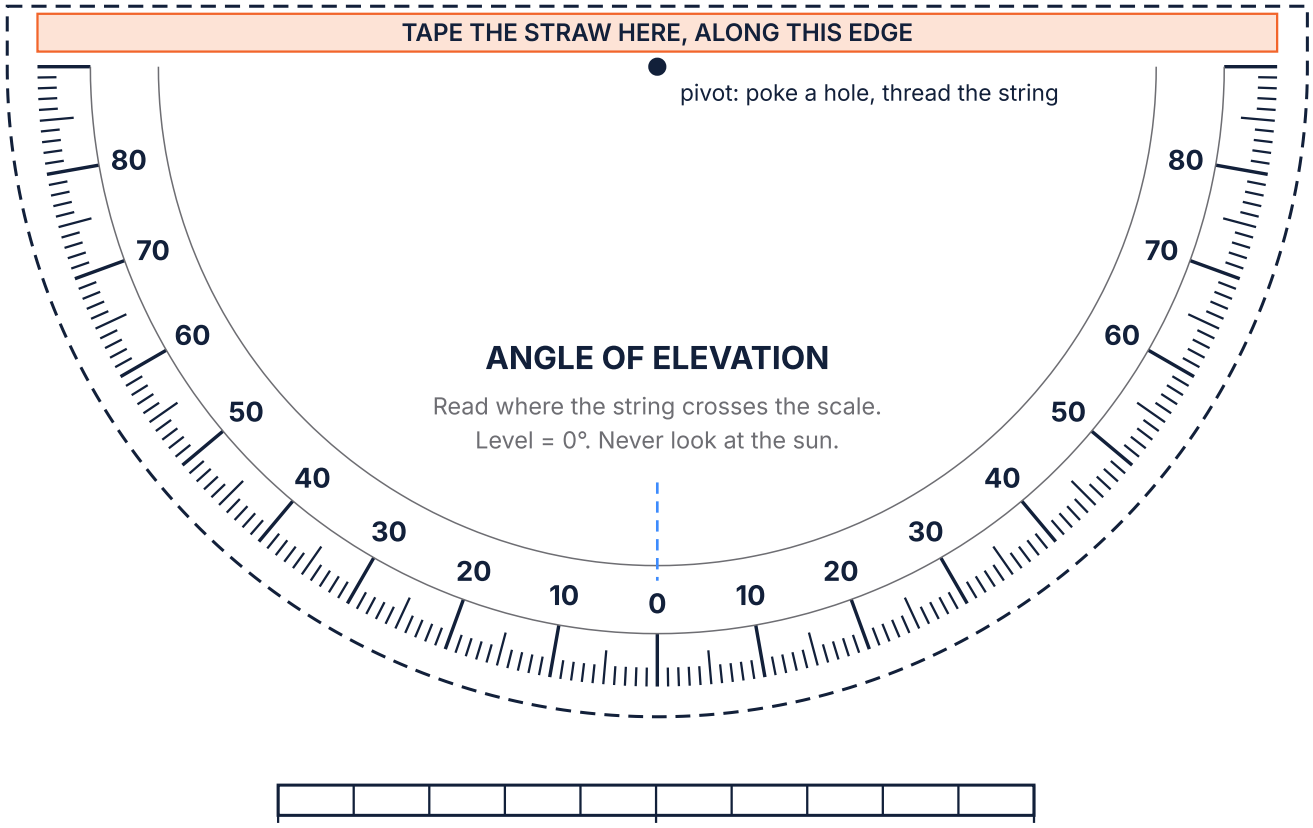
4. Name two things that could make a height measurement wrong.

5. **Extension (tangent):** with a 50 m baseline, an angle of 45° gives _____ m and 47° gives _____ m. At 75°: _____ m; at 77°: _____ m. Which angle is more sensitive to a 2° mistake? _____

Inclinometer template

Lesson 8 · Print at 100% (actual size)

1. Print at **100%**. Check the 10 cm bar with a ruler. Glue onto cardstock and cut along the dashed line.
2. Tape a drinking straw along the top edge, on the orange band.
3. Poke a small hole at the pivot dot. Thread about 25 cm of string through it and tape the end at the back.
4. Tie a small weight (a washer or nut) to the string so it hangs below the scale.
5. Look through the straw at the top of the object. Pinch the string against the card, then read the angle.



This bar should measure exactly 10 cm. If not, print again at 100% ("actual size").

Angle	Multiplier	Angle	Multiplier
5°	0.09	45°	1.00
10°	0.18	50°	1.19
15°	0.27	55°	1.43
20°	0.36	60°	1.73
25°	0.47	65°	2.14
30°	0.58	70°	2.75
35°	0.70	75°	3.73
40°	0.84	80°	5.67

Check it: look through the straw at something at your own eye height. The string should hang on 0°.

Tip: make two, so two trackers can measure every launch from different sides.

Never look at the sun through the straw.

Name _____ Date _____

W8b Safety rules

Lesson 8 · The NAR Model Rocket Safety Code and classroom rules

Words: safety code · launch controller · safety key · misfire · LCO · RSO · preflight check

Classroom rockets: glasses on · never aim at anyone · wait for "launch!" · an adult runs the fizzy demo · never chase a rocket into a road, tree or power line.
Motor rockets (12+): adults handle motors, igniters and the key · 15 ft back · count down from 5 · misfire: key out, wait 60 s · wind under 20 mph · never catch a rocket.

1. Is it safe?

Story	Safe or not safe?	Which rule?
Zoe puts on safety glasses before the stomp rocket launch.		
Max aims his straw rocket at his little sister.		
Lily drops the fizzy tablet in the canister herself and leans over it to watch.		
Sam's dad keeps the launch key in his pocket until everyone is at least 15 feet back.		
The motor rocket didn't launch, so Mia ran straight to the pad to look at it.		
It's a 25 mph wind, but the family really wants to fly today.		
The rocket landed in a tall tree, so Leo started climbing up to get it.		
Ava counts down from 5 out loud, and everyone watches the rocket.		
Uncle Jo wants a higher flight, so he tries to open the motor and add more fuel.		
Noah runs under the parachute to catch the rocket before it lands.		

2. Launch team jobs

Job	Who (adult or student?)	Name
Countdown caller		
Stomper (warm-up stomp rockets)		
Trackers (inclinometers)		
Recorder (flight log)		
Timers		
Recovery crew		
Launch Control Officer (key, button)		
Range Safety Officer (checks the rocket)		
Loads the motor and igniter		

Name _____ Date _____

W8c Launch checklists

Lesson 8 · Get ready for launch day

1. Weather check

Forecast wind: _____ mph. Under 20 mph? _____ (Under 10 mph means less drift.) Rain? _____ Burn ban or very dry grass? _____

2. Field check

Field size: _____ m by _____ m. Rocket Builder's suggested field: _____ m. Big enough? _____ If not: a smaller motor that still gets a ✓, or a club launch.

3. Preflight checklist (printed rocket, with an adult)

- ☐ Weighed, no motor: _____ g (app said _____ g)
- ☐ Fins firm, no cracks
- ☐ Shock cord (braided flat elastic) tied tightly at both ends
- ☐ Parachute not torn, lines not tangled, folded to slide in easily
- ☐ Nose fit (coin test, during assembly): _____ nickels (target _____)
- ☐ Balance point with a motor in (an adult puts it in, no igniter): CG _____ mm from the tip
- ☐ App's CP: _____ mm. CP − CG = _____ mm. Body width _____ mm
- ☐ **GO** only if CP − CG is at least one body width
- ☐ Motor taken out again by an adult
- ☐ Prediction written on the flight log

4. Launch box

- ☐ Safety glasses for everyone
- ☐ Inclinometers, tape measure, stopwatches, flight log on a clipboard
- ☐ Rocket, spare wadding, warm-up stomp rockets
- ☐ Adult only: motors, igniters, the safety key
- ☐ Pad, rod, blast deflector, controller, fresh batteries
- ☐ Bucket of water or extinguisher; water, hats, sunscreen

Name _____ Date _____

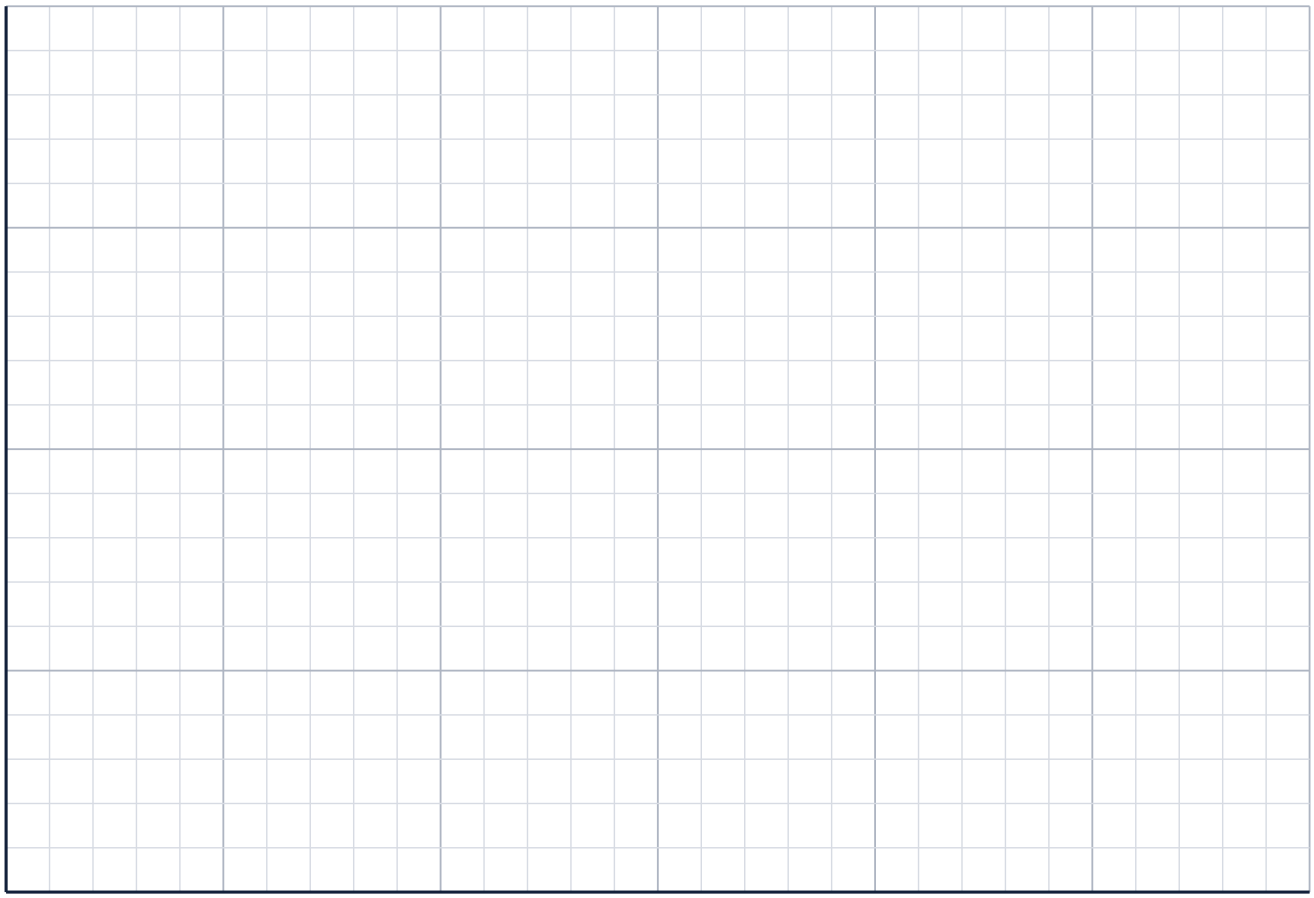
W9 Graph your data

Lesson 9 · Data and graphing

My data set: _____ (from Lesson _____, or prediction vs flight)

Graph type: bar graph / line graph / scatter plot (circle one). Remember: a title, labels on both axes, units, and evenly spaced numbers.

Title: _____



Mean of one group of trials: (_____ + _____ + _____) ÷ 3 = _____ **Range** = _____ − _____ = _____

1. As _____ went up, _____ went _____.
2. One thing that might have made my data less accurate is

3. Draw a line of best fit by eye. Is the relationship a straight line? Where does it bend?

Name _____ Date _____

F Flight log (printed rocket)

12+ only

Lesson 9 · Launch day: predict, fly, compare

	Flight 1	Flight 2	Flight 3
Rocket name			
Date and time			
Place			
Wind (mph) and direction			
Temperature			
Rocket mass, no motor (g)			
Motor (an adult loads it)			
Parachute size			
Predicted altitude (m), written before the flight			
Tracker 1: baseline (m) and angle			
Tracker 2: baseline (m) and angle			
Measured altitude (m)			
Liftoff to parachute (s)			
Parachute to landing (s)			
Landed how far from the pad?			
Did it fly straight?			
Parachute opened near the top?			
Condition after landing			
Percent difference from the prediction			

Altitude = baseline × multiplier (or × tan of the angle) + eye height. Average the trackers. Percent difference = (predicted − measured) ÷ predicted × 100.

Launch day rules: adults handle motors, igniters and the key · glasses on, at least 15 ft back · count down from 5 · misfire: key out, wait 60 s · never chase a rocket into trees, roads or power lines · never catch it.

Name _____ Date _____

C Mission report planner and rubric

Lesson 9 · Mission report

Make a poster, slides, a written report or a 3–5 minute talk. Plan each part here.

1. Mission What did you set out to do?

2. Design Your Rocket Builder rocket with the blue (CG) and red (CP) dots and its score, and why you chose it (use your Lesson 6 data).

3. The science (a) Newton's 3rd law and thrust · (b) why the balance point is in front of the push point · (c) how a parachute works.

4. Prediction vs flight Table or graph: the app's prediction and the measured altitude, with the percent difference.

5. What happened and why Reasons for any differences.

6. Next time One change, and what you predict it will do.

7. Safety Two rules your team followed and why they matter.

Rubric

	4 Excellent	3 Good	2 Getting there	1 Just starting	Score
Science	Explains Newton's 3rd law, stability and parachutes correctly, in own words, with examples	All three, small mistakes	One or two	Missing or mostly incorrect	
Design process	Several iterations with data; one change at a time; data justifies the choice	Iterations and a reason	A design, little data	No reasons	
Data and math	Flight log complete; heights correct; percent difference from the prediction	Mostly complete; small errors	Some data; calculation incomplete	Little or no data	
Explaining results	Two or more sensible reasons; a testable next step	One reason and a next step	A reason or a next step	Neither	
Communication and safety	Clear, labelled pictures and graphs; two safety rules and why	Clear, one piece missing	Hard to follow in places	Most parts missing	

Total _____ / 20. 17–20 mission accomplished · 13–16 solid flight · 9–12 needs another iteration · below 9 back to the pad.

Name _____ Date _____

Quick checks, Lessons 1–5

Answer on the line. Answers are in each lesson plan and in the answer keys.

Lesson 1

1. A rocket pushes gas down; the gas pushes the rocket up. Which law?
2. Same push, one balloon carries 10 clips. Which accelerates more, and why?
3. True or false: a rocket needs air to push against.
4. Trials 3.2 m, 3.6 m, 3.4 m. Mean?

Lesson 2

1. During the coast, which forces act on the rocket?
2. Thrust 6 N, weight 1 N, drag 0.5 N. Net force?
3. Thrust 6 N on a 1.2 N rocket: at least 5 times?
4. Steady speed under a parachute: balanced?

Lesson 3

1. Which must be in front: CG or CP?
2. Body 2 cm wide; CP 3 cm behind the CG. Score?
3. Is 0.5 cal OK to fly?
4. Name two ways to raise the score.

Lesson 4

1. Name three things that make drag bigger.
2. Twice as fast: how much more drag?
3. Why must the three test rockets weigh the same?
4. Why not put huge fins on every rocket?

Lesson 5

1. In B6-4, what do the B, the 6 and the 4 mean?
2. 5 N average for 2 s: impulse and class?
3. Rocket + motor 1.2 N, thrust 5 N: pass the 5× rule?
4. The rocket slows while coasting. Where does its kinetic energy go?

Name _____ Date _____

Quick checks, Lessons 6–9

Answer on the line. Answers are in each lesson plan and in the answer keys.

Lesson 6

1. Criterion vs constraint: what's the difference?
2. Why change one thing at a time?
3. Your design scores 0.8 cal. Two fixes?
4. Your design scores 3.6 cal. Problem?

Lesson 7

1. A parachute falls 3 m in 1.5 s. Descent rate?
2. At terminal speed, which forces are balanced?
3. Landing speed doubles from 4 to 8 m/s. Kinetic energy?
4. From 100 m at 4 m/s in a 4.5 m/s wind: drift?

Lesson 8

1. How far back for a D motor or smaller?
2. After a misfire: which two things before anyone goes to the pad?
3. Baseline 50 m, 60° (×1.73), eye 1.5 m. Height?
4. The CG is 10 mm behind the app's CP. Go or no-go?

Lesson 9

1. Order: apogee, liftoff, burnout, landing, parachute opens.
2. Trackers: 119 m and 138 m. Mean?
3. Predicted 150 m, measured 120 m. Percent difference?
4. Where is gravitational potential energy greatest?

K Answer keys (1 of 3)

Teachers

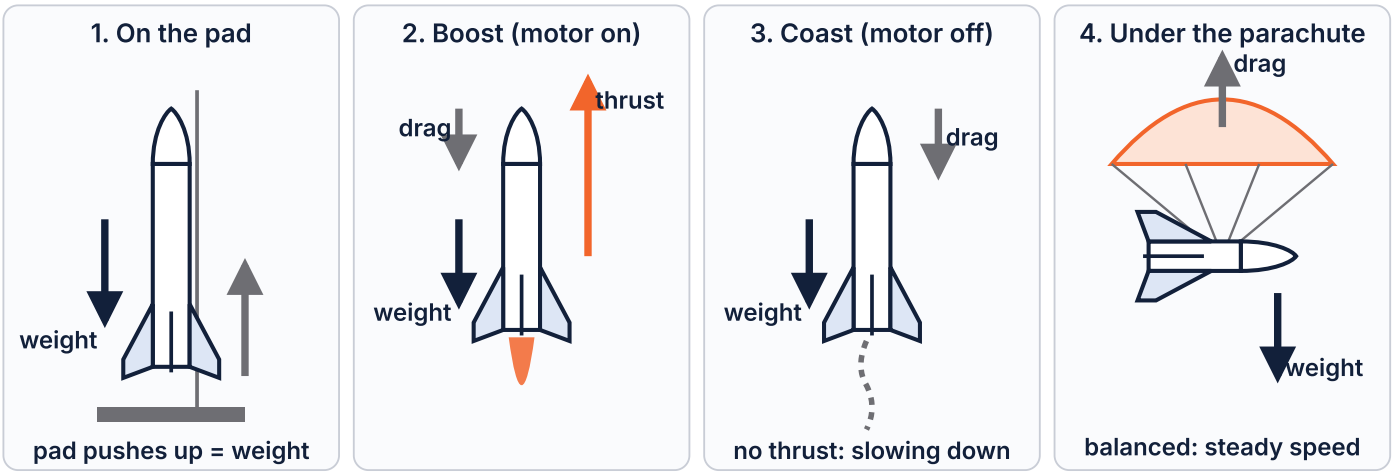
For teachers

W1 Balloon rocket

- Data varies. Expect: bigger balloons go further (more air = a longer push). More paper clips go less far (more mass, same push = less acceleration).
- Q1: the air pushes back on the balloon (action and reaction). Q2: it went less far / slower; the same force on more mass gives less acceleration. Q3: no unbalanced force until the air rushed out (law 1); friction on the string and air drag finally stopped it.
- Extension: 0.1 ÷ 0.010 = 10 m/s²; 0.1 ÷ 0.020 = 5 m/s².

W2 Forces

- 1 On the pad: weight down, the pad pushes up (equal). 2 Boost: big thrust up; weight and drag down. 3 Coast: weight and drag both down; no thrust. 4 Parachute: weight down, drag up (equal).
- Balanced: 1 and 4. Unbalanced: 2 and 3.
- Launch angle: about 40–45° usually goes furthest. Watch it launch order: liftoff 1, boost 2, coast 3, top 4, parachute 5. Power bar: the app's thrust ÷ weight; it passes at 5× or more.



W3 Swing test

- Data varies. Usually C (fins + nose clay) is most stable: its balance point is furthest in front of its push point. A often tumbles; D is often wobbly.
- Nose clay moves the balance point forward (a bigger gap); tail clay moves it back, toward or behind the push point.
- 4.5 ÷ 3 = 1.5 cal: just right.

W4 Drag test

- Data varies. The flat nose usually goes least far (most drag). Cone and round are often close; small differences may be luck: more trials, a fairer launcher.
- Fin trade-off: no fins wobble and land short; medium fins fly straight; very large fins fly straight but may lose a little distance from drag and weight.
- Extension: 0.5 × 1.2 × 1600 × 0.65 × 0.00071 ≈ 0.44 N. Lower Cd gives a higher predicted altitude.

K Answer keys (2 of 3)

Teachers

For teachers

W5 Motor codes and impulse

- Decode: A8-3 = A, 8 N, 3 s, 30 m · B6-4 = B, 6 N, 4 s, 60 m · C6-5 = C, 6 N, 5 s, 120 m · D12-5 = D, 12 N, 5 s, 150 m.
- Impulse: a 3 × 0.8 = 2.4 N·s, A · b 5 × 0.9 = 4.5 N·s, B · c 10 × 1.7 = 17 N·s, D · d 15 × 3.4 = 51 N·s, F.
- Thrust-to-weight: 0.8 N; 5 ÷ 0.8 ≈ 6.3; pass. 1.2 N; 4.7 ÷ 1.2 ≈ 3.9; does not pass (too heavy for this motor).
- Part 3: from the app's How high will it go? card. Part 5: pad = stored (propellant); boost = kinetic and potential growing (and heat); apogee = mostly potential.

W5b Thrust curve

- Peak 12 N at about 0.05 s.
- Area ≈ 0.3 + 0.54 + 0.73 + 0.45 + 2.2 + 0.1 ≈ 4.3 N·s: a B motor (2.51–5).
- Average ≈ 4.3 ÷ 0.86 ≈ 5.0 N. The code's number is rounded, and each real motor differs a little.
- Weight ≈ 0.84 N; net ≈ 3.9 N; a ≈ 3.9 ÷ 0.086 ≈ 45 m/s² (about 4½ g).

W6 Design log

- Data varies with the app version and choices. Typical trend: with the same fins, taller rockets score higher. Very short rockets show “fins grew” and a score just above 1.
- Sample (M18, standard fins, body 350 mm, about 400 mm tall): clipped delta 2.0, trapezoid 1.7, swept 1.7, delta 1.4, rectangle 0.7 cal (the app would enlarge the rectangle's fins). Swept-back fins move the push point further back.
- Choice: any design meeting the criteria, with a reason drawn from the data.

W7 Parachute drop test

- Data varies. Bigger canopies fall slower; more washers fall faster; no parachute lands in well under a second.
- Practice: 120 ÷ 4 = 30 s; 30 × 4.5 = 135 m. A 60 m field is not big enough for the drift.
- Too big a parachute: the rocket hangs in the air longer and drifts further (trees, roads, outside the field).
- Landing energy (0.08 kg): 2 m/s 0.16 J · 4 m/s 0.64 J · 8 m/s 2.56 J · 16 m/s 10.24 J (a curve: double the speed, 4× the energy). At 4 m/s: 40 g 0.32 J · 80 g 0.64 J · 160 g 1.28 J (a straight line through zero).

W8 Altitude tracking

- Practice 1: 25 × 0.84 + 1.3 = 22.3 m. Practice 2: 80 × 1.43 + 1.5 ≈ 116 m. Scale drawing: about 7 squares = 14 m (tan 35° × 20 m = 14 m).
- Errors: angle reading (string swinging), baseline measured wrong, not catching the very top, the rocket drifting toward or away from you, eye height forgotten.
- Extension: 50.0 m and 53.6 m; 186.6 m and 216.6 m. Steep angles (75°) are much more sensitive.

K Answer keys (3 of 3)

Teachers

For teachers

W8b Safety rules

- Stories: 1 safe (glasses on) · 2 not safe (never aim at anyone) · 3 not safe (an adult handles the tablets; never lean over a canister) · 4 safe (key with the adult; 15 ft back) · 5 not safe (misfire: key out, wait 60 s; adults handle motors) · 6 not safe (no launches over 20 mph) · 7 not safe (never recover from tall trees) · 8 safe (count down out loud) · 9 not safe (never open or change a motor) · 10 not safe (never catch a rocket).
- Jobs: countdown caller, stomper, trackers, recorder, timers and recovery crew = students (recovery only when the adult says so). LCO, RSO and loading motors and igniters = adults.

W8c Launch checklists

- GO only if the measured CG (motor in) is at least one body width in front of the app's CP. Nose fit: about 4–5 nickels for an M18 Starter rocket; the build notes give each size's target.

W9 Graph your data

- Check: title, both axes labelled with units, even scale, correct plotting, a sensible trend sentence. Drop-test speed goes with 1 ÷ √area, so it curves rather than falling in a straight line.

Quick checks

Lesson 1: 1. Third law. 2. No clips: same force, less mass, more acceleration. 3. False. 4. 3.4 m.

Lesson 2: 1. Weight and drag. 2. 4.5 N up. 3. Yes, just: 6 ÷ 1.2 = 5. 4. Yes.

Lesson 3: 1. The CG. 2. 1.5 cal. 3. No. 4. Bigger or swept fins, longer body, nose weight.

Lesson 4: 1. Speed, frontal area, blunt shape, roughness. 2. About 4 times. 3. Fair test: only the nose changes. 4. Drag and weight; over-stable.

Lesson 5: 1. Class B, about 6 N, 4 s delay. 2. 10 N·s, C. 3. No: about 4.2. 4. Mostly into potential energy; some into heat (drag).

Lesson 6: 1. Must do vs a limit. 2. To know which change caused the result. 3. Taller, bigger/swept fins, nose weight, lighter motor. 4. Over-stable: weathercocks.

Lesson 7: 1. 2 m/s. 2. Drag and weight. 3. 4 times bigger. 4. About 113 m.

Lesson 8: 1. 15 ft (5 m). 2. Key out; wait 60 s. 3. About 88 m. 4. No-go.

Lesson 9: 1. Liftoff, burnout, apogee, parachute, landing. 2. 128.5 m. 3. 20%. 4. At apogee.

Flight log and mission report

- Use the rubric. Check the altitude math: baseline × multiplier + eye height, averaged over trackers; percent difference = (predicted − measured) ÷ predicted × 100.