GHOST KEY / SENTINEL

TWO 45-MINUTE PERIODS

Fly first. Make sense of it.

Share the ship; complete your own calculations and explanations. You need three short maneuvers and two shots, not a calculation of the whole mission.

Name _____ Class _____ Date _____

Crew partner _____ Device / flight label _____

Your mission

Carry the SH team through the CN minefield, disable both batteries, and reach the relay with the station intact. Hold the dock at **5 m/s or less for 5 s**. The ship begins at rest with its bow pointing up. The turret aims independently through 360°. Entry-to-dock separation: 4,800 m; battery range: 3,600 m.

Period 1 / 45 minutes	Period 2 / 45 minutes
0-4: Briefing and roles	0-18: Finish braking and two axes (pp. 5-6)
4-16: Manual exploration	18-30: Analyze two shots (p. 7)
16-31: Calibrate and graph (pp. 2-3)	30-40: Predict and test one revision (p. 8)
31-45: Select evidence; finish p. 4; export	40-45: Debrief, export, and submit (p. 8)

Manual exploration / before calibration

Pilot: directional buttons; choose Half or Full. **Gunner:** aim and Fire. Swap roles halfway through the exploration time. Try a sustained burn, release to coast, thrust opposite your motion, and move sideways. Fire at least twice, with one shot while drifting if possible.

Pause freely to talk. Use Zoom, Sector, or Follow to see the map. You have six rounds, a 10 s reload, limited fuel, and at most 240 s of active flight per attempt. The first defense alert pauses the mission; read it, then resume when ready. A miss or failed mission still counts as evidence.

What happened when you released a direction? What did you try to slow down?

What surprised you about a sideways maneuver or a shot?

At minute 16: pause even if the mission is unfinished. Missing a maneuver or shot? Ask for a teacher-provided sample; label its flight. Windows need not be in time order. **Both partners write before either taps Compare.** By the end of period 1, finish p. 4, note the other window times and shot IDs, and export.

Calibrate the thrusters

Open Calibrate thrusters. Each isolated test begins at rest and runs for 10 s while your mission stays paused. Test one bank at a time.

Ship mass: **2.0×10^6 kg**. Full forces: main **8.0×10^6 N**; other banks **4.0×10^6 N**. Do one zero trial, then Half and Full for each bank. For each row: record force and signed final velocity; calculate $a = (v_f - v_i)/t$ with $v_i = 0$ and $t = 10$ s. **Both write first; then tap Compare acceleration.** Keep your first a; add any correction beside it.

Bank / direction	Power	Force magnitude ($\times 10^6$ N)	Recorded final v_f (m/s)	Your signed a before Compare (m/s^2)
Any bank / no thrust	Zero			
Main / +y	Half			
Main / +y	Full			
Braking / -y	Half			
Braking / -y	Full			
Port / -x	Half			
Port / -x	Full			
Starboard / +x	Half			
Starboard / +x	Full			

Show one acceleration calculation with units. Bank and power: _____

Compare full main thrust with full braking thrust. How should this affect the time you allow to slow down?

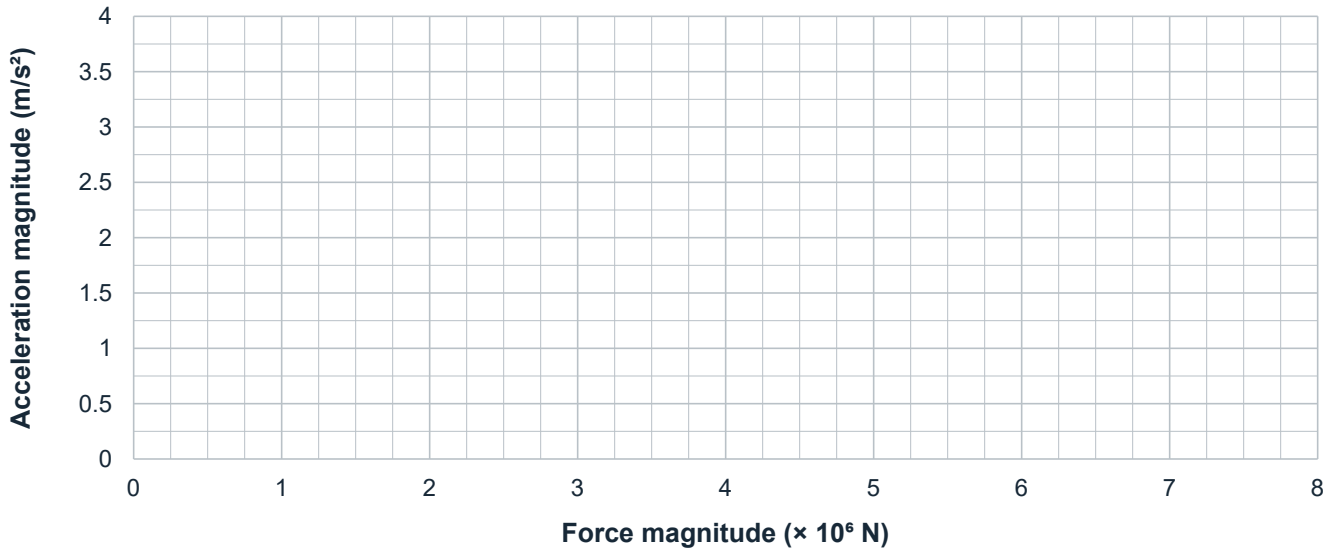
Force column: 1 means 1,000,000 N. **Keep this table.** In Top view, +x is right (starboard), -x is left (port), and +y is up. Camera changes do not change the axes.

Model: thrust changes velocity; no thrust means no acceleration in clear space. Drag and gravity are omitted, mass stays constant, and firing does not recoil the ship in this introductory mission.

Turn measurements into a model

Use the checked values from p. 2 to graph acceleration magnitude against force magnitude. Plot absolute values; keep signed directions and first calculations in your table. All banks share one graph.

Label each point: M = main, B = braking, P = port, S = starboard. Plot the zero point once. Different banks may share a point: keep all applicable labels. Draw one best-fit line.



At fixed mass, what does doubling the force do to acceleration? Support your claim with two trials.

Equation bank / choose what fits each segment

Force and motion	Displacement and position
$F_{net} = ma$	$d = v_i t + \frac{1}{2}at^2$
$a = (v_f - v_i)/t$	$d = \bar{v}t$; $\bar{v} = (v_i + v_f)/2$
$v_f = v_i + at$	$x_f = x_i + d_x$; $y_f = y_i + d_y$

Use one axis at a time. Subscripts i and f mean initial and final. x and y label components: $d_x = x_f - x_i$, not the final x coordinate. t is elapsed time, not the replay clock reading. $\bar{v}$ means average velocity. The constant-acceleration equations apply within each segment; begin a new segment whenever thrust changes.

Direction help for p. 6: use degree mode. For two nonzero final components, find reference angle $\alpha = \tan^{-1}(|v_{fy}|/|v_{fx}|)$. Use signs in **(x, y) order**: (+,+) → θ = α; (-,+) → 180° - α; (-,-) → 180° + α; (+,-) → 360° - α. On an axis: right 0°, up 90°, left 180°, down 270°. At rest, direction is undefined.

Source: NYSED, *Reference Tables for Physical Science: Physics*, 2025, pp. 1-2. Component, coordinate and angle helpers are derived notation. **Optional after core work:** graph slope = Δ|a|/Δ|F| = 1/m; convert the force scale to newtons first.

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TARGET / FINISH IN PERIOD 1

Maneuver 1 / Speed up

Choose a simple powered segment, ideally an initial burn from rest. This is a calculation explaining an observed flight, not a prediction made before it.

1 / Record. In Replay & analyze, enter a start time, tap Show this window, then Keep this window for paper analysis. Choose one or two segments. Leave comparisons hidden.

Flight _____ Clock: _____ to _____ s Elapsed t (end - start) = _____ s

Segment	Duration (s)	Bank(s) / power	a_x (m/s²)	a_y (m/s²)
1				
2, if needed				

Include coasts. Get a from calibration; use actual elapsed time. Expand Initial coordinates when needed.

Recorded givens	Horizontal / x	Vertical / y
Initial coordinate (m)		
Initial velocity v_i (m/s)		

2 / Calculate. Axis: x / y (circle). Find d, final v and final coordinate. Use signs, direction words, equations and units.

Carry final values into the next segment. Add segment displacements; final coordinate = initial coordinate + total d.

3 / Compare. Both partners finish step 2 before either taps **Compare with my work**. Keep your first values; record the comparison separately.

Selected axis	Your calculation	After Compare
Final coordinate (m)		
Final velocity (m/s)		

How did the net force change your velocity? Cite a calculated or observed value. What happened to the other velocity component?

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REQUIRED / PERIOD 2

Maneuver 2 / Slow down

Choose a braking interval. Include a short coast before it if the window is simple enough. Choose the bank that opposes the motion you want to slow; the correct direction depends on your velocity.

1 / Record. In Replay & analyze, enter a start time, tap Show this window, then Keep this window for paper analysis. Choose one or two segments. Leave comparisons hidden.

Flight _____ Clock: _____ to _____ s Elapsed t (end - start) = _____ s

Segment	Duration (s)	Bank(s) / power	a_x (m/s²)	a_y (m/s²)
1				
2, if needed				

Include coasts. Get a from calibration; use actual elapsed time. Expand Initial coordinates when needed.

Recorded givens	Horizontal / x	Vertical / y
Initial coordinate (m)		
Initial velocity v_i (m/s)		

2 / Calculate. Axis: x / y (circle). Find d, final v and final coordinate. Use signs, direction words, equations and units.

Show equations and units for each segment. Add d values; final coordinate = initial coordinate + total d.

Before Compare: open Velocity-time graph; choose x or y. Sketch shape, axes, units, zero and thrust changes. Numerical velocity ticks appear later.

3 / Compare. Both partners finish step 2 and the sketch before either taps **Compare with my work**. Keep your first values; record the comparison separately.

Selected axis	Your calculation	After Compare
Final coordinate (m)		
Final velocity (m/s)		

How is braking different from releasing the controls? Use the signs of velocity and acceleration. What happened to the other velocity component?

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REQUIRED / PERIOD 2

Maneuver 3 / Move sideways

Choose a lateral burn while the ship also moves vertically. Aim for a window ending with both velocity components nonzero. Ask for a sample if you need one.

1 / Record. In Replay & analyze, enter a start time, tap Show this window, then Keep this window for paper analysis. Choose one or two segments. Leave comparisons hidden.

Flight _____ Clock: _____ to _____ s Elapsed t (end - start) = _____ s

Segment	Duration (s)	Bank(s) / power	a_x (m/s²)	a_y (m/s²)
1				
2, if needed				

Include coasts. Get a from calibration; use actual elapsed time. Expand Initial coordinates when needed.

Recorded givens	Horizontal / x	Vertical / y
Initial velocity v_i (m/s)		

2 / Calculate. Find d and final v in BOTH axes. Show equations and units for every segment. Add segment displacements; carry final v into the next segment.

One required resultant / still before Compare: final speed = $\sqrt{(v_{fx}^2 + v_{fy}^2)}$. Find direction θ in degrees counterclockwise from +x; use the direction help on p. 3. Show work.

My resultant: _____ m/s at _____°; direction words: _____

3 / Compare. Both finish both axes AND the resultant; then tap **Compare with my work**. Keep first values.

End of window	Calculated x	Compared x	Calculated y	Compared y
Displacement d (m)				
Final v (m/s)				

Compared resultant: _____ m/s at _____°. Keep both; explain any difference.

What happened in the axis with no thrust, or with different thrust? Use your component results.

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PERIOD 2 / 12 MINUTES

Two shots / One moving launcher

Choose two actual shots, ideally one aimed at each battery. A miss is valid. Prefer at least one shot made while drifting. Use the Recorded shots cards and replay; label each flight if you use different attempts.

Relative to means measured by that observer. Copy **Round relative to ship** and **Ship relative to map · at launch** from the shot card, not the later replay display. Add x to x and y to y to find **Round relative to map**. The launch speed is 600 m/s relative to the ship; map speed can differ.

$v_{round,map,x} = v_{round,ship,x} + v_{ship,map,x}$ (and the same for y).
These are derived frame labels. For each shot, **both partners write BOTH sums** before either taps **Compare shot with my work**. Then fill the last column. Keep your first sums. No resultant or aiming calculation is required.

Shot 1

Flight _____ Shot ID _____ Fired at _____ s Intended target _____

Component	Round / ship (m/s)	Ship / map (m/s)	Your sum, with signs (m/s)	Round / map After Compare (m/s)
x				
y				

Replay result: hit / miss / unclear. Explain how the ship's motion affected this shot.

Shot 2

Flight _____ Shot ID _____ Fired at _____ s Intended target _____

Component	Round / ship (m/s)	Ship / map (m/s)	Your sum, with signs (m/s)	Round / map After Compare (m/s)
x				
y				

Replay result: hit / miss / unclear. Explain how the ship's motion affected this shot.

For a future shot, what would you change or keep: aim, ship velocity, or timing? Explain why.

Use Sector to watch a distant impact. The addition diagram shows velocities, not a predicted path. The turret aims independently. Your shots are kinetic rounds; enemy torpedoes use a different model. No laser interception is required.

Predict, test, and debrief

Make one new 10 s console trial. It branches from a selected window's initial state and preserves your original mission. Keep your first prediction, including any error.

Select an early safe window in Replay & analyze; tap **Open console revision**. Agree on one command: change power, reverse a bank, or coast. Set Burn time to **10 s**. Both partners calculate separately for that same command; choose one partner's four values to enter. Keep both first predictions on paper.

Window start _____ s Initial (x, y) = (_____, _____) m

Initial (v_x, v_y) = (_____, _____) m/s

My command: a_x = _____ m/s², a_y = _____ m/s²; duration = 10 s

Before running: calculate final position and velocity in both axes. Enter final coordinates, not displacement: $x_f = x_i + d_x$ and $y_f = y_i + d_y$.

Quantity	My first prediction / before running	Observed / after running
Final x (m)		
Final y (m)		
Final v_x (m/s)		
Final v_y (m/s)		

When both partners have written, enter one set of four predictions and select **Commit prediction & run revision**. Actual elapsed time: _____ s. Compare both papers to the result. If the trial ends early, note why and use that actual time.

Did the result support your prediction? Explain one agreement or discrepancy using force, motion, or timing.

Submit: pp. 1-8: three maneuvers, one resultant magnitude/direction, one velocity-time sketch, two shots, and your first prediction. Export flight & study record from Replay & analyze. Save where your teacher directs; device records do not synchronize.

Teacher review: _____ Date: _____ Follow-up: _____

Written-work approval is separate from winning the mission. Page 9 is an optional extension.

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OPTIONAL EXTENSION / AFTER CORE WORK

Maneuver 4 / Your choice

Analyze one additional recorded maneuver: a different power level, a diagonal burn, a course correction, or a longer coast. State what new question it helps you answer.

After core work: **1 / Record.** In Replay & analyze, enter a start time, tap Show this window, then Keep this window for paper analysis. Choose one or two segments. Leave comparisons hidden.

Flight _____ Clock: _____ to _____ s Elapsed t (end - start) = _____ s

Segment	Duration (s)	Bank(s) / power	a_x (m/s²)	a_y (m/s²)
1				
2, if needed				

Include coasts. Get a from calibration; use actual elapsed time. Expand Initial coordinates when needed.

Recorded givens	Horizontal / x	Vertical / y
Initial coordinate (m)		
Initial velocity v_i (m/s)		

2 / Calculate. Find d and final v in BOTH axes. Show equations and units for every segment. Add segment displacements; carry final v into the next segment.

3 / Compare. Both finish both axes; then tap **Compare with my work**. Keep first values.

End of window	Calculated x	Compared x	Calculated y	Compared y
Displacement d (m)				
Final v (m/s)				

What does this fourth maneuver add to your explanation of how Sentinel moves?