

Unfamiliar data and practical evaluation — solutions

Matching worked solutions and teaching prompts | 36 marks

AQA AS Physics 7407 • First-year A Level 7408

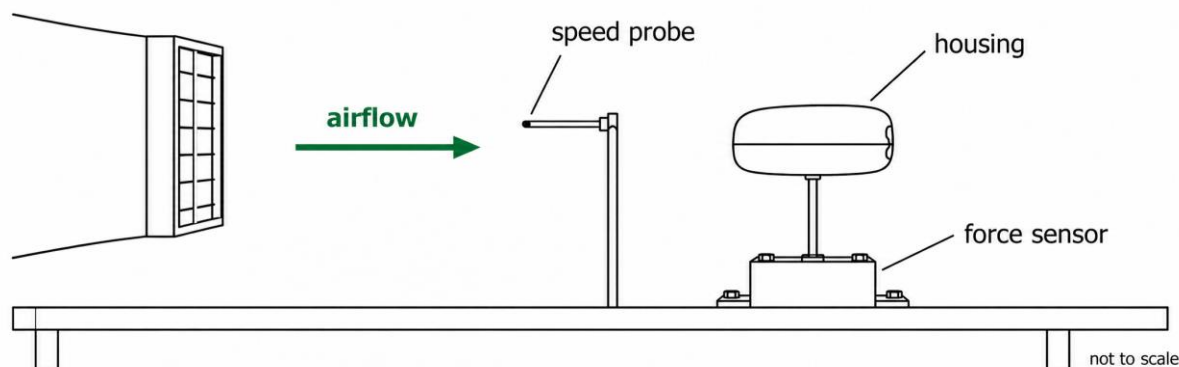
Skills practised and AQA references

AQA AS 7407 / first-year A Level 7408: 3.1.1 — units; 3.1.2 — random/systematic error, repeatability, measurement uncertainties and gradient/intercept uncertainty.

Skills: MS 1.1, 1.2 and 1.5 — significant figures, means and combined uncertainties; MS 3.1–3.4 — data, graphs, linear relationships, gradients and intercepts. Supporting context: 3.4.1.4 — drag.

Testing a housing in a wind tunnel

A team tests a protective housing for a remote environmental sensor in a wind tunnel. A force sensor measures horizontal drag and a probe measures air speed. The team must test a proposed relationship, improve the method and decide whether a redesigned housing meets a force limit.



Use $S = F + b$, where F is drag and b is a constant zero offset. Test the supplied model $F = Cv^2$, hence $S = Cv^2 + b$. Neglect mounting-rod drag. Use worst-case uncertainty rules.

1. Check the measurements [4 marks]

With the fan off, there is no horizontal drag but the force sensor consistently reads +0.040 N.

(a) Classify this zero offset as a random or systematic error. State how the team should correct a force reading before treating it as drag. [2 marks]

Systematic: the zero is displaced by a consistent amount. [1] Subtract +0.040 N from each raw reading, $F = S - b$, or tare with the fan off. [1] Repeats do not remove the offset.

(b) At one fixed air speed the repeated raw readings are 0.390 N, 0.400 N and 0.410 N. Calculate the mean and estimate its absolute uncertainty using half the range. [2 marks]

Mean $S = (0.390 + 0.400 + 0.410)/3 = 0.400$ N. [1] Half-range = $(0.410 - 0.390)/2 = 0.010$ N, so $S = (0.400 \pm 0.010)$ N. [1]

Teaching prompt: Repeatability is not accuracy. Repeats do not remove a consistent zero offset.

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2. Test the proposed drag model [8 marks]

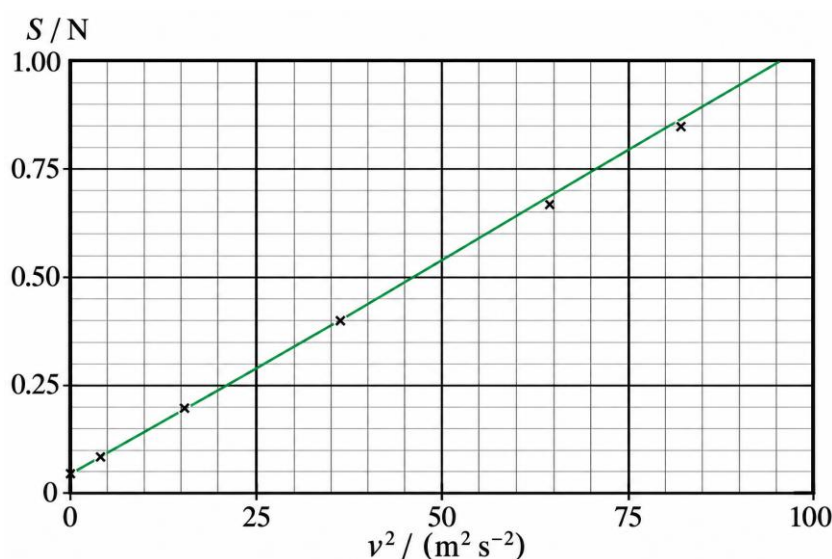
The table gives mean raw sensor readings. Do not subtract the zero offset for this graph: plot S against v^2 so that the intercept can be examined. The 8.00 m s^{-1} mean is investigated further in Question 4.

Speed $v / \text{m s}^{-1}$	$v^2 / \text{m}^2 \text{s}^{-2}$	Mean reading S / N
0.00	0	0.040
2.00	4.00	0.080
4.00	16.0	0.200
6.00	36.0	0.400
8.00	64.0	0.670
9.00	81.0	0.850

(a) Complete the two missing values of v^2 in the table. [1 mark]

For $v = 4.00 \text{ m s}^{-1}$, $v^2 = 16.0 \text{ m}^2 \text{s}^{-2}$; for $v = 8.00 \text{ m s}^{-1}$, $v^2 = 64.0 \text{ m}^2 \text{s}^{-2}$. Both correct. [1]

(b) Plot all six points of S against v^2 on the grid. Draw one straight line of best fit rather than joining successive points. [3 marks]



Plot $(0, 0.040)$, $(4, 0.080)$, $(16, 0.200)$, $(36, 0.400)$, $(64, 0.670)$ and $(81, 0.850)$, with v^2 in $\text{m}^2 \text{s}^{-2}$ and S in N . Three to five points within half a small grid division. [1] All six correctly plotted. [1] One straight best-fit line balancing the small scatter, with a positive intercept close to 0.040 N . [1] The green reference is $S \approx 0.0100v^2 + 0.040$; an experimental line need not pass through every point.

(c) Use a large triangle on your line to determine C , including its unit. Show the coordinates used. [2 marks]

For example, line coordinates $(10 \text{ m}^2 \text{s}^{-2}, 0.140 \text{ N})$ and $(80 \text{ m}^2 \text{s}^{-2}, 0.840 \text{ N})$ give $C = (0.840 - 0.140)/(80 - 10)$. [1] $C \approx 0.0100 \text{ N s}^2 \text{m}^{-2}$. [1] Accept about $0.0095\text{--}0.0105 \text{ N s}^2 \text{m}^{-2}$ from a reasonable line. Use a triangle spanning at least half the occupied horizontal range; do not force a triangle to the origin.

(d) Is the raw reading S directly proportional to v^2 ? Explain what the graph suggests about the proposed relationship $F = Cv^2$ after zero correction. [2 marks]

S is not directly proportional to v^2 because the best-fit line has a nonzero intercept: S is about 0.040 N when $v = 0$. [1] Subtracting the constant offset gives a force consistent with $F \propto v^2$ over the tested range, because the corrected line is close to a straight line through the origin. [1] This supports the model within the tested range and uncertainties; it does not prove it at every speed.

Teaching prompt: A linear graph need not show direct proportionality. For $S = Cv^2 + b$, the gradient is C and the intercept is b . A constant zero correction moves the line vertically, not sideways.

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3. Propagate the uncertainties [6 marks]

At $v = (6.00 \pm 0.10) \text{ m s}^{-1}$, use $S = (0.400 \pm 0.010) \text{ N}$ and $b = (0.040 \pm 0.005) \text{ N}$. Treat the quoted uncertainties as separate contributions and use worst-case addition.

(a) Calculate the zero-corrected drag and its absolute uncertainty. [2 marks]

$F = S - b = 0.400 - 0.040 = 0.360 \text{ N}$. [1] Absolute uncertainties add on subtraction: $\Delta F = 0.010 + 0.005 = 0.015 \text{ N}$, so $F = (0.360 \pm 0.015) \text{ N}$. [1] Do not subtract the uncertainties or combine their percentages for this subtraction.

(b) Use $C = F/v^2$ to calculate the worst-case percentage uncertainty in this single-point estimate of C . [2 marks]

Percentage force uncertainty = $0.015/0.360 \times 100 = 4.17\%$; percentage speed uncertainty = $0.10/6.00 \times 100 = 1.67\%$. [1] Keeping guard digits, percentage C uncertainty = $(0.015/0.360 + 2 \times 0.10/6.00) \times 100 = 7.50\%$. [1] The percentage speed uncertainty is doubled because v is squared; exact numerical factors add no uncertainty.

(c) A separate analysis of the full graph, including force and speed uncertainties, gives limiting gradients 0.0096 and $0.0104 \text{ N s}^2 \text{ m}^{-2}$. Use their midpoint and half their range to report C with its absolute uncertainty. Is it consistent with a reference value $0.00980 \text{ N s}^2 \text{ m}^{-2}$? [2 marks]

Midpoint = $(0.0096 + 0.0104)/2 = 0.0100$ and half-range = $(0.0104 - 0.0096)/2 = 0.0004$, so $C = (0.0100 \pm 0.0004) \text{ N s}^2 \text{ m}^{-2}$. [1] Yes: 0.00980 lies in the interval 0.0096 – $0.0104 \text{ N s}^2 \text{ m}^{-2}$. [1] Consistency within uncertainty is not proof that the central estimate equals the reference exactly. This full-graph estimate is separate from the single-point uncertainty in (b).

Teaching prompt: For a difference, add absolute uncertainties. For products, quotients and powers, add the appropriately weighted percentage uncertainties. Keep enough guard digits until the final answer.



4. Evaluate suspect data and drift [6 marks]

At $v = 8.00 \text{ m s}^{-1}$ the recorded raw readings are 0.660 N, 0.670 N, 0.680 N and 0.940 N. The log states that the stand was knocked during the fourth run.

(a) Decide whether there is evidence to exclude a reading. Justify your decision and calculate a suitable mean for this speed. [2 marks]

Exclude the fourth reading, 0.940 N, because there is a recorded disturbance to the apparatus during that run, as well as a clear discrepancy from the other readings. [1] Mean of the undisturbed readings = $(0.660 + 0.670 + 0.680)/3 = 0.670 \text{ N}$. [1] Document the reason and repeat the affected run where possible; do not silently delete data.

(b) The mean 0.670 N is slightly below the fitted model prediction, about 0.680 N. Does this difference alone justify deleting the mean from the graph? Explain. [1 mark]

No. A small difference from an expected model can arise from measurement variation and must be judged against uncertainty; disagreement with a prediction alone is not evidence of an experimental fault. [1] Keeping only data that agree with the model would bias the test.

(c) The sensor zero slowly increases as it warms. All speeds are tested in increasing order. Explain how this could bias C and give one specific way to reduce or correct the effect. [2 marks]

The later, higher-speed readings acquire a larger positive offset, which can make the $S-v^2$ graph too steep and overestimate C. [1] Allow the sensor to stabilise and check the fan-off zero before/after each speed, applying the appropriate zero correction. [1] Accept monitoring zero during the sequence and correcting drift. Randomising or reversing the order is a useful diagnostic, but alone does not calibrate away a changing zero.

(d) A technician uses the fitted relationship to certify performance at 12.0 m s^{-1} without further measurements. Explain why the current evidence is insufficient. [1 mark]

12.0 m s^{-1} is beyond the largest measured speed, 9.00 m s^{-1} : the extrapolation assumes that the same relationship and C still apply. Further measurements near the intended operating speed are required. [1] The flow around the housing or its alignment may change; a good fit below 9 m s^{-1} does not validate the higher-speed claim.

Teaching prompt: An anomaly needs an evidence-based judgement, not deletion to make a graph straighter. Zero drift correlated with the independent variable can alter the apparent gradient, unlike one constant offset.



5. Judge a redesigned housing [5 marks]

Use $C_A = 0.0100 \text{ N s}^2 \text{ m}^{-2}$ for the original housing. For redesigned housing B, $C_B = (0.0072 \pm 0.0004) \text{ N s}^2 \text{ m}^{-2}$. Both coefficients refer to otherwise comparable tests. Treat $v = 8.00 \text{ m s}^{-1}$ as exact for this comparison; the stated coefficient uncertainty already includes the measurement contributions.

(a) Calculate the central drag estimates for A and B at this speed. Determine the percentage reduction in drag relative to A. [3 marks]

$F_A = C_A v^2 = 0.0100 \times (8.00)^2 = 0.640 \text{ N}$. [1] $F_B = 0.0072 \times 64.0 = 0.4608 \text{ N} \approx 0.461 \text{ N}$. [1] Reduction = $(0.640 - 0.4608)/0.640 \times 100 = 28.0\%$. [1] Use the original drag, not the redesigned drag, as the denominator.

(b) The design is accepted only if the highest drag allowed by the quoted uncertainty is no greater than 0.480 N . Calculate the upper drag estimate for B and decide whether acceptance can be confirmed. [2 marks]

Upper coefficient = $0.0072 + 0.0004 = 0.0076 \text{ N s}^2 \text{ m}^{-2}$; upper drag = $0.0076 \times 64.0 = 0.4864 \text{ N} \approx 0.486 \text{ N}$. [1] Acceptance cannot be confirmed: this exceeds 0.480 N , although the central estimate is below the limit. [1] This is not proof that B fails in every run; a smaller uncertainty or a lower-drag design is needed to demonstrate this criterion.

Teaching prompt: Distinguish the central estimate from an uncertainty bound. "Cannot confirm compliance" is more precise than claiming the actual force must exceed the limit.



6. Plan a stronger investigation [7 marks]

Parts (a)–(c) scaffold a six-mark-style method. The adjustable fan, force sensor, speed probe and a calibrated force gauge are available. Explain how to obtain trustworthy evidence for the proposed drag relationship, not just how to collect more numbers.

(a) Describe the zero and calibration checks you would make on the horizontal force sensor. [2 marks]

With the complete housing/rod fitted and the fan off, measure or tare the horizontal-force zero and check it again during/after the run. [1] Use the calibrated force gauge to apply several known horizontal forces in the measurement direction across the intended range; compare readings and correct any scale error, not only the zero. [1] A zero check alone does not establish a correct gradient of sensor reading against true force.

(b) Describe the measurements, repeats and controlled conditions needed when changing air speed. [2 marks]

Measure the actual air speed with the same upstream probe at a fixed suitable position, wait for stable readings and obtain repeated force/speed measurements at several well-spaced speeds covering the intended operating range. [1] Keep the same housing orientation, mounting geometry and probe position; monitor temperature/zero drift and use reversed/randomised speed order as a check. [1] A fan control setting is not itself a measurement of air speed.

(c) Describe the graph and uncertainty analysis, and how you would use the evidence to make a design decision. [2 marks]

Plot mean raw S against v^2 ; test a straight-line fit with a freely determined intercept b and obtain C from a large gradient triangle. Alternatively plot zero-corrected F against v^2 and test a line through the origin within uncertainty. [1] Include measurement uncertainties/error bars and acceptable limiting gradients to bound C , then compare the resulting force range with the design limit only over the tested speeds. [1] Investigate discrepancies and record reasons for exclusions rather than forcing the expected model.

(d) State one specific precaution when adjusting the fan or changing a housing. [1 mark]

Switch off the fan before adjusting the probe/housing, and keep the fan guard in place to prevent contact with the moving blades. [1] Accept securing the housing and stand so that airflow cannot dislodge them, or another specific relevant precaution.

Teaching prompt: Calibration, repeats and uncertainty address different weaknesses. Link each improvement to the error or limitation it is intended to reduce.

