

FUNDAMENTALS OF AI-AUGMENTED ENGINEERING

CHAPTER 6 / LAB-6: Engineering Lab (3 Hours)

Recover the Missing Data

Smartphone vibration measurements · linear interpolation · validation · decay

Predict what was withheld — then let the experiment reveal what was actually there.

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Authors

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Problem

›

Model

›

Compute

›

Analyze

›

Validate

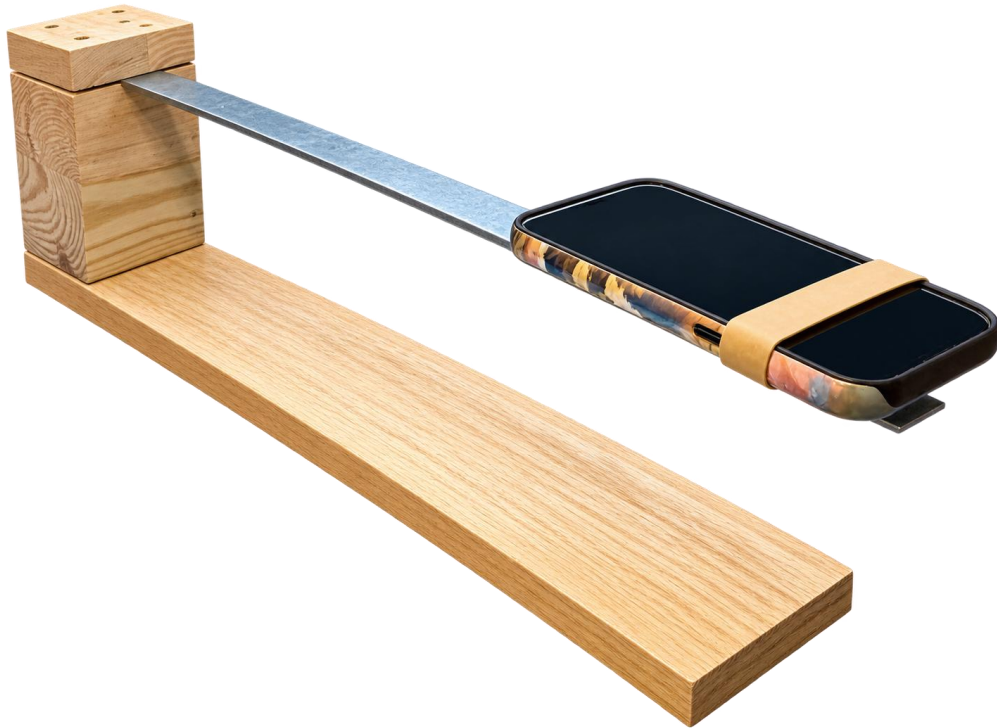
›

Improve

The engineering workflow you will use throughout this book



Recover the Missing Data — what is this lab about?



A vibrating beam becomes a data-acquisition experiment.

- Use your own phone as an accelerometer and collect a 20-second vibration record with phyphox.
- Export the measurements to Excel — your experimental data become the evidence.
- Program 1 withholds selected measurements near a vibration peak and near a zero crossing. You interpolate first; the program reveals the withheld measurements only after you commit.
- Program 2 repeats the idea on the vibration-decay envelope, then fits an exponential decay model.
- Your job is not to make the data look perfect. Your job is to predict, reveal, compare, and explain.

MEASURE › ACQUIRE › INSPECT › INTERPOLATE › COMMIT › REVEAL › VALIDATE

Problem

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Learning objectives & tools

BY THE END OF THIS LAB, YOU CAN

- Acquire experimental acceleration data with a smartphone sensor
- Recognize sampling rate, oscillation, peaks, and zero crossings in a measured record
- Apply straight-line interpolation between measured points
- Validate an interpolation against withheld experimental measurements
- Explain why interpolation error depends on local curvature and data spacing
- Recognize a decaying vibration envelope and interpret a decay constant λ and an estimated damping ratio ζ

TOOLS YOU WILL USE

- Cantilever beam from Lab 5
- Your smartphone + rubber bands
- phyphox — "Acceleration (without g)"
- Excel (.xlsx export)
- Python with pandas, numpy, matplotlib, openpyxl
- Program 1 —
Lab6_Vibration_Signal_Interpolation.py
- Program 2 —
Lab6_Vibration_Decay_Analysis.py
- Your engineering judgment

THE PHONE MEASURES. THE PROGRAM HIDES. YOU PREDICT. THE EXPERIMENT REVEALS.

Problem



Model



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Analyze



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What you will do — step by step

- 1 BEFORE LAB** — install phyphox · verify Python + packages · test both programs with the instructor sample data (phyphox-accel-20s.xlsx)
- 2 SET UP** — secure the phone face-up to the cantilever beam near the free end
- 3 ACQUIRE** — phyphox "Acceleration (without g)" — timed run: 3 s start delay + 20 s recording
- 4 EXPORT** — save the phyphox data as Excel (.xlsx) — the file stays unchanged
- 5 PROGRAM 1** — interpolate withheld measurements near a vibration PEAK and near a ZERO CROSSING — commit before reveal
- 6 REVEAL + VALIDATE** — compare your predictions with the withheld experimental measurements — explain the difference
- 7 PROGRAM 2** — interpolate withheld peak-envelope measurements near 2 s and near 15 s — commit before reveal
- 8 DECAY** — fit $A(t) = A_0 e^{(-\lambda t)}$ · interpret λ and the estimated damping ratio ζ
- 9 REPORT** — YOUR data, figures, comparisons, and engineering interpretation
- 10 SUBMIT** — the report + your team's original phyphox Excel file



Beam + phone + rubber bands — the whole apparatus.

Would you trust a number a program printed for a moment nobody measured? Today you will decide that — after the experiment has had its say.

Problem

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Prepare your phone and computer before you arrive

1 · INSTALL PHYPHOX

Install the free phyphox app on the phone you will use in lab.

phyphox.org/download/
iPhone / iPad: App Store · Android: Google Play

Open the app and confirm that "Acceleration (without g)" runs and shows live sensor data.

2 · PREPARE PYTHON

Place both Lab 6 Python programs in one working folder.

In Terminal / Command Prompt:
`pip install pandas numpy matplotlib openpyxl`

These packages let Python read the Excel export, process the measurements, and draw the graphs.

3 · TEST BEFORE LAB

Download the instructor sample file `phyphox-accel-20s.xlsx` and put it in the SAME folder as the programs.

Run Program 1 and Program 2 all the way through once.

If something fails, fix it BEFORE lab — do not spend experiment time installing software.

SAMPLE DATA ARE FOR READINESS ONLY. YOUR LAB REPORT MUST USE YOUR TEAM'S OWN EXPERIMENTAL DATA.

Problem



Model



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Instructor sample data — practice, not your experiment

BEFORE LAB — USE IT

The file phyphox-accel-20s.xlsx is a 20-second pilot run recorded by the instructor on his own phone. It is provided so you can:

- verify that both Python programs run on your computer
- practise the ENTER → COMMIT → REVEAL workflow
- see what a successful 20-second record looks like
- solve installation or file-path problems before lab

You may use it for the Lab Extension when the extension specifically asks for it.

LAB REPORT — DO NOT SUBSTITUTE IT

No part of the main Lab 6 analysis or report may be based on the sample data.

Your figures, interpolation results, decay constant and interpretations must come from your team's own .xlsx file.

Submit that original Excel export together with the report — the file is the evidence that the analysis is connected to your experiment.

PRACTISE WITH OUR DATA. LEARN FROM YOUR DATA. SUBMIT YOUR DATA.

Problem



Model



Compute



Analyze



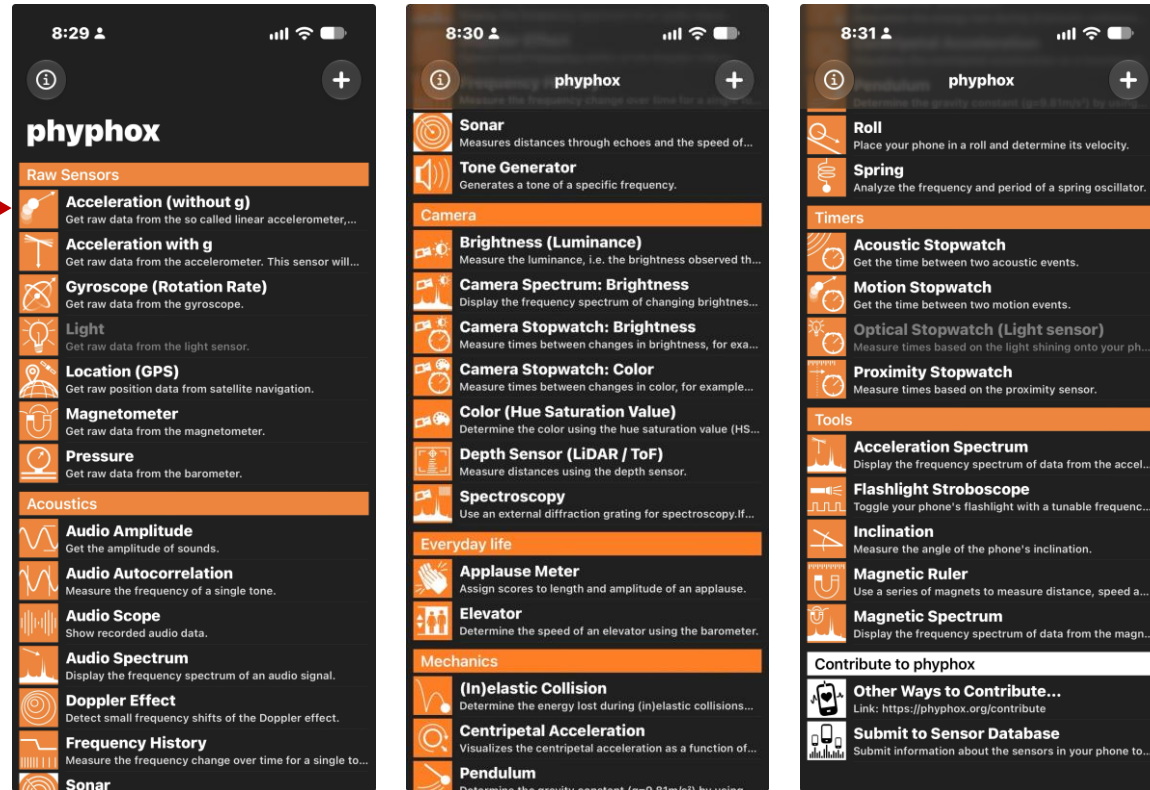
Validate



Improve



phyphox — what it is, and how Lab 6 uses it



experiment list · Acceleration (without g) · experiment menu

PHYPHOX

- A free physics app (RWTH Aachen University) that reads the sensors already built into your phone.
- We use "Acceleration (without g)": the phone's acceleration along its own x, y, z axes in m/s^2 , with gravity removed — so a phone at rest reads about zero.
- The phone records many measurements per second and time-stamps every one — that dense, evenly spaced record is what makes a missing-data question meaningful.
- The experiment menu exports the whole record as an Excel file. That file is your primary experimental record.

CHECKPOINT — the live x, y, z graphs must respond when you move the phone before you start any timed run.

Problem

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Compute

Analyze

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Measure first — then interpolate, commit, reveal

0:00–0:10		Phase 0 · Readiness — verify phyphox, Python, both programs Individual readiness check · sample data ran end-to-end at home.
0:10–0:25		Phase 1 · SET UP — beam, phone, safety Phone face-up near the free end, secured with rubber bands · hands clear.
0:25–0:40		Phase 2 · ACQUIRE — the 20-second run Timed run: 3 s delay + 20 s · inspect the live graphs · repeat if the run is not clean.
0:40–0:50		Phase 2 · EXPORT + INSPECT Export to Excel · verify the "Raw Data" sheet and its columns · note the sampling rate.
0:50–1:35		Phase 3 · PROGRAM 1 — peak + zero-crossing interpolation Inspect the full record · read the two challenge tables · calculate · COMMIT.
1:35–1:50		Phase 3 · REVEAL + VALIDATE Compare prediction with the withheld measurements · explain the difference.
1:50–2:30		Phase 4 · PROGRAM 2 — decay-envelope interpolation Envelope · peak record · early (≈ 2 s) and late (≈ 15 s) challenges · COMMIT · REVEAL.
2:30–2:45		Phase 4 · DECAY — exponential fit, λ, estimated ζ Read the fitted model on your record · interpret λ · report ζ as an estimate.
2:45–3:00		Phase 5 · ANALYZE + close-out Figures saved · record complete · submission check · the report follows.

Problem



Model



Compute



Analyze



Validate



Improve



One beam · one phone · one clean release



Phone secured with rubber bands near the free end — the setup used for every run.

PHYSICAL SETUP

- Use the cantilever beam from Lab 5.
- Place the phone face-up near the free end.
- Secure it firmly with rubber bands — no sliding, no rotating.
- The phone must move **WITH** the beam.
- Keep hands and faces clear of the moving beam as it vibrates and do not shake the table.

WHY THIS WORKS

The phone's accelerometer samples the motion many times each second.

When the beam is displaced and released, the Z-direction acceleration oscillates — and the oscillation gradually shrinks because the real system dissipates energy.

Today that real, imperfect signal is the subject: interpolation on measured data, not on a textbook curve.

DO NOT DROP, STRIKE, OR OVER-BEND THE BEAM. Secure the phone before every run. Nobody touches the table, beam, or phone during a recording.

Problem

**Model**

Compute



Analyze



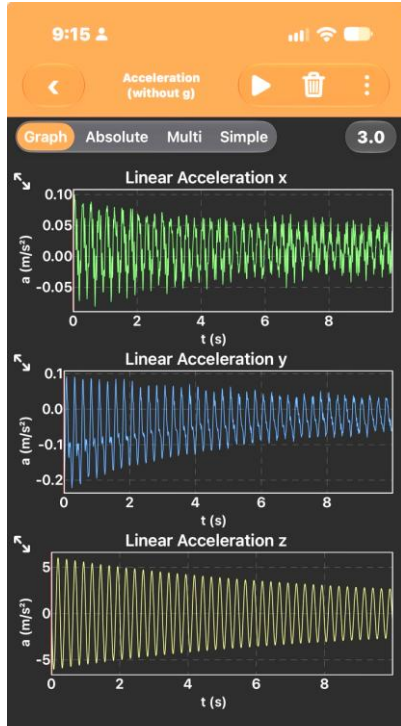
Validate



Improve



phyphox — choose the experiment and check the axes



ON YOUR PHONE

- 1 Open phyphox.
- 2 Select "Acceleration (without g)".
- 3 Confirm that the X, Y and Z acceleration graphs respond when the phone moves.
- 4 In the beam setup, the Z direction should show the clearest vibration response.
- 5 Do not worry if your amplitudes differ from the instructor sample — your phone, attachment, release and beam are experimental variables.

CHECKPOINT — the live graphs respond before you start the timed run.

Problem



Model

**Compute**

Analyze



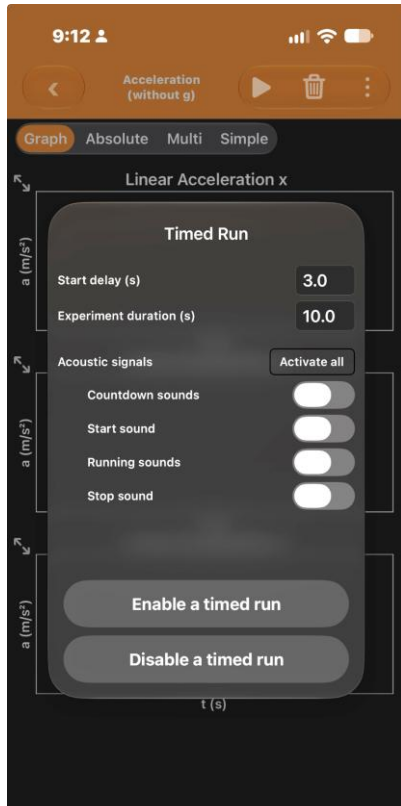
Validate



Improve



Set the timed run: 3 s delay · 20 s duration



TIMED RUN

Set:

- Start delay = 3.0 s
- Experiment duration = 20.0 s

The delay gives you time to displace the beam; the 20 s window captures the whole decay.

THEN

- Press and hold the PLAY button on the phyphox display, gently displacing the beam tip approximately 10–15 mm. Then lift your finger quickly in vertical direction. **This single action simultaneously** releases the beam to vibrate and triggers the 3-second phyphox start-delay countdown. The initial transient occurs during the countdown; 20 s data acquisition begins automatically after the 3-second delay.
- Start the timed run. Keep hands and faces clear of the moving beam as it vibrates.
- Do not touch the table, beam, or phone and do not shake the table or the setup during the measurement for 20 seconds of data acquisition or recording.

A clean run shows a strong oscillation that gradually decays. If the record is clipped, cut short, or disturbed, decide as a team to repeat — and note the reason.

Problem



Model



Compute



Analyze



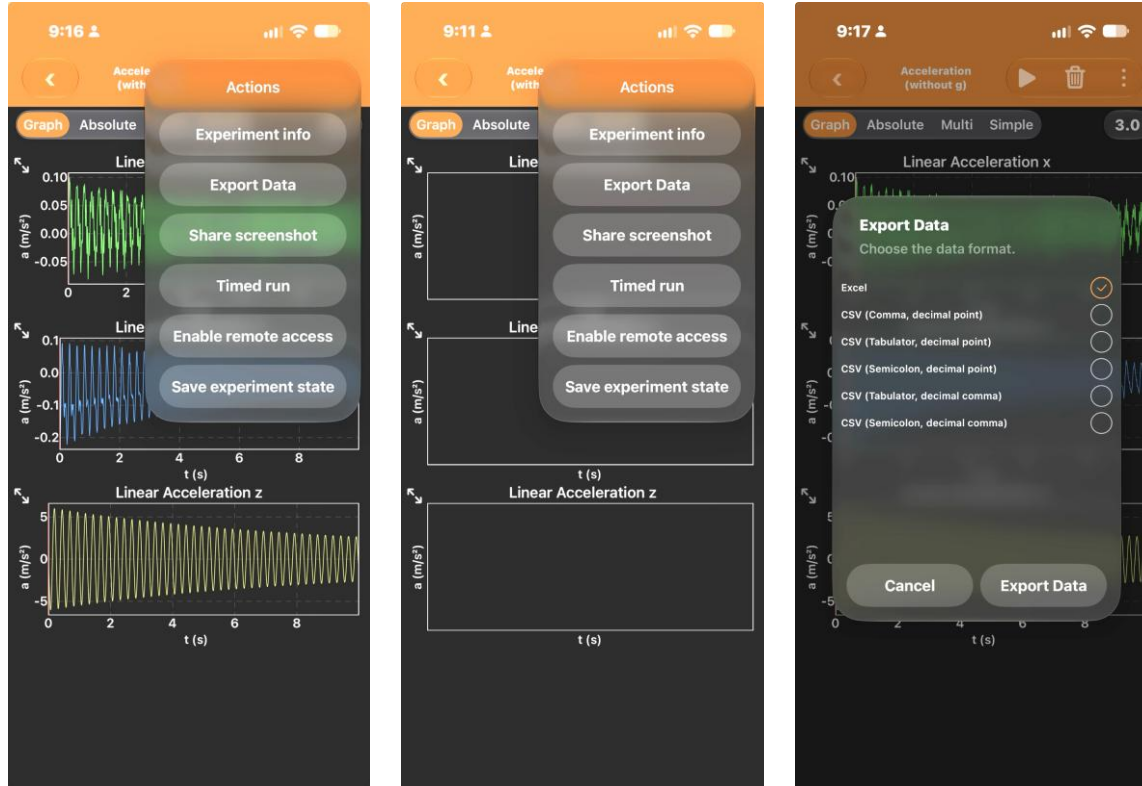
Validate



Improve



Save your experimental record as Excel



experiment menu → Export Data → Excel

EXPORT

Review the data visually. You should see a clean decaying sinusoidal acceleration in z direction as shown on the first image here. If you approve then export the data as follows:

Experiment menu → Export Data → Excel.

Save the .xlsx file and move it to the SAME folder as the two Lab 6 Python programs.

Give it a name you will recognize and record that filename in your report.

Keep the original file unchanged: no edits, no deleted rows, no "cleaning".

THIS .XLSX FILE IS PART OF YOUR LAB SUBMISSION — IT IS YOUR PRIMARY EXPERIMENTAL RECORD.

Problem



Model



Compute



Analyze



Validate



Improve



Know what is inside the exported file

THE "RAW DATA" SHEET

Both programs read the phyphox "Raw Data" sheet with these columns:

Time (s)

Linear Acceleration x (m/s^2)

Linear Acceleration y (m/s^2)

Linear Acceleration z (m/s^2)

Absolute acceleration (m/s^2)

Review the excel file and confirm the data is there.

Do not rename these columns or the sheet before running the supplied programs.

SAMPLING — WHAT YOU SHOULD NOTICE

A 20-second run typically contains on the order of two thousand rows: the phone is sampling roughly 100 times per second. Yours may differ — count your rows and write down YOUR sampling rate.

The dense, evenly spaced record is exactly why we can withhold a few measurements and ask a meaningful interpolation question.

The missing values in the programs are withheld from YOUR measured record — they are not invented.



TALK TO YOUR AI TEAMMATE "Here is my phyphox export — how many rows, what time step, which column is Z? Do not modify the file."



ENGINEER DECIDES the sampling rate you report is the one in YOUR file.

Problem



Model



Compute



Analyze



Validate

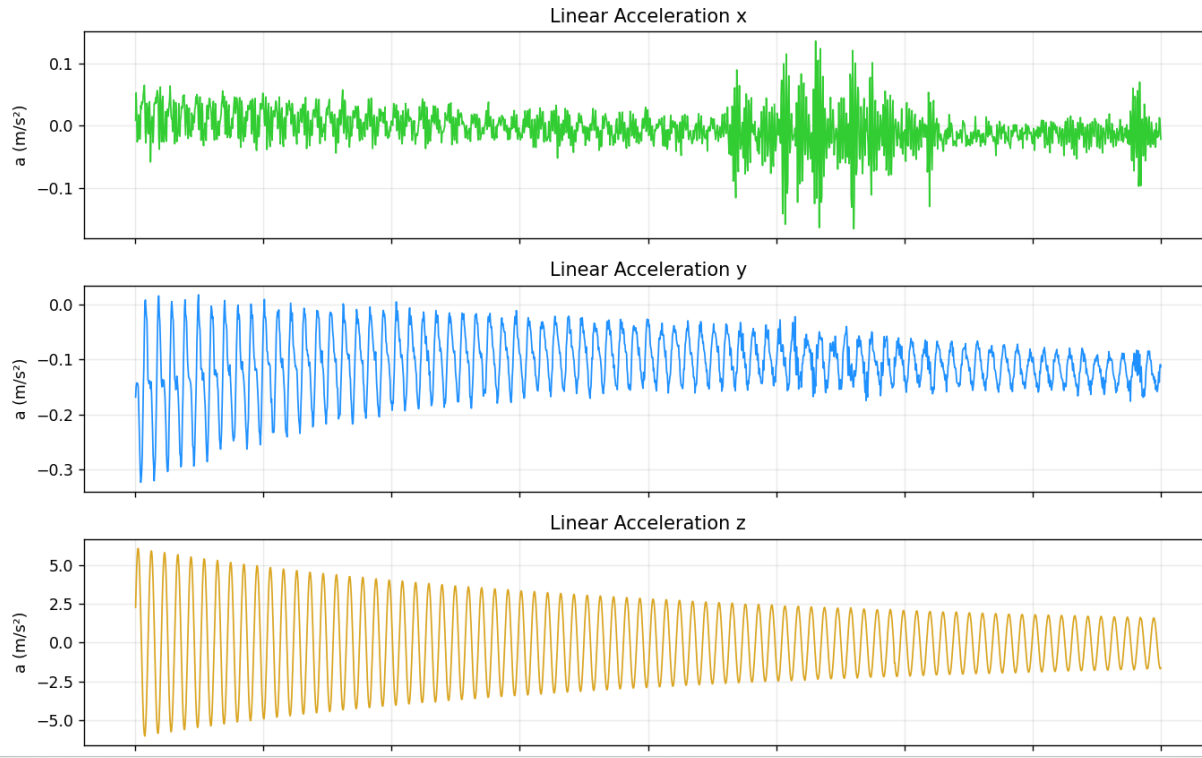


Improve



Program 1 — first inspect the complete record

Raw Experimental Acceleration Data



RUN PROGRAM 1

Lab6_Vibration_Signal_Interpolation.py

Enter the exact name of your phyphox Excel file when the program asks.

Figure 1 displays the complete X, Y and Z acceleration measurements. Compare it with the graphs on your phone, then press ENTER to confirm.

The program then selects a short Z-acceleration window near the middle of your recording and withholds measurements in two different local situations:

- near a vibration PEAK
- near a ZERO CROSSING

Do not skip ahead. The program is designed so you must commit before the withheld measurements are revealed.

Problem



Model



Compute



Analyze



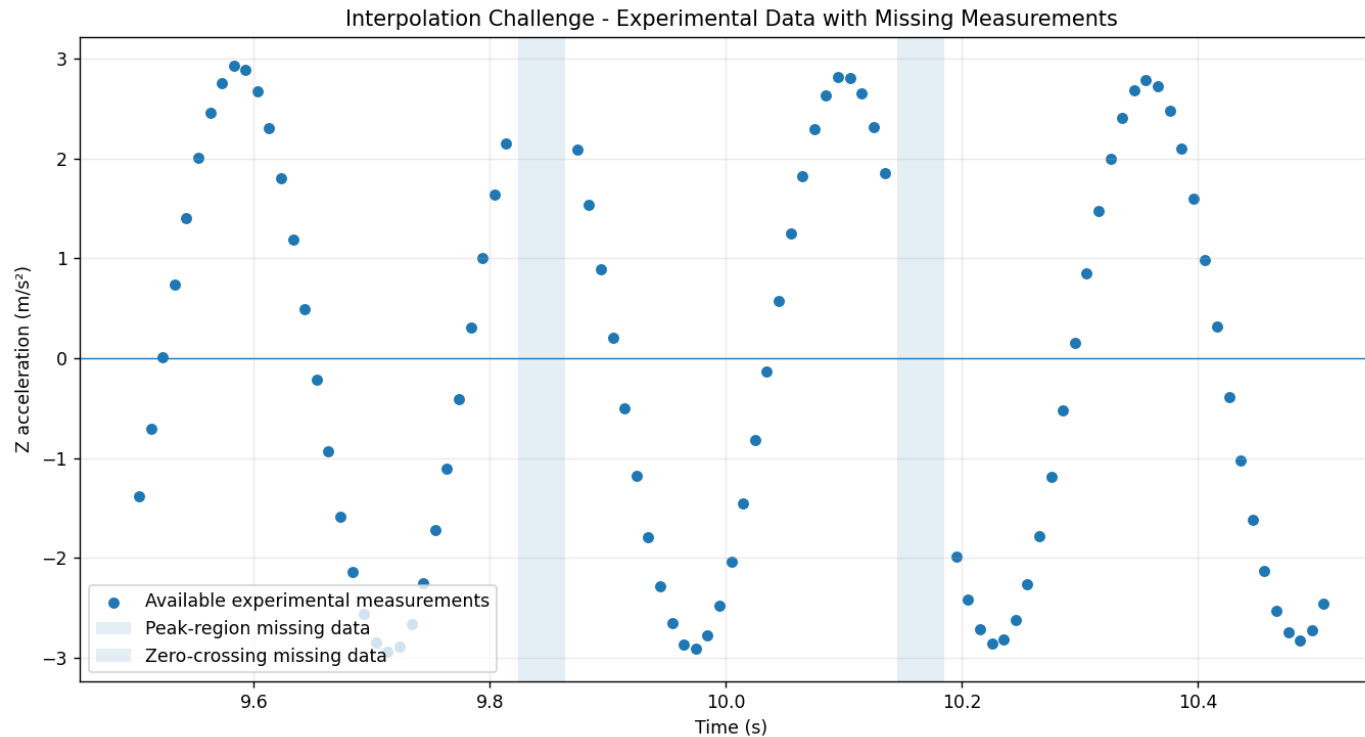
Validate



Improve



Two gaps — same rule, different local behaviour



YOUR TASK

The shaded bands mark the withheld measurements. The program prints a table for each challenge: the two available bounding measurements, and the five withheld times marked MISSING.

For each missing time, use straight-line (linear) interpolation between the two bounding measurements. Write the relation, substitute the numbers, calculate — then enter the prediction when the program asks.

Think before reveal: where is the signal nearly straight? Where is it strongly curved? Should the interpolation perform equally well in both places?

A PREDICTION MADE AFTER REVEAL IS NOT A PREDICTION. The challenge graph stays open while you calculate. Do not close it — and do not look for the withheld values anywhere else.

Problem



Model

**Compute**

Analyze



Validate



Improve



Straight-line interpolation — the calculation you own

For two measured points (t_1, a_1) and (t_2, a_2), the straight-line estimate at a time t between them is

$$a(t) = a_1 + (a_2 - a_1) \frac{(t - t_1)}{(t_2 - t_1)}$$

a is the Z acceleration in m/s^2 ; t in s. Same equation as Chapter 6 — different data, same assumption.

DO NOT TURN THIS INTO BUTTON-PUSHING

Record the two bounding measurements, substitute the numbers, calculate each missing value, and keep units with the quantities. Every calculation goes in the report — it is your evidence that the prediction was yours.

ENGINEERING QUESTION

Linear interpolation assumes the signal between the two bounding points behaves approximately like a straight line. Is that assumption equally good everywhere on an oscillating curve — at a peak and at a zero crossing?



TALK TO YOUR AI TEAMMATE "Check my substitution — do not compute the values for me."



ENGINEER DECIDES the number you type in is yours; the program only records it.

Problem



Model



Compute



Analyze



Validate



Improve



Enter your predictions — then the reveal

1

ENTER — one prediction per missing time

The program asks "Prediction at t = ... s:" for each withheld time, Challenge A first, then Challenge B. Type the number in m/s^2 . The experimental values stay hidden.

2

COMMIT — "Predictions recorded."

Press ENTER to REVEAL. From this moment your ten numbers are fixed; they are copied into the report exactly as typed — even the ones that turn out far from the measurement.

3

REVEAL — the validation tables

For each challenge: time · prediction · measured · absolute error · % difference, and the mean absolute error for the gap. Two validation figures are saved in your folder.

4

VALIDATE — compare, then explain

Peak versus zero crossing: which prediction was closer, by how much, and why? Curvature, spacing, amplitude, noise — in that order of suspicion.

SAVED FIGURES

Lab6_Peak_Interpolation_Validation.png

Lab6_Zero_Crossing_Validation.png

Both are report-ready. Keep them with your Excel file; both go into the report.

Reading % difference: near a zero crossing the measured value is close to 0, so a small absolute error can be a huge percentage. Report absolute error in m/s^2 there, and say why.



ENGINEER DECIDES the numbers you commit are yours — the program logs them, you own them.

Problem



Model



Compute



Analyze



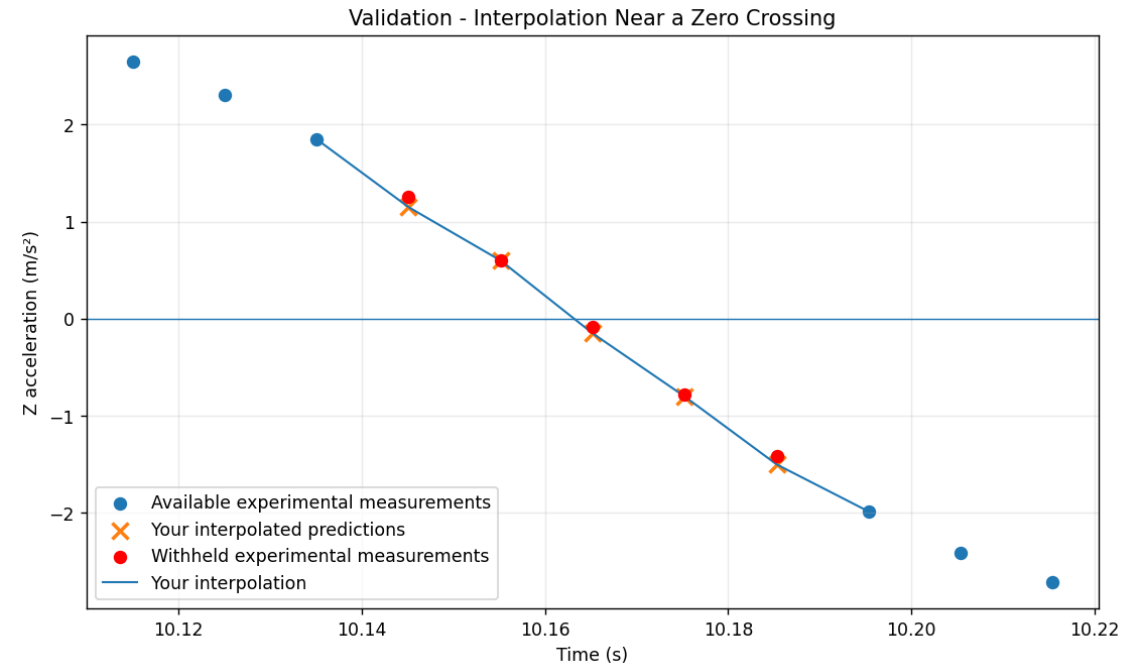
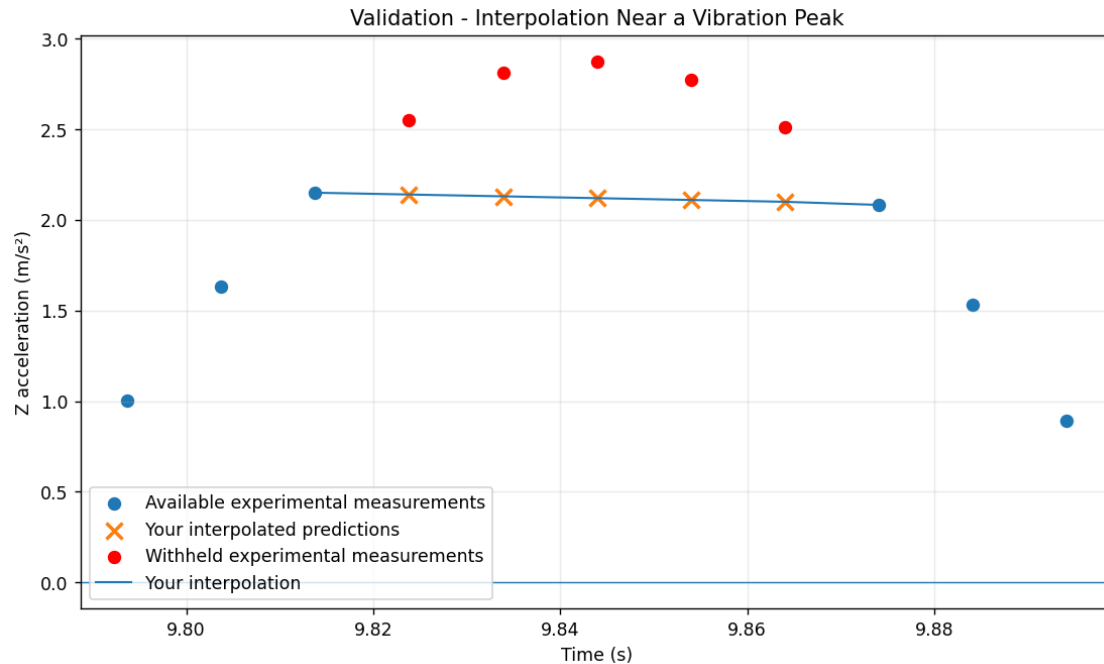
Validate



Improve



The experiment gets the last word



Instructor pilot record — a deliberately naive straight line across the peak (left) and the same rule at the zero crossing (right). Your figures will differ.

BLUE = AVAILABLE MEASUREMENTS · ORANGE X = YOUR PREDICTION · RED = WITHHELD EXPERIMENTAL MEASUREMENT

Compare the peak and zero-crossing results. Explain the difference using local curvature, measurement spacing, and the straight-line assumption — not by adjusting anything.

Problem



Model



Compute



Analyze



Validate



Improve



From oscillation to decay envelope

RUN PROGRAM 2

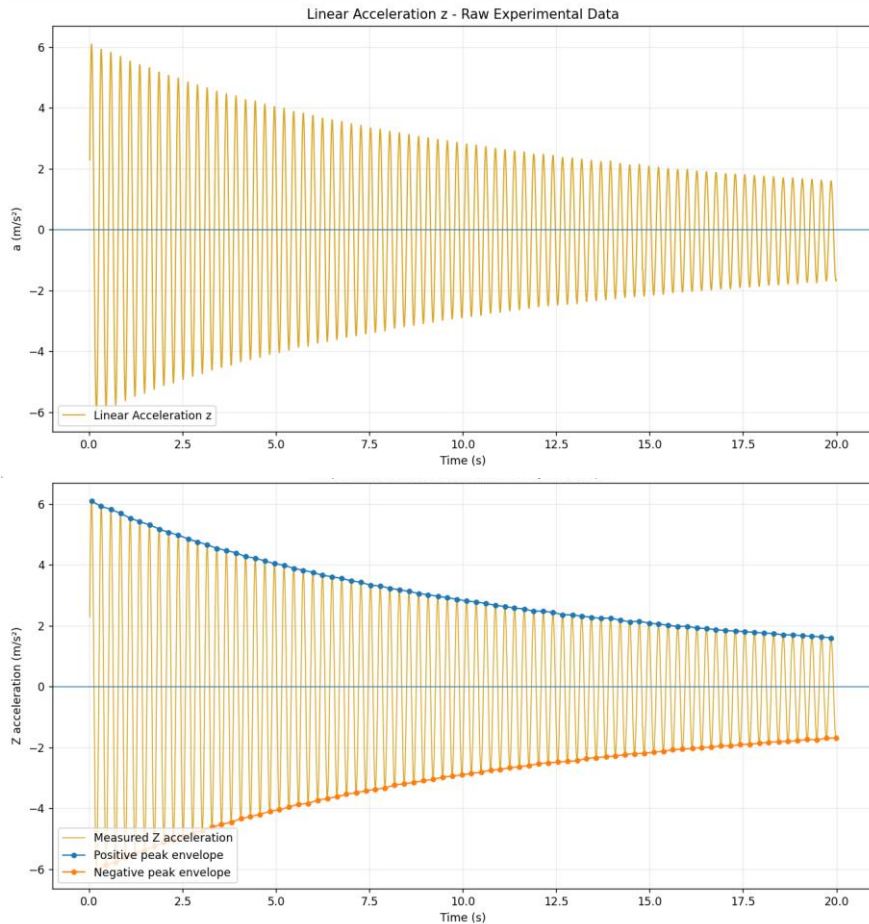
Lab6_Vibration_Decay_Analysis.py

Program 2 uses the same experimental Excel file.

First, inspect the Z acceleration alone (Figure 1) and confirm it matches your phone.

Then the program identifies the positive and negative peaks of every cycle and draws the two peak envelopes (Figure 2). The vibration stays oscillatory, but its amplitude shrinks with time.

WHAT CHANGES: instead of the signal itself, the program now works with the absolute peak amplitudes $|\text{peak}|$. Positive and negative peaks together give one $|\text{peak}|$ value every half cycle — a simple, decaying record.



Problem



Model



Compute



Analyze



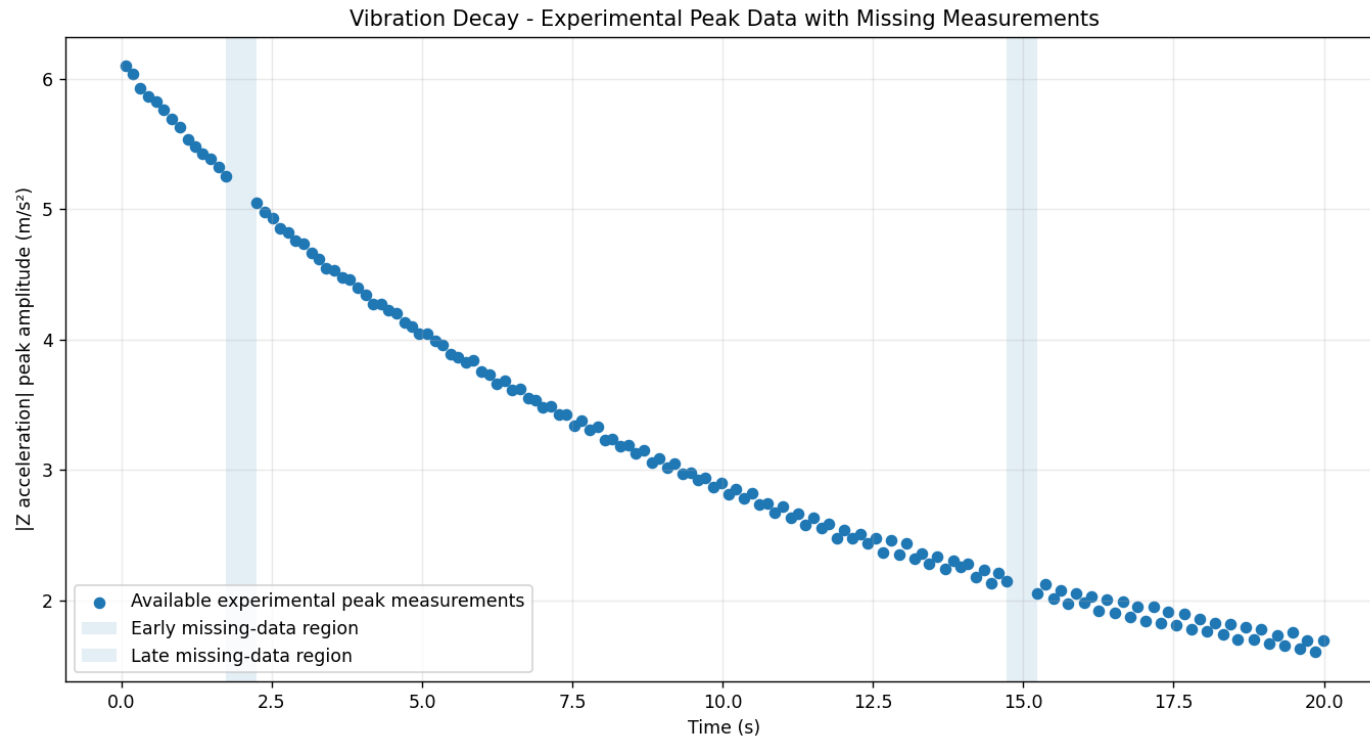
Validate



Improve



Interpolate early and late on the decay record



TWO MISSING-DATA REGIONS

The program withholds three consecutive |peak| measurements in each of two regions:

- near 2 s — early, large amplitude
- near 15 s — late, small amplitude

Each region prints five rows: a bounding measurement, three MISSING times, a bounding measurement. Interpolate with the same straight-line rule, then enter your predictions.

Only after you commit does the program reveal the withheld peak measurements.

Ask before the reveal: does the later, lower-amplitude region behave differently from the early region? Same rule — is the same confidence justified?

Problem



Model

**Compute**

Analyze



Validate



Improve



Inspect · commit · reveal — the decay record

1 · INSPECT

Confirm the measured Z acceleration.

View the positive and negative peak envelopes.

Notice: oscillatory, but shrinking.

2 · COMMIT

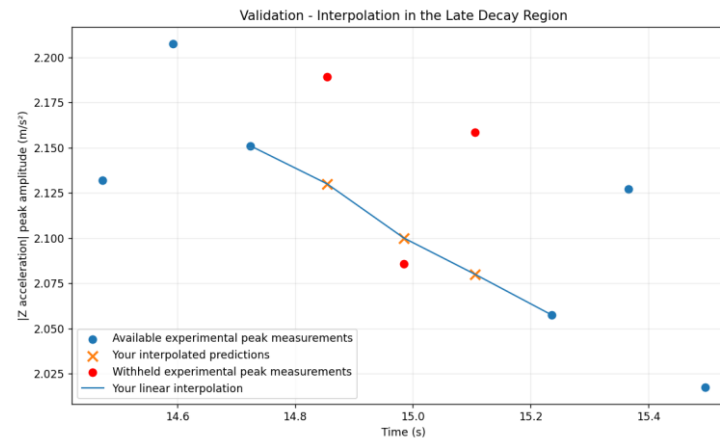
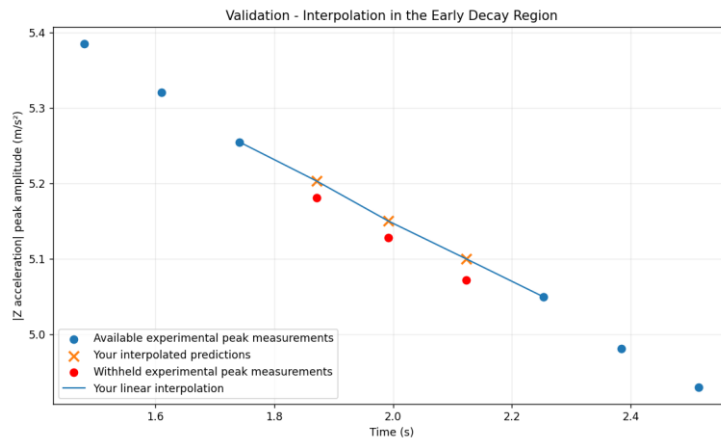
Three predictions near 2 s, three near 15 s
— $|Z \text{ acceleration}|$ in m/s^2 .

"Predictions recorded." Then ENTER to reveal.

3 · REVEAL

Validation tables for both regions:
prediction · measured · absolute error · %
difference · mean absolute error.

Two saved figures.



Lab6_Decay_Early_Validation.png

Lab6_Decay_Late_Validation.png

Compare the two regions. Explain, do not adjust.

Problem

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A compact model for the envelope

$$A(t) = A_0 e^{-\lambda t}$$

$A(t)$ — peak amplitude at time t (m/s²)

A_0 — amplitude at $t = 0$ (m/s²)

λ — decay constant (s⁻¹)

DECAY CONSTANT λ

λ tells how quickly the vibration amplitude dies away.

Units: s⁻¹. Larger $\lambda \rightarrow$ faster decay; smaller $\lambda \rightarrow$ slower decay.

The program fits the model to your measured |peak| values and prints A_0 , λ , and how well the model follows the data (R^2).

The fitted curve is a model of the measured envelope — not a replacement for the measurements.



TALK TO YOUR AI TEAMMATE "What does $\lambda = [\text{my value}] \text{ s}^{-1}$ mean for this beam? Do not change my number."

LIGHT INTRODUCTION TO DAMPING

For a lightly damped system the program also estimates a damping ratio

$\zeta \approx \lambda / (2\pi f)$, f = vibration frequency measured from your record.

Report ζ as an ESTIMATED damping ratio, often as a percentage. No vibration-theory derivation is required — or expected.



ENGINEER DECIDES the model describes the envelope; the measurements remain the evidence.

Problem



Model



Compute



Analyze



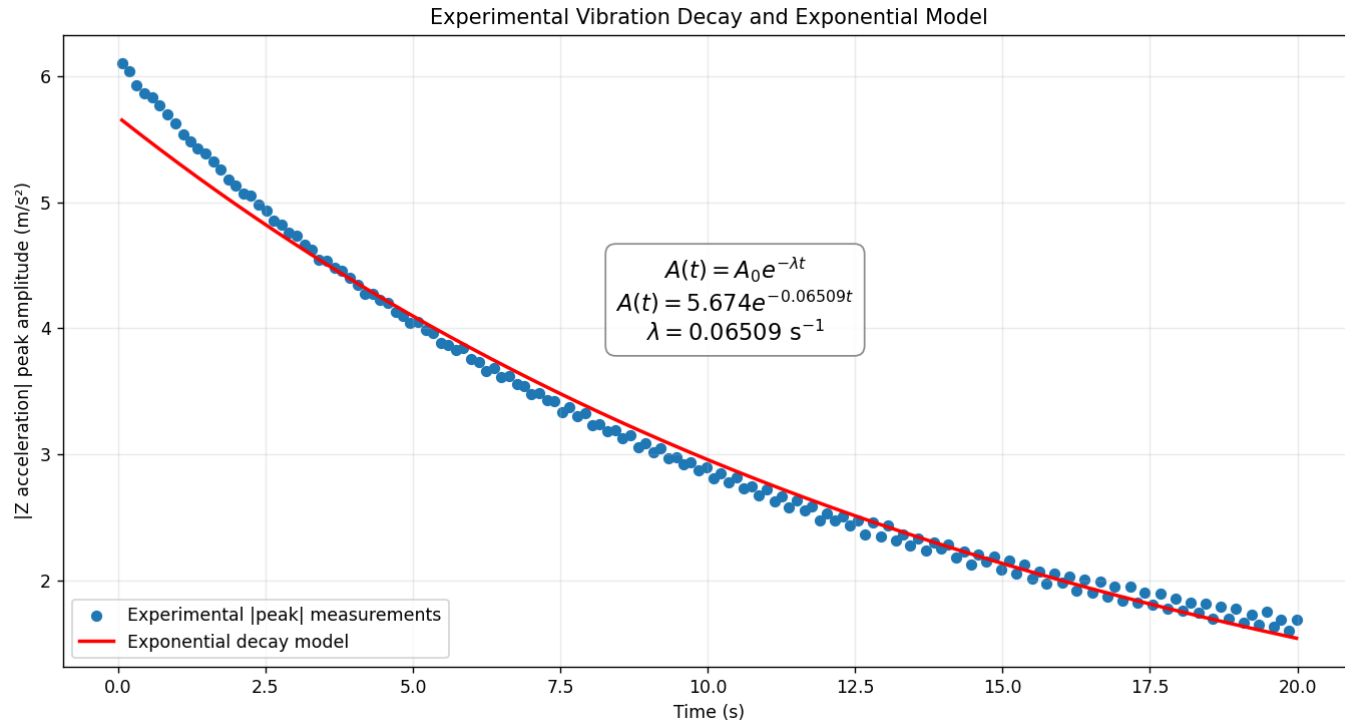
Validate



Improve



The fitted model on your record



WHAT THE PROGRAM REPORTS

Exponential decay model $A(t) = A_0 e^{-\lambda t}$

- Decay constant λ (1/s)
- Measured damped frequency f_d (Hz)
- Estimated damping ratio ζ — and as a percentage
- Decay-model R^2 (indicates model fit quality)

Saved figure: Lab6_Decay_Exponential_Model.png

Copy every value into the report exactly as printed, with units — then interpret λ in one or two sentences of your own.

Damped vibration frequency, f_d : the number of vibration cycles per second observed in the measured response. If the measured period is T , then $f_d = 1/T$.

Damping ratio, ζ : a dimensionless measure of how strongly the vibration decays.

For this lightly damped experiment, we estimate it from

$$\zeta \approx \frac{\lambda}{2\pi f_d}$$

A larger ζ indicates faster decay relative to the vibration frequency.

Look at where the measured |peak| points sit relative to the curve. Early? Late? Above or below? That pattern is evidence about the model — and about your experiment.

Problem

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Interpolation is a claim — validate the claim

WHAT YOU PREDICTED

Your straight-line interpolation values.

These were committed before reveal.

Keep them — even when they are not close. A wrong prediction with a good explanation is worth more than a "corrected" one.

WHAT WAS MEASURED

The withheld phyphox measurements.

These are the experimental comparison values.

They may include noise, scatter, and local irregularity — that is what real measurements look like. They are never edited.

WHAT YOU EXPLAIN

Absolute error (m/s^2) always; percent error where the measured value is not near zero.

Why did the interpolation perform as it did? Was the local signal nearly straight? How did spacing, curvature, amplitude and noise affect the result?

VALIDATION DOES NOT MEAN "THE NUMBERS MATCH." It means you compared a claim with evidence — and explained what you found. Never clean, smooth, replace or trim a measurement to improve the agreement.



TALK TO YOUR AI TEAMMATE "Help me organise this comparison — do not change either column."



ENGINEER DECIDES you decide what the difference means; the AI helps you say it clearly.

Problem



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What evidence belongs in the report?



EXPERIMENTAL RECORD

- Brief setup description + phone orientation
- phyphox recording settings
- Your phyphox Excel filename
- Sampling-rate observation
- Raw Z-acceleration figure
- Any acquisition issue or rerun decision



INTERPOLATION + VALIDATION

- Program 1 peak challenge
- Program 1 zero-crossing challenge
- Bounding measurements, equation, calculations
- Committed predictions · revealed measurements
- Error comparison + explanation
- Program 2 early / late envelope challenges



ENGINEERING INTERPRETATION

- Why local curvature and spacing matter
- What the decay envelope means
- Fitted decay constant λ , measured f , estimated ζ
- What "validation" meant in this experiment
- Limitations: sensor, attachment, release, orientation, beam, sampling, noise

THE REPORT COMMUNICATES WHAT MATTERS. THE .XLSX FILE PRESERVES WHAT WAS MEASURED. Use the Lab 6 Engineering Report Template — every section maps to one of these three columns.

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Submission checklist

SUBMIT TOGETHER

- Completed Lab 6 engineering report (PDF, unless instructed otherwise)
- Your team's ORIGINAL phyphox Excel (.xlsx) export from the experiment — unchanged
- Program 1 figures: Lab6_Peak_Interpolation_Validation.png · Lab6_Zero_Crossing_Validation.png
- Program 2 figures: Lab6_Decay_Early_Validation.png · Lab6_Decay_Late_Validation.png · Lab6_Decay_Exponential_Model.png
- The calculations, committed predictions and engineering interpretations requested in the report template

FINAL CHECK

Can another engineer trace your report back to your measured data?

Did you keep prediction separate from reveal?

Did you explain disagreement instead of hiding it?

Did you use YOUR team's data for the main lab?

AI MAY HELP YOU ANALYZE AND COMMUNICATE. IT MAY NOT INVENT, REPLACE, OR CLEAN UP YOUR MEASUREMENTS.

Problem



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Lab Extension — a controlled comparison

WHY USE THE INSTRUCTOR DATA AGAIN?

Every team collects a slightly different vibration record.

The instructor file is one common reference record for the whole class. That lets you separate two questions:

1. What does interpolation do on the SAME data set?
2. How does your team's physical experiment differ from that common record?

THE CHALLENGE — INDIVIDUAL

Run both programs on the instructor sample; commit and reveal exactly as in lab.

Compare selected results with your team's: sampling rate, frequency, interpolation errors, λ , estimated ζ .

Do not ask which is "better". Ask what changed and why — sampling / phone · attachment · release · beam response · noise / scatter.

Evidence first, explanation second. Use ENGR200_Lab6_Extension.docx.

 **ENGINEER DECIDES** the question is not which record is better — it is what changed between two real experiments, and what evidence says so.

Problem



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LAB 6 · RECOVER THE MISSING DATA

You measured a vibration.
Then we hid part of it.
You interpolated before seeing the answer.
The experiment revealed what was actually there.

The important question is not whether interpolation produced a number.
It is when that number deserves your trust.

MEASURE › PREDICT › REVEAL › VALIDATE › IMPROVE

Problem

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