

FUNDAMENTALS OF AI-AUGMENTED ENGINEERING: A CONVERSATIONAL APPROACH

Taner Onsay, Ph.D. & Sebnem Onsay
Authors
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The engineering workflow you will use throughout this book

CHAPTER - 7

PART 3 · ≈ 18 MIN

The Curve Has Meaning

The same shot, now vertically. A wrong model fails loudly, physics proposes a better one, and the fitted coefficients turn into release height, release velocity — and an acceleration that is close to g , but not equal to it.

3

Problem

›

Model

›

Compute

›

Analyze

›

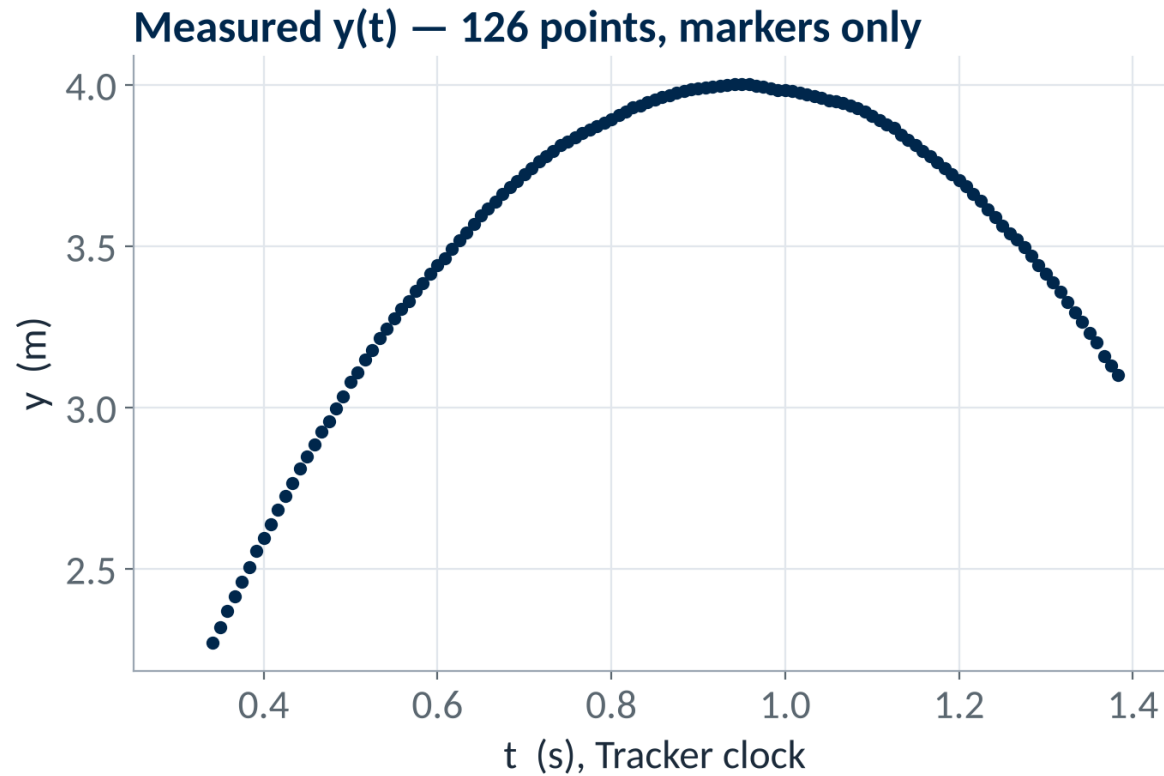
Validate

›

Improve



$y(t)$ is curved. Which curve should we try — and who decides?



WHERE WE ARE

Part 2 found the best line for $x(t)$. Its coefficients came out of least squares. **What do they mean?**

BEFORE ANY SOFTWARE

Name a candidate form for $y(t)$ — and the **physical reason** you expect it. You sketched an arch in Part 1. Why an arch?

Least squares will fit ANY form we hand it. Choosing the form is the engineer's job.

Problem



Model



Compute



Analyze



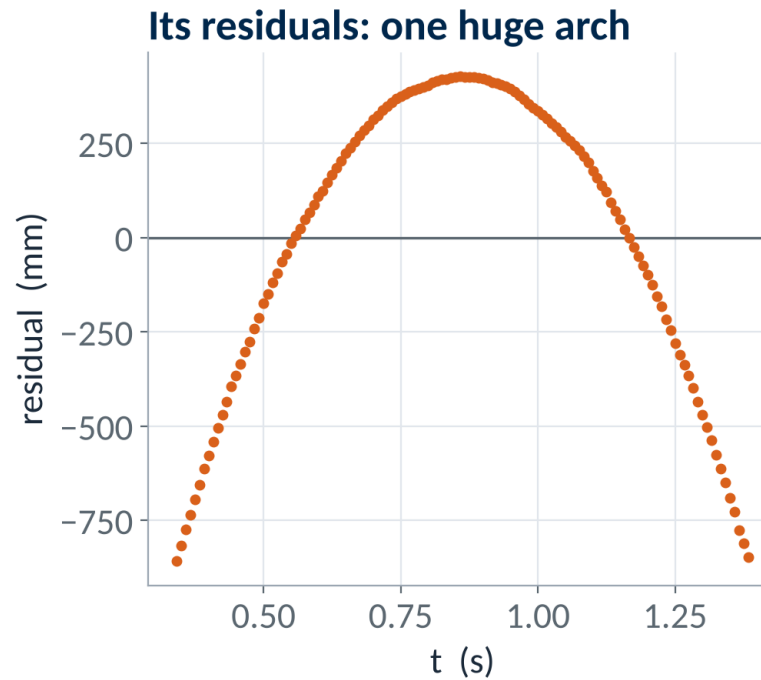
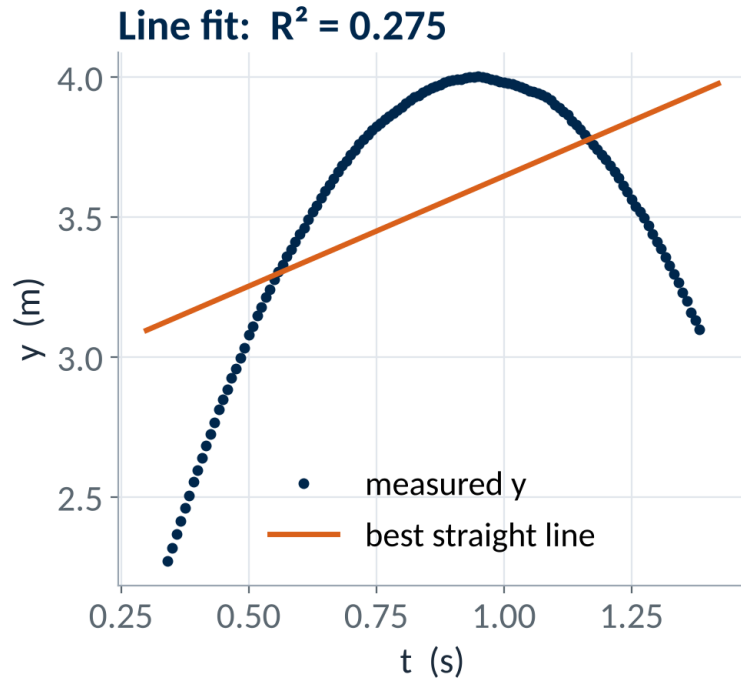
Validate



Improve



Fit the wrong form on purpose — and read its residuals



THE NUMBERS

Best line through $y(t)$:

$$R^2 = 0.275$$

largest residual 0.86 m

THE SHAPE

Not scatter — one giant arch. The residuals **are** the curve the line could not follow.

Residual shape can tell us the model FORM is wrong. A straight line cannot represent this motion.

Problem



Model



Compute



Analyze



Validate



Improve



Constant acceleration → a quadratic in time

IDEAL PROJECTILE, AFTER RELEASE

$$a_y = -g \quad (\text{constant})$$

$$y(t) = y_0 + v_{y0} t + \frac{1}{2} a_y t^2$$

$$y(t) = y_0 + v_{y0} t - \frac{1}{2} g t^2$$

Physics proposes the FORM (a quadratic) and a CONSTRAINT on one coefficient (it should involve g).

$$y(t) = A_y t^2 + B_y t + C_y$$

Fitted coefficient	Physical meaning
A_y	$\frac{1}{2} \times$ vertical acceleration
B_y	vertical velocity at $t = 0$
C_y	vertical position at $t = 0$

"at $t = 0$ " — wherever the clock says zero is. Remember that phrase.

Same shape, two languages: the data-fit coefficients A, B, C — and the physics terms $\frac{1}{2}a, v_0, y_0$.

Problem



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Improve



PREDICT

	DATA-FIT MODEL	PHYSICS MODEL
Form	$y = A_y t^2 + B_y t + C_y$	$y = y_0 + v_{y0} t - \frac{1}{2} g t^2$
Coefficients come from	whatever best fits the data	physics — and must make physical sense
Question it answers	Does it fit?	Does it fit AND make sense?
Warning	An excellent fit can still mislead	Correct physics can disagree with imperfect data

If the ideal physics model is right, what number should A_y come out to?

Write it down — with units — before the fit appears.

Hint: $A_y \leftrightarrow \frac{1}{2} a_y$

A curve fit can become a TEST of a physical model. The physics model makes a prediction about a fitted coefficient.

Problem



Model



Compute



Analyze



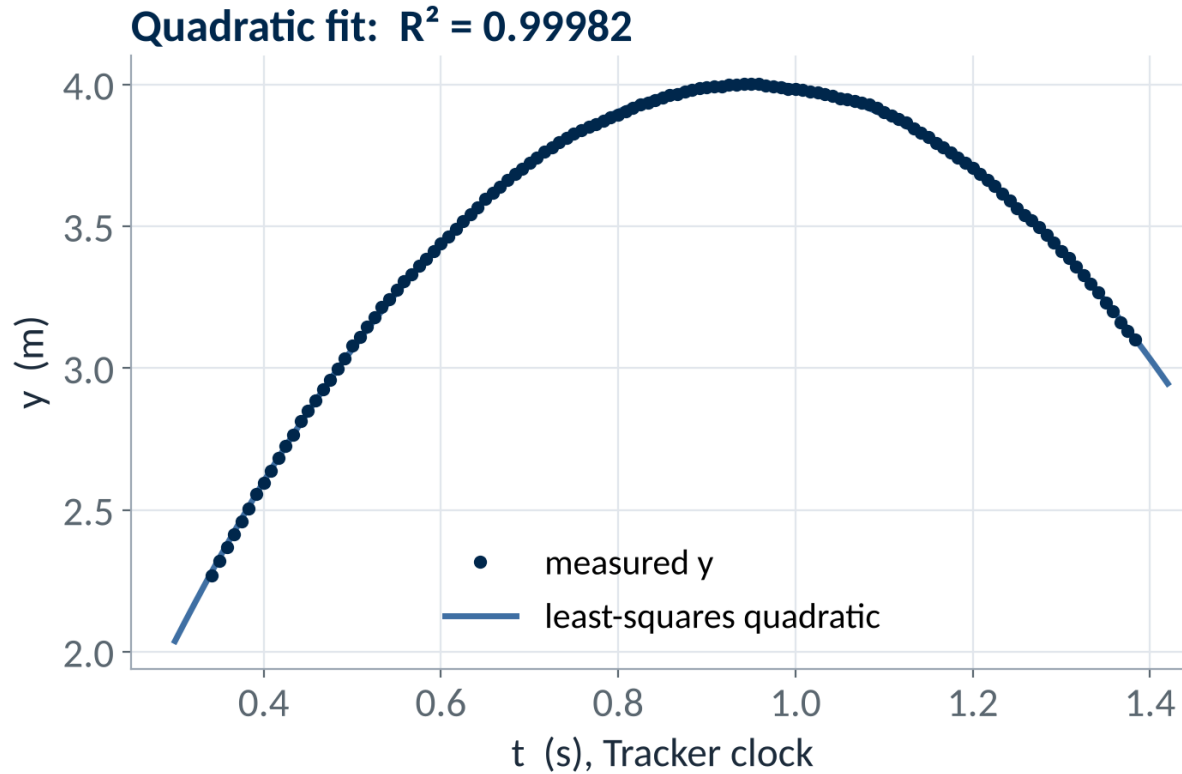
Validate



Improve



Same least squares, one more coefficient



RESULT · ALL 126 POINTS

$$A_y = -4.71 \text{ m/s}^2$$

$$B_y = 8.92 \text{ m/s}$$

$$C_y = -0.21 \text{ m}$$

$R^2 = 0.99982$ · RMS residual 6.1 mm

HOW

Excel order-2 trendline or LINEST — minimizing $SSE = \sum r^2$, exactly as in Part 2.

R^2 went from 0.275 to 0.99982 by changing the FORM, not the data.

Problem



Model



Compute



Analyze



Validate



Improve



Why did the fit give -9.43 m/s^2 and not -9.81 ?

-9.43 m/s^2

$$a_{y,\text{fit}} = 2A_y$$

from 126 measured points

-9.81 m/s^2

$-g$

what the ideal model expects

3.9 %

difference in magnitude

small — but not zero

MODEL?

Is something missing from the ideal projectile model?

DATA / TEST?

Is something about the measurements biasing the fit?

COMPARISON?

Are we comparing equivalent quantities, in equivalent coordinates?

An open question — on purpose. Part 3 creates the discrepancy. Parts 4 and 5 investigate it.

Problem



Model



Compute



Analyze



Validate



Improve



ACCEPT, MODIFY or REJECT?

AI ANALYST

“The fitted acceleration is -9.43 m/s^2 instead of -9.81 m/s^2 . Therefore air resistance caused the discrepancy.”

FIND THE JUMP

Which part is an OBSERVATION, and which part is a CLAIM about a cause? What evidence would the claim need?

YOUR VERDICT

ACCEPT — the evidence supports both halves.

MODIFY — keep the observation, qualify the cause.

REJECT — the statement is not supported.

One sentence of justification. We will not settle the cause today.

Observed disagreement $\neq$ assigned cause. "Therefore" needs evidence the fit alone cannot provide.

Problem ›

Model ›

Compute ›

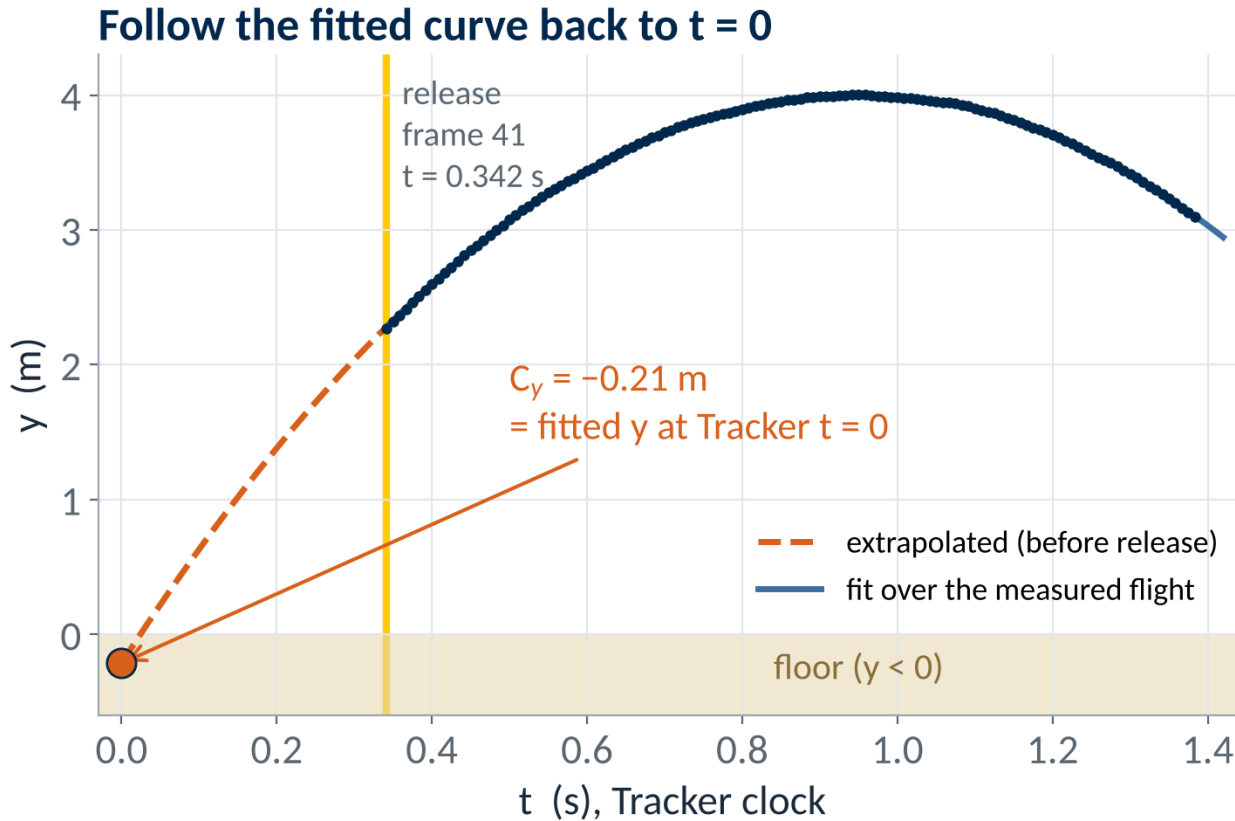
Analyze ›

Validate ›

Improve



$C_y = -0.21$ m. Did the ball start 21 cm below the floor?



WHAT THIS NUMBER REALLY IS

$$C_y = y(t = 0)$$

Tracker's $t = 0$ is the start of the VIDEO — 0.34 s before release. C_y is the fitted curve extrapolated back to that moment.

SO WHAT WENT WRONG?

Nothing in the computation. The number is correct for the chosen time origin. **The interpretation was wrong.**

Computation can be correct while interpretation is wrong. A coefficient means something only relative to its origin.

Problem



Model



Compute



Analyze



Validate



Improve



Time since release: $\tau = t - t_r$, $t_r = 0.3417$ s (frame 41)

Coefficient	Tracker clock (t)	Release clock (τ)	Changed?
A_y (m/s ²)	-4.713	-4.713	no
B_y (m/s)	8.918	5.697	yes
C_y (m)	-0.214	2.283	yes
A_x (m/s)	3.7375	3.7375	no
B_x (m)	-1.025	0.252	yes

NOT DATA CLEANING

A change of reference. Every raw Tracker value stays exactly as measured; only the label on the clock moves.

WHAT DID NOT MOVE

A_y and A_x — the curvature and the slope do not care where zero is.

$$y(\tau) = -4.713 \tau^2 + 5.697 \tau + 2.283 \quad x(\tau) = 3.7375 \tau + 0.252$$

Shifting $t = 0$ changes B and C — never A. Choose the origin so the coefficients mean what you need.

Problem



Model



Compute

**Analyze**

Validate



Improve

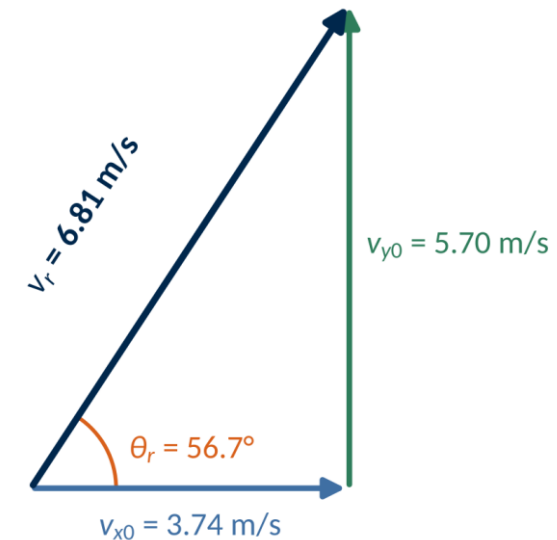


On the release clock, the fit describes the ball at the moment it left the hand

Fitted (release clock)	Physical parameter	Value
C_y	release height	2.283 m
B_y	vertical velocity at release, v_{y0}	5.70 m/s
A_x	horizontal velocity, v_{x0}	3.74 m/s
$2A_y$	vertical acceleration	-9.43 m/s ²

$$v_r = \sqrt{v_{x0}^2 + v_{y0}^2} \approx 6.81 \text{ m/s}$$

$$\theta_r = \text{atan}(v_{y0} / v_{x0}) \approx 56.7^\circ$$



Check: measured height at frame 41 is 2.270 m; the fit says 2.283 m.

MEASURED DATA → FITTED COEFFICIENTS → PHYSICAL PARAMETERS

Problem ›

Model ›

Compute ›

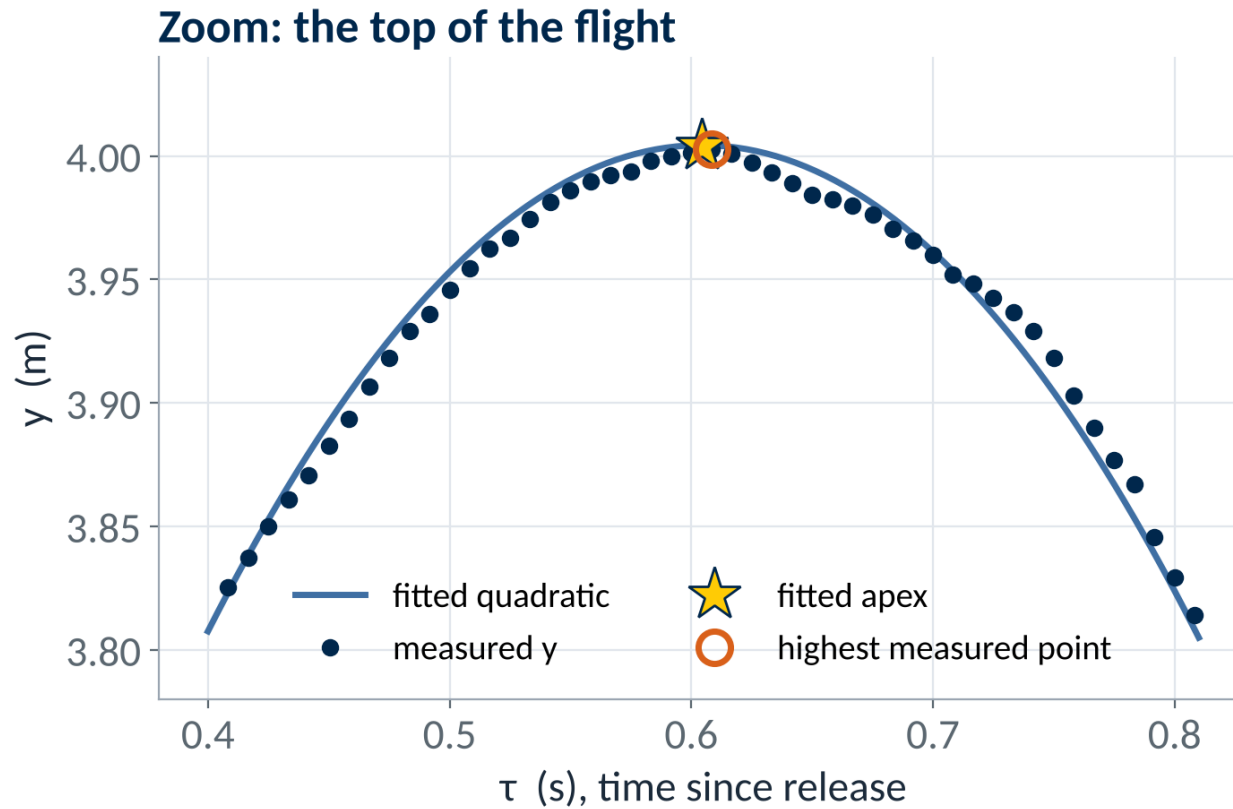
Analyze ›

Validate ›

Improve



The apex: the model's prediction against what the camera saw



Apex	From the fit	Measured
time since release	$\tau = 0.604$ s	0.608 s (frame 114)
height	4.004 m	4.003 m
horizontal position	$x = 2.511$ m	2.510 m

HOW TO READ IT

Agreement within 2 mm in height and 0.004 s in time. Encouraging evidence — but these apex points were part of the fit, so it is a consistency check, not independent proof.

Beyond coefficients and R^2 : ask whether the model reproduces a physically observable feature.

Problem



Model



Compute



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Excel made it transparent. Python makes it repeatable.

```
data = np.loadtxt("IMG1958_tracker_raw.csv",
                  delimiter=",", skiprows=1)
t, x, y = data[:, 0], data[:, 1], data[:, 2]

A_y, B_y, C_y = np.polyfit(t, y, 2)    # least squares
y_hat = A_y*t**2 + B_y*t + C_y
r = y - y_hat                          # residuals
R2 = 1 - np.sum(r**2)/np.sum((y - y.mean())**2)

tau = t - 41/120                        # release clock
A_r, B_r, C_r = np.polyfit(tau, y, 2)
tau_apex = -B_r/(2*A_r)
```

IT PRINTS

```
A_y = -4.7134   B_y = 8.9178
C_y = -0.2138   R^2 = 0.99982
a_y,fit = -9.43   (-3.9 %)
release: B_y = 5.6970
          C_y = 2.2829
apex: tau = 0.604 s
       y = 4.004 m
```

SAME NUMBERS AS EXCEL

Two implementations of one piece of reasoning.

The engineering model does not change because the software changes.

Problem



Model



Compute



Analyze



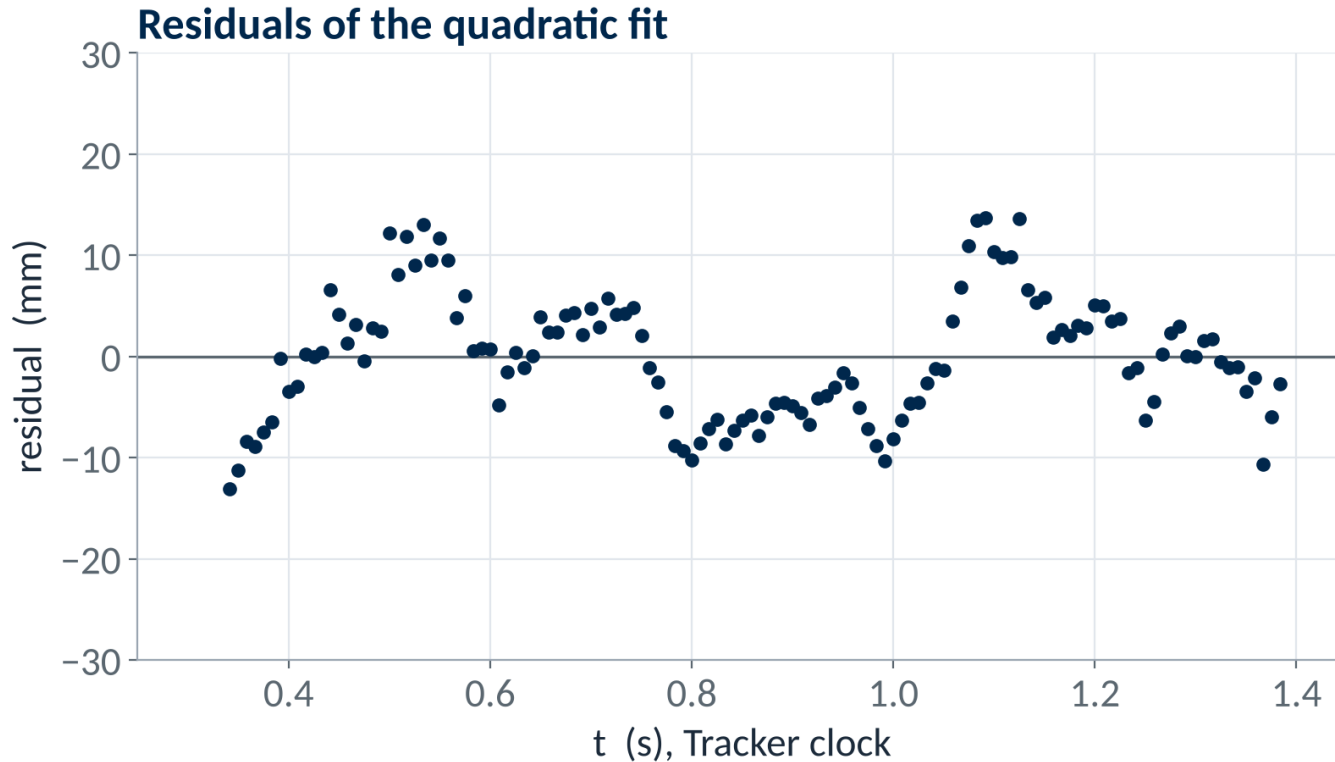
Validate



Improve



The quadratic's residuals: small — but are they random?



SIZE

RMS 6.1 mm; largest 13.7 mm — on a 1.7-m rise and fall.

SHAPE

Runs of same-sign points, a dip near the top, a sudden jump near $t \approx 1.05$ s. **Not completely random.**

The residuals are small, but they are not completely random. Cause: not decided here.

Problem



Model



Compute



Analyze

**Validate**

Improve



Strong evidence — and two open questions

A quadratic fits $y(t)$ extremely well

$R^2 = 0.99982$, RMS 6.1 mm.

Coefficients carry physics

On the release clock: height, velocities, angle.

The origin decides the meaning

$C = -0.21$ m became 2.28 m. A did not move.

The apex agrees

Within 2 mm and 0.004 s.

THE QUESTION FOR PART 4

The fit is excellent.

The coefficients look physical.

The apex agrees.

So is the model validated?

STILL OPEN

$a_{y,fit} = -9.43 \text{ m/s}^2$, 3.9 % from $-g$. Residuals small but structured.
Causes: not yet investigated.

FITS $\neq$ VALIDATED. Part 4 asks what the evidence so far can — and cannot — establish.

Problem



Model



Compute



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Improve