

CHAPTER - 3

PART 7 · ≈ 60 MIN

Can We Trust the Model? Engineering Judgement

A model is not simply good or bad. A model is adequate or inadequate for a particular purpose — and finding out which is an engineering skill, not a calculation.

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Observe

›

Idealize

›

Model

›

Solve / Analyze

›

Validate

›

Report



The tow train, one more time — now on a bench, and now with a stopwatch on it.

BENCH TOW TRAIN · PREDICTED VS MEASURED

ART SLOT

[ORIGINAL PLOT: speed against time for the bench cart train. The Part 3 prediction is a straight line; the tracked measurement falls below it, and the gap widens with speed. A residual strip runs beneath the main axes.]

WHAT WE ASSUMED IN PART 3

- a level surface
- known masses
- a known applied force
- a rigid connection
- negligible rolling resistance
- ideal, undeformable components



The measured acceleration is about 4% below the prediction

Not scattered around it. Below it, every run. That is information, and this Part is about reading it.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



PREDICT

The measurement is 4% below the prediction, and the gap grows with speed.

Name three candidate explanations — and for each one, say what evidence would distinguish it from the others.



Write them down before the next slide names the categories.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



Not four kinds of mistake. Four different things to go and check.

Category	What it means	A clue that often points this way
MODEL	missing or oversimplified physics	a systematic divergence that grows — the shape is wrong, not just the level
PARAMETERS	a mass, force, coefficient or stiffness not known accurately	the shape is right; the level or slope is off by a consistent factor
MEASUREMENT	resolution, calibration or technique limits	scatter about the prediction, comparable in size to the known resolution
IMPLEMENTATION	signs, units, algebra, coordinates, coding	usually large, often physically nonsensical, and it does not scale with anything

Four different things to go and check — and the third column is the fastest way to decide which one to check first.





The categories organise the search. They do not do it for you.

These signatures are diagnostic hints that often help. They are not a rule. A parameter error can grow with speed; a model omission can look like a constant offset; and two causes can be present at once.



So what does the clue buy you?

An order in which to look. Start with the category the pattern suggests, and be willing to be wrong about it.



What actually settles it

Evidence: an independent estimate of the parameter, a repeat measurement, a coast-down test, a unit check — something that could have come out the other way.



And two causes at once

Common, and not a disaster. Fix the dominant one first, recompare, and see what is left.

A category you cannot support with evidence is a guess wearing a label.

Observe



Idealize



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Report



$\Sigma F = ma$ is not on trial here. The model built on top of it is.

PREDICTION $\neq$ MEASUREMENT does not mean “the equation is wrong”



What is almost never wrong

Newton's second law. It has survived every test in the engineering range, and a 4% disagreement on a lab bench is not the counterexample.



What is usually wrong

Something you assumed while turning the law into a model of this particular system — and you wrote those assumptions down in Part 2.



Why this distinction matters

A student who concludes the physics is broken stops looking. A student who suspects the model goes and finds the rolling resistance.

The question is never “is the physics right?” It is “which of my assumptions has just been caught?”

Observe



Idealize

**Model**

Solve / Analyze



Validate



Report



The central engineering idea of this Part, and the one that separates it from a lab exercise.

A model is not simply GOOD or BAD.
A model is ADEQUATE or INADEQUATE for a particular PURPOSE.

ONE GAP, TWO VERDICTS

ART SLOT

[ORIGINAL DIAGRAM: the same 4% disagreement shown twice, once against a tolerance band that easily contains it and once against a band that does not; the verdict under each is different.]



Decision A — adequate

“Can this tractor get a fully loaded train moving at all?” A 4% error changes nothing. The model is adequate, and refining it would be wasted effort.



Decision B — inadequate

“Will the train clear the crossing before the gate closes?” Now 4% decides the answer. The same model is inadequate, and must be improved.

Same model. Same 4%. Two different verdicts — because adequacy is a property of the model and the decision together.

Observe



Idealize



Model



Solve / Analyze



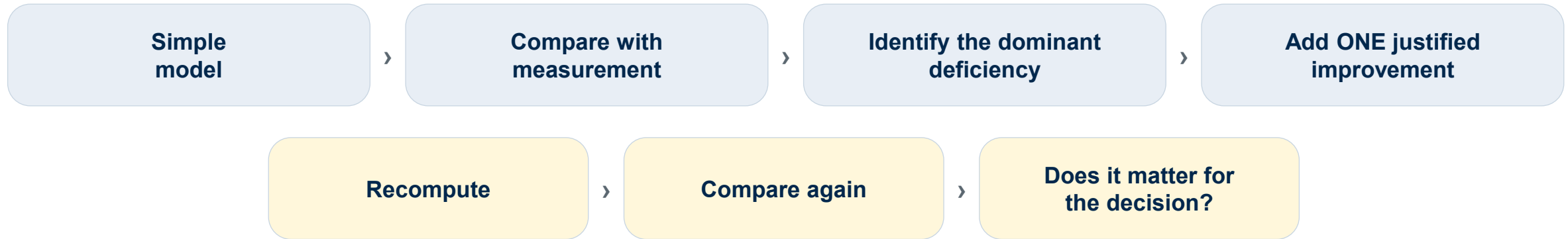
Validate



Report



One change at a time, and stop when it stops mattering.



Why one change at a time

Add rolling resistance, a coupling compliance and a mass correction together and the model will agree beautifully — and nobody can say which change did the work. You will have bought agreement and learned nothing.



Why there is a stopping rule

Complexity is not a virtue. Once the residual is smaller than the decision cares about, and smaller than the measurement uncertainty, further refinement is not engineering — it is decoration.

Use the simplest model that is adequate for the engineering decision.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



Four candidates, and what each would have to look like.

Candidate	Category	What we would expect to see, and what we do see
rolling resistance neglected	MODEL	a growing shortfall, always the same sign — which is what the data shows
hanging mass mis-weighed	PARAMETERS	a constant proportional offset, present even at very low speed — not observed
frame rate or scale error	MEASUREMENT	random scatter of the size of one pixel per frame — far too small to explain 4%
a sign or unit slip	IMPLEMENTATION	an error of tens of per cent, or a nonsensical direction — not what we have

Notice what made this diagnosis possible: the assumptions were written down in Part 2 and were still there to be checked.



Three candidates ruled out on evidence. One left, and it names the fix.



The verdict

The evidence points at a missing force, not at a bad number and not at a bad measurement. That is a MODEL deficiency — the physics in the model is incomplete.



So we add exactly one thing

A rolling-resistance force proportional to the normal force, with a coefficient estimated from a separate coast-down test — independently of this experiment.



Why the coefficient must come from somewhere else

A value fitted to this experiment would guarantee agreement with this experiment, and would tell us nothing.



And why only one change at a time

If two changes go in together and the model improves, neither of them has been tested.

Diagnose on evidence, change one thing, and keep the coefficient's source independent of the comparison.

Observe



Idealize



Model

**Solve / Analyze**

Validate



Report



The improved model agrees. Now ask whether the improvement was worth making.

BEFORE AND AFTER, WITH RESIDUALS

ART SLOT

[ORIGINAL PLOT: two panels. Left, the original prediction with its residual strip showing a systematic trend. Right, the same with rolling resistance included and the residual now flat and small.]

THE HONEST REPORT

Residual falls from a systematic 4% to a scattered 0.8%, which is the size of the tracking uncertainty. The remaining disagreement is no longer distinguishable from noise.



But was it worth it?

For Decision A, no — the original model was already adequate. For Decision B, yes, and the coefficient must now be checked against a second, independent test before anyone relies on it.



Fitting is not validating

A coefficient tuned until the curves match has bought agreement, not evidence. It becomes evidence only when an independent estimate or a second experiment agrees with it.

Report the residual, the assumption you changed, and the verdict against a stated purpose. All three, or none of it means anything.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



In class and then as homework — one full cycle, done properly.

PREDICT ›

MEASURE ›

COMPARE ›

DIAGNOSE ›

IMPROVE ›

RECOMPARE ›

REPORT

IN CLASS · ABOUT 35 MIN

Two or three loaded carts coupled in line on a level floor, pulled by a known force from a hanging mass or an in-line scale.

Predict the acceleration from your Part 3 model. Film the run. Track it. Plot prediction and measurement together and quantify the gap.

AS HOMEWORK

Diagnose the gap using the four categories and the evidence you have.

Add one justified improvement, recompute, and recompare.

Deliver the report below — and state a purpose against which you are judging adequacy.

Everything in Chapters 1 to 3 appears in this one artefact: modelling, kinetics, tracking, computation and judgement.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

Report



Six headings. Two pages. Nothing decorative.

1 The model and its assumptions

What you idealised, and the list you are prepared to be held to.

2 The measurement and its uncertainty

How you measured, and how well. A number, not an apology.

3 The comparison

Prediction against measurement, quantified. A residual plot beats an adjective.

4 The diagnosis, with evidence

Which category, and what in the data points there rather than somewhere else.

5 The one improvement

What you changed, why it was justified, and how much it actually moved the answer.

6 The verdict

Adequate or inadequate — for a purpose you state explicitly. This is the sentence the whole report exists for.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



The order is the point. Reverse it and the exercise teaches nothing.

1 You interpret first

Write your own diagnosis of the disagreement, with your evidence, before any AI sees the data.

2 Then it challenges you

Ask it to attack your assumptions and to propose alternative explanations you did not consider.

3 Then you judge the challenge

Is each objection physically defensible?
Respond to the ones that are, and say why the others are not.

AI does not make the final engineering judgement. You do, and you sign it.



The Master Plan line that governs this slide

Observation, prediction, measurement, model selection, assumptions, evidence, interpretation and final judgement remain the student's own.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



None of these has a numerical answer.

1 “A more complicated model is a better model.”

Not unless it changes the answer by more than the measurement uncertainty and more than the decision cares about. Otherwise it is decoration with a maintenance cost.

2 “I tuned the coefficient until it matched, so the model is validated.”

Fitting is not validation. The fitted value has to be checked against an independent estimate or a second experiment before it counts as evidence.

3 “Experimental error explains the gap.”

Then state the size of the error and compare it with the size of the gap. Usually it does not — and the moment you quantify it, you know.

4 “Friction is the reason.”

Offered reflexively for every discrepancy, including ones where friction would push the wrong way. Name the force, give it a direction, and check its sign against the data.

Observe



Idealize



Model



Solve / Analyze

**Validate**

Report



Part 7 — engineering judgement



You can now EXPLAIN

- the four places a disagreement can come from
- why prediction $\neq$ measurement does not indict the physics
- why adequacy is a property of a model and a decision together
- why one change at a time is the only way to learn anything
- why fitting a parameter is not the same as validating a model



You can now DO

- compare a prediction with a measurement quantitatively
- diagnose a disagreement and defend the diagnosis with evidence
- add one justified improvement and recompute
- judge adequacy against a purpose you state
- report the result so that someone else could challenge it

This is the Part that most distinguishes this course from a traditional treatment of the same material.

Observe



Idealize



Model



Solve / Analyze



Validate



Report



Force and acceleration can do this. The question is whether they should have to.

A TO B, ALONG AN AWKWARD PATH

ART SLOT

[ORIGINAL DIAGRAM: a coaster profile or a haul road with a changing grade, marked A at one end and B at the other; the curvature and slope visibly change along the way.]

WE CAN DO THIS

- identify the forces at every point
- get the acceleration at every point
- integrate the motion from A to B

If all I want is the speed at B, do I really need to know the acceleration at every point in between?



That question is not answered here

It is the reason Chapter 4 exists. Show that the force-acceleration route works and is the wrong tool, then stop.

Next — Chapter 4: Energy Methods for Particles.

Observe



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Report