

**AI-AUGMENTED ENGINEERING DYNAMICS:
A CONVERSATIONAL APPROACH**

Chapter 3 — Forces and Particle Motion

Part 1 · From Motion to Force

Taner Onsay, Ph.D.

Author

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Observe



Idealize



Model



Solve / Analyze



Validate



Report

The engineering workflow you will use throughout this book

CHAPTER - 3

PART 1 · ≈ 50 MIN

Why Does Motion Change?

Gravity has not switched off, yet the passengers float. Acceleration is the evidence that a net force exists — and what a scale reads is the support force, not the gravitational force.



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Chapter 2 asked how the particle is moving. Chapter 3 asks what is causing that motion to change.

CHAPTER 2 — KINEMATICS

Question	How is it moving?
Tools	position, velocity and acceleration in x – y , n – t and r – θ
Answer	a complete description of the motion
Missing	why the motion changed at all

CHAPTER 3 — KINETICS

Question	What is causing it to change?
Tools	the same three descriptions, now carrying forces
Answer	the forces required, or the motion produced
New idea	net force is the cause; acceleration is the effect



One sentence to carry through the whole chapter

A particle accelerates only when the forces on it do not balance.



And one habit

Find the acceleration and you have found the evidence of a net force. That works in both directions.

Every coordinate description you learned in Chapter 2 gets a force partner in Chapter 3. The mirror is deliberate.

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Gravity is still acting. So why is everyone floating?

ZERO-G CABIN · VIDEO AND STILL



https://www.youtube.com/watch?v=FO_Ox_dH0M8

Interior of a wide-body aircraft cabin stripped of seats and padded, people floating mid-air.



What you can see

People and loose objects drifting. No up, no down, no contact with the floor. The aircraft is in ordinary air, a few kilometres above the ground.



What you cannot see yet

What the aircraft itself is doing. Hold that thought — it is the whole answer, and you already modelled it in Chapter 2, Part 3.

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PREDICT

During the float, is the gravitational force on a passenger larger, smaller, or the same as on the ground?

What does a bathroom scale underneath that passenger read?

A light passenger and a heavy passenger let go at the same instant. Does either drift toward the floor?



Commit to all three before the next slide. Write them down.

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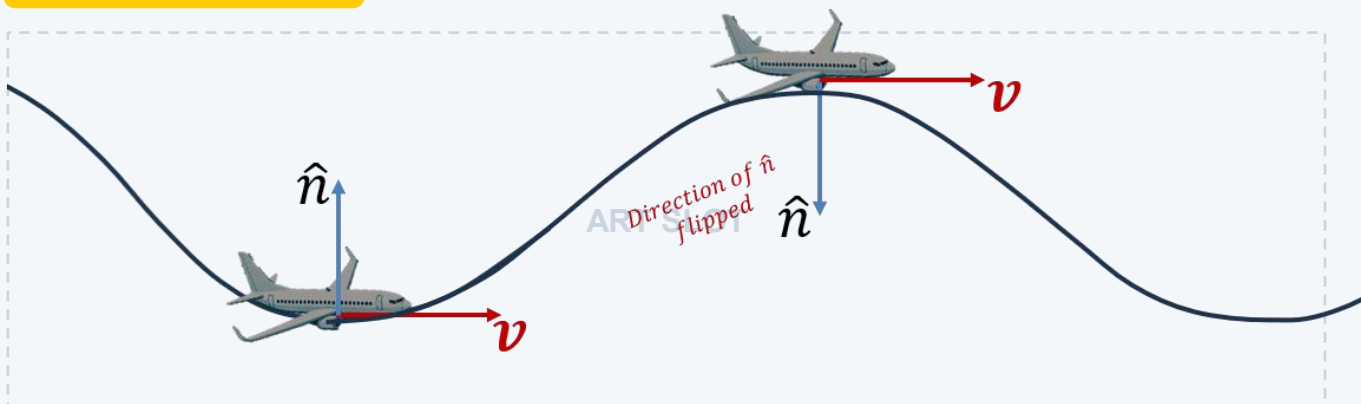


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The aircraft is falling — along the same parabola you modelled in Chapter 2, Part 3.

PARABOLIC FLIGHT PATH



[IMAGE PLACEHOLDER: Side-view illustration of an aircraft flying a parabolic trajectory against a clean sky gradient, the aircraft drawn small at five points along one parabolic arc; no labels, no axes, no arrows; 16:9.]



The cabin is a projectile

Engines throttled back, nose over the top: for about 25 seconds the aircraft is in free-flight motion.



So is the passenger

Both have the same downward acceleration, g . Neither gains on the other, so the floor never has to push.



The Chapter 2 model answers a Chapter 3 question

You already know how this motion works. What is new is reading it backwards: no contact force, therefore no scale reading.

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Build the model in public — it is shorter than the question that provoked it.

THE PASSENGER, ISOLATED

$$\sum \vec{F} = m \vec{a} \text{ with } \vec{a} = \vec{g}$$

The only force acting on the passenger is the gravitational force. So the contact force from the floor (Force Normal to surface: N) must be zero:

$$N = 0$$

That is the whole answer. Nothing was switched off.



Most of Chapter 3 is this shape

Isolate, list, read the consequence.

1

Isolate one body

The passenger alone — not the passenger and the cabin.

2

List what touches it

Nothing. The floor is falling away at the same rate.

3

Read the consequence

No contact, so no contact force, so the scale reads zero.

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A scale reads the contact or support force — not the gravitational force on you.

Stand still on a bathroom scale and the two happen to be equal, which is why the distinction is easy to miss. Accelerate — up, down, or around a curve — and they separate. This chapter keeps coming back to that gap.



Gravitational force

$W = mg$. Depends on the body's mass and on the local gravitational field. It does not care what the body is doing.



Contact / support force

N, or a seat force, or a cord tension. Whatever the surroundings must supply, given how the body is accelerating. This is what gets measured.



Careful with the words

It is accurate to say a scale reads the support force. It is not accurate to say a person never feels gravity — keep the claim on what is being measured.

Apparent weight is this chapter's recurring thread: Zero-G, the elevator, the hill crest, the loop, the rotating ride.

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One free-body diagram, one equation, and the whole first thread of the chapter.

ELEVATOR + SCALE

The scale does not measure your gravitational force mg . It measures the support force N exerted on you by the scale.



A person standing on a bathroom scale inside an elevator car.

VERTICAL EQUATION OF MOTION

$$\sum \vec{F}_y = m \vec{a}_y \Rightarrow N - mg = m a_y$$

$$N = m (g + a_y)$$

Positive y taken upward. N is the scale reading; mg is not. Nothing in this equation asks how fast the elevator is moving.



Speed is not the partner of force

Only the rate of change of velocity is. That is the whole content of the second law.



One equation, five situations

Set a_y to zero, positive, negative, or $-g$ and the next slide is already finished.

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A 70 kg passenger, tracked through one elevator trip.

State of the elevator	a_y (m/s^2)	N (N)	N / W	What you feel
At rest, or constant speed	0	687	1.00	normal
Starting upward	+2.0	827	1.20	heavier
Slowing on the way up	-2.0	547	0.80	lighter
Free fall (cable cut)	-9.81	0	0.00	weightless
Parabolic flight arc	-9.81	0	0.00	weightless



The last two rows are the same physics

A falling elevator and a parabolic arc differ only in horizontal velocity — which never entered the equation.



g-force is only this ratio

N / W states the support force without units. A 2 g pull-out and a 0 g arc are one calculation.

Illustrative numbers — replace them with the class's own measurement from the building elevator.

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Statics used the first and third. Dynamics is built on the second.

I First law

With no net force, velocity does not change. Read that carefully: does not change, not is zero.

II Second law

An unbalanced force -- net force ($=\sum \vec{F}$) produces an acceleration $\vec{a}$ in the same direction and in proportion to it. This is Chapter 3.

III Third law

Interaction forces come in equal and opposite pairs, acting on different bodies. Parts 2 and 4 both need this.

THE GOVERNING EQUATION OF THE CHAPTER

$$\sum \vec{F} = m \vec{a}$$



It is a law of nature, not a derivation

Newton's second law was established experimentally and has survived every test in the engineering range. We use it; we do not prove it.

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One is a property of the body. The other is a force that depends on where the body is.



Mass m

An absolute property: the body's resistance to a change in velocity. The same on Earth, on the Moon, and in the Zero-G aircraft.



Weight W

A force: the gravitational pull on the body, $W = mg$. It changes with the local field — and $W = mg$ is itself an application of $\Sigma F = ma$.

UNITS — THE TWO SYSTEMS DISAGREE ABOUT WHICH ONE IS BASIC

SI · mass is the base unit, in kilograms; weight is derived. $W \text{ (N)} = m \text{ (kg)} \cdot g \text{ (m/s}^2\text{)}$, $g = 9.81 \text{ m/s}^2$. $1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$.

FPS · weight is the base unit, in pounds; mass is derived. $m \text{ (slug)} = W \text{ (lb)} / g \text{ (ft/s}^2\text{)}$, $g = 32.2 \text{ ft/s}^2$. $1 \text{ slug} = 1 \text{ lb} \cdot \text{s}^2/\text{ft}$.

If a problem gives you pounds, it has given you a force. Divide by g before it meets $\Sigma F = ma$.

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The equation is a statement about an inertial frame. Say which frame you are using.



For everything in this chapter

A frame fixed to the ground is inertial enough. The Earth's rotation contributes far less acceleration than anything we will compute.



Where that stops being enough

Satellites and long-range trajectories use a frame fixed to the stars. Chapter 6 returns to frames that rotate.



The failure mode to watch for — it arrives in Part 3

A crate rides on the bed of a truck that is accelerating. Write $\Sigma F = ma$ in the frame of the truck and the answer is wrong, because that frame is accelerating. Write it in the ground frame and everything works. This course avoids accelerating frames deliberately and out loud rather than repairing them.

The habit to build: before writing the equation, name the frame. One line on the page — “inertial x–y frame fixed to the ground.”

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The licence to treat a whole train, or a whole vehicle, as one particle.

FOR A SYSTEM OF n PARTICLES

$$\sum \vec{F}_{ext} = m \vec{a}_G$$

Internal forces between members of the system cancel in equal and opposite pairs — Newton's third law — so only external forces survive. G is the mass centre of the whole system.



Why this matters in Part 2

We will draw a boundary around a tow tractor and two carts and treat the whole train as one body. This equation is what makes that legal.



Internal versus external

The same force can be either. It depends entirely on where you drew the boundary — which is Part 2's whole subject.



Forward link

Chapter 7 returns to this equation for rigid bodies, where G becomes the mass centre of a body with size.

Recognise this result and know when you are leaning on it. You will not be asked to derive it.

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Decide before discussing. Every one of these is a real student sentence.

1 “There is no gravity up there.”

At the altitude a parabolic flight uses, g is within about 1% of its sea-level value. The gravitational force on a 70 kg passenger is still roughly 680 N.

2 “Heavier things need more force, so they fall faster.”

More mass means more gravitational force—but also more resistance to acceleration. Both increase in the same proportion, so the acceleration remains g .

3 “In SI, mass and weight are the same thing.”

They are not the same kind of quantity. One is in kilograms and belongs to the body; the other is a force in newtons and belongs to the situation.

4 “ $\Sigma F = ma$ is true in any frame.”

Only in an inertial one. Keep this claim in mind — in Part 3 a crate on an accelerating truck turns it from a caution into a real error.

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Ten lines of Python — and one confident, wrong explanation to take apart.

ACTIVITY C1 · PLOT $N(t)$

You are given a velocity profile $v(t)$ for one elevator trip.

1. Differentiate it numerically to get $a_v(t)$.
2. Compute $N(t) = m(g + a_v)$.
3. Plot $v(t)$, $a_v(t)$ and $N(t)$ on a shared time axis.
4. Mark where the scale reads more than, less than, and exactly the passenger's weight.

Deliverable — the three-panel plot, plus one sentence saying which feature of $v(t)$ produced each feature of $N(t)$.



AI as Critic — not as author

You are handed a fluent, confident, wrong explanation of the floating passengers that blames the altitude. Find the error and write the repair yourself. Only then ask an AI to critique your repair — and judge whether its critique is sound.



MEASURE · do it for real

A bathroom scale filmed in a building elevator, or a phone accelerometer on the same ride, gives a genuine $N(t)$ in thirty seconds. Use your own trace instead of the supplied profile.

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Push the equation to a case whose answer you already know.

$$N = m (g + a_y)$$

1 Set $a_y = 0$

$N = mg$. The everyday case, where the distinction between support force and weight is invisible.

2 Set $a_y = -g$

$N = 0$. Free fall, and the Zero-G arc. The model reproduces the phenomenon we started from.

3 Make a_y large

N grows without limit. A 2 g pull-out doubles the seat force — physically sensible, and what pilots report.



This is the first of six validation moves in the chapter

Limiting cases, units, signs, order of magnitude, an independent method, and comparison with measurement. Name the move you are using each time.

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Part 1 — why motion changes



You can now EXPLAIN

- why a floating passenger is evidence of free fall, not of absent gravity
- what a scale, a seat or a road surface actually reads
- why mass and weight are different kinds of quantity
- which of Newton's laws Dynamics is built on
- why $\Sigma F = ma$ must be written in an inertial frame



You can now DO

- compute a support force from a known acceleration, and the reverse
- convert between mass and weight in SI and FPS without guessing
- read an acceleration off a velocity graph and turn it into a force
- state the frame you are working in before writing an equation
- check a result with a limiting case and say what the check proved

Next — Part 2: we know a net force exists. We cannot use that until we can say exactly which forces act, on what system. Deciding that is a modelling decision, not a sketch.

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