



AI-AUGMENTED ENGINEERING DYNAMICS: A CONVERSATIONAL APPROACH

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Author

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OBSERVE



IDEALIZE



MODEL



SOLVE / ANALYZE



VALIDATE



REPORT

How this course thinks — every week, every problem.

By Taner Onsay, PhD

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

Chapter 5 — Momentum Methods for Particles

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The engineering workflow you will use throughout this book

CHAPTER - 5

PART 1 · ≈ 60 MIN

What Changes a Particle's Momentum?

Two identical objects fall the same distance. One survives the landing and one does not. This Part builds the quantity that connects a force history to a change in motion: the impulse.

Observe

Idealize

Model

Solve / Analyze

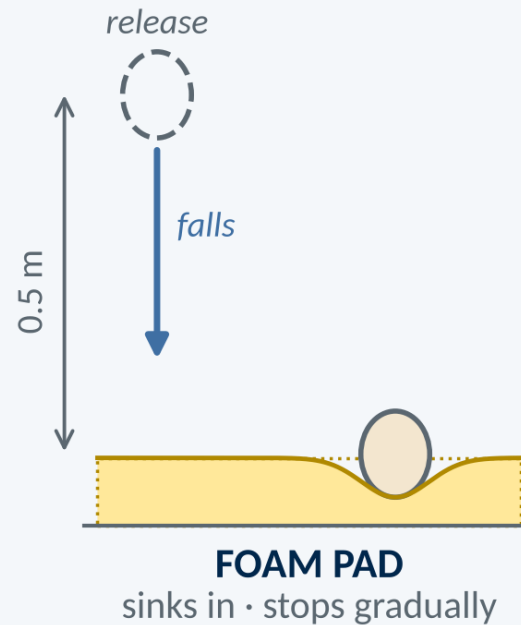
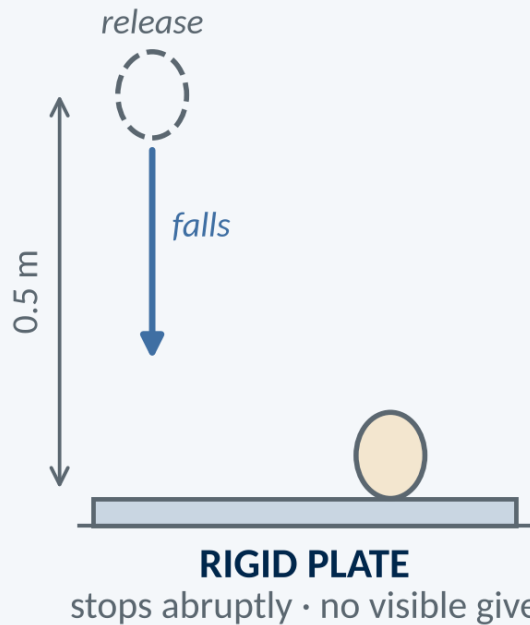
Validate

Report



Same Drop, Different Landing

TWO IDENTICAL OBJECTS · SAME DROP



WHAT WE OBSERVE

- Same object, same 0.5 m drop
- Same speed when it reaches the surface
- Both end at rest, with no rebound
- Only the landing surface differs

A raw egg dropped on the plate cracks. On the foam it survives. What did the foam actually change?



The engineering question for this Part

What does a cushion actually change during a landing — and how could we measure it?

Observe

Idealize

Model

Solve / Analyze

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Report



Make Two Predictions

PREDICTION 1

Which object has the larger change in momentum during the landing?

- A** the egg on the rigid plate
- B** the egg on the foam pad
- C** they are the same

PREDICTION 2

Which object feels the larger peak contact force?

- A** the egg on the rigid plate
- B** the egg on the foam pad
- C** they are the same

PREDICT

Vote on both questions, then write one sentence explaining each choice. Think of momentum as “mass × velocity” for now; we define it precisely next. We return to these predictions at the end of the Part.

Observe

Idealize

Model

Solve / Analyze

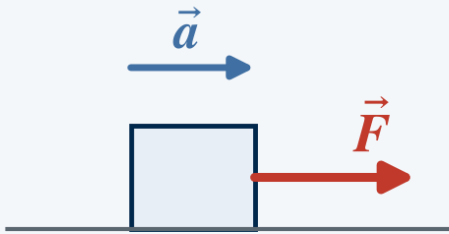
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Force at an Instant, over a Distance, over Time

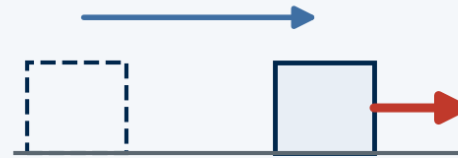
CHAPTER 3 · FORCE-ACCELERATION



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

Force sets the acceleration at one instant.

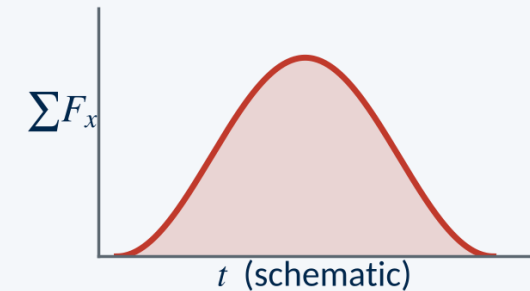
CHAPTER 4 · WORK-ENERGY



$$T_1 + U_{1 \rightarrow 2}^{\text{net}} = T_2$$

Force acting through a displacement changes kinetic energy, a scalar.

CHAPTER 5 · IMPULSE-MOMENTUM



$$\vec{L}_1 + \vec{I}_{1 \rightarrow 2} = \vec{L}_2$$

Force acting over a time interval changes momentum, a vector.

All three come from the same Newton's second law. They differ in what the force is accumulated over: nothing, distance, or time.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

Report



Momentum: Newton's Second Law Restated

DEFINITION

$$\vec{L} = m\vec{v}$$

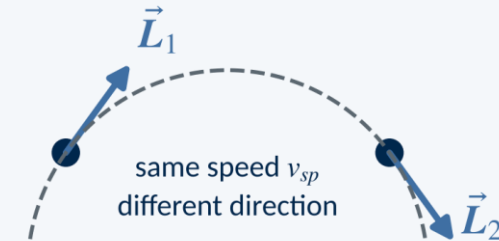
A vector in the direction of the velocity · units kg·m/s

FOR CONSTANT MASS

$$\sum \vec{F} = m\vec{a} = m \frac{d\vec{v}}{dt} = \frac{d(m\vec{v})}{dt} = \frac{d\vec{L}}{dt}$$

$$\sum \vec{F} = \frac{d\vec{L}}{dt}$$

The net force sets how fast momentum changes.



A turn at constant speed v_{sp} still changes $\vec{L}$: direction counts.

NOT A NEW LAW

This is Newton's second law written in momentum form. Nothing new has been assumed.



Quick check: if $\sum \vec{F} = \mathbf{0}$ over an interval, what happens to $\vec{L}$?

It stays constant, in magnitude and in direction.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

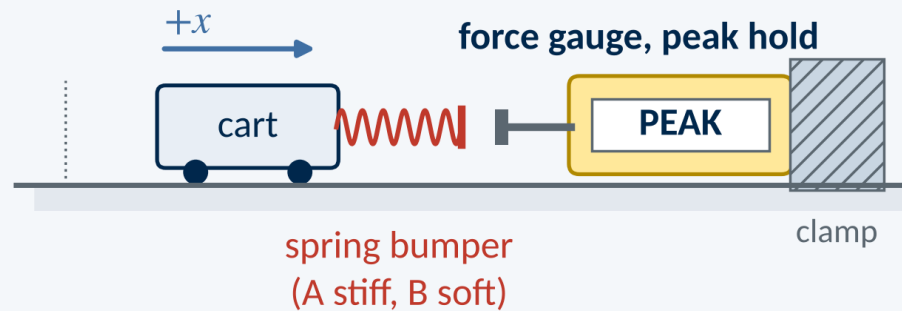
Report



Same Cart, Two Bumpers

FORCE GAUGE · PEAK HOLD · IF PRETESTED

same launch speed every run



PREDICT

- Which run gives the larger peak reading?
- Which contact lasts longer?
- Which run changes the cart's momentum more?

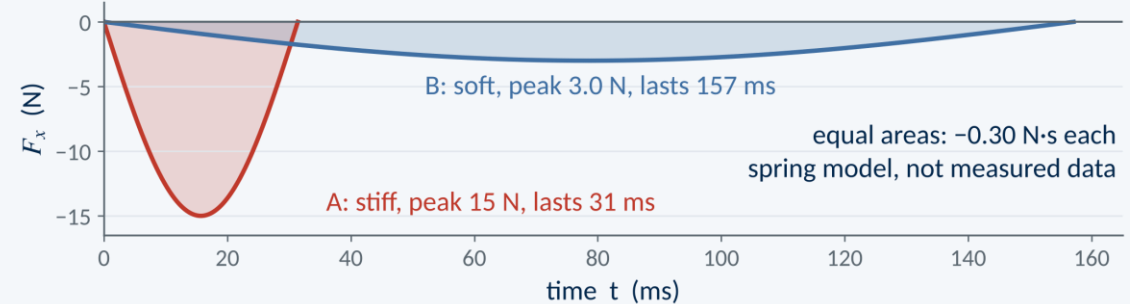
Readings (live run): A _____ N B _____ N

WHAT THE GAUGE CANNOT SHOW

One peak number per run, from a gauge whose response to a 31 ms pulse is unverified.

No force history, so peak force alone cannot establish impulse. The model completes the story.

MODEL, NOT DATA



Observe

Idealize

Model

Solve / Analyze

Validate

Report



Impulse: Accumulated Net Force

DERIVATION

$$\sum \vec{F} = \frac{d\vec{L}}{dt}$$

multiply by dt

$$\sum \vec{F} dt = d\vec{L}$$

integrate from state 1 to state 2

$$\int_{t_1}^{t_2} \sum \vec{F} dt = \vec{L}_2 - \vec{L}_1$$

LINEAR IMPULSE

$$\vec{I}_{1 \rightarrow 2} = \int_{t_1}^{t_2} \sum \vec{F} dt$$

IMPULSE-MOMENTUM PRINCIPLE

$$\vec{L}_1 + \vec{I}_{1 \rightarrow 2} = \vec{L}_2$$

Initial momentum + net impulse = final momentum



A vector

Points along the change in $\vec{L}$. Per component: $I_{x,1 \rightarrow 2} = \int \sum F_x dt$



Units

N·s = kg·m/s, since 1 N = 1 kg·m/s²



Net force

The impulse of one force alone is only its own share of the change.

Observe

Idealize

Model

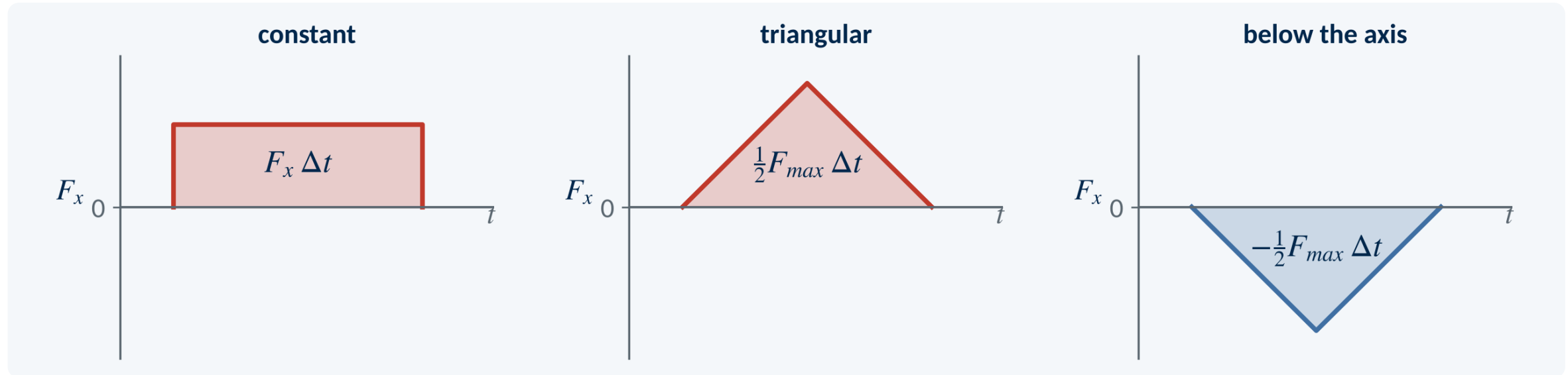
Solve / Analyze

Validate

Report



Impulse Is Signed Area



Peak alone does not decide

A tall, brief pulse and a low, long pulse can carry the same impulse. Only the area counts.



Sign and direction count

Area below the axis is negative: it reduces L_x . If a force changes direction during the interval, $\vec{I}$ need not point along the force at any single instant.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

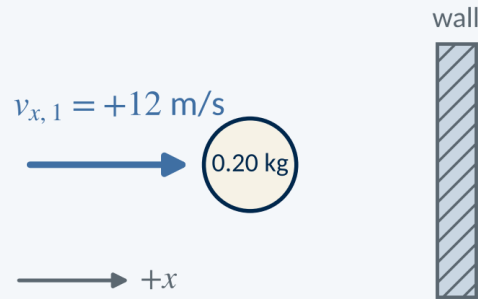
Validate ›

Report



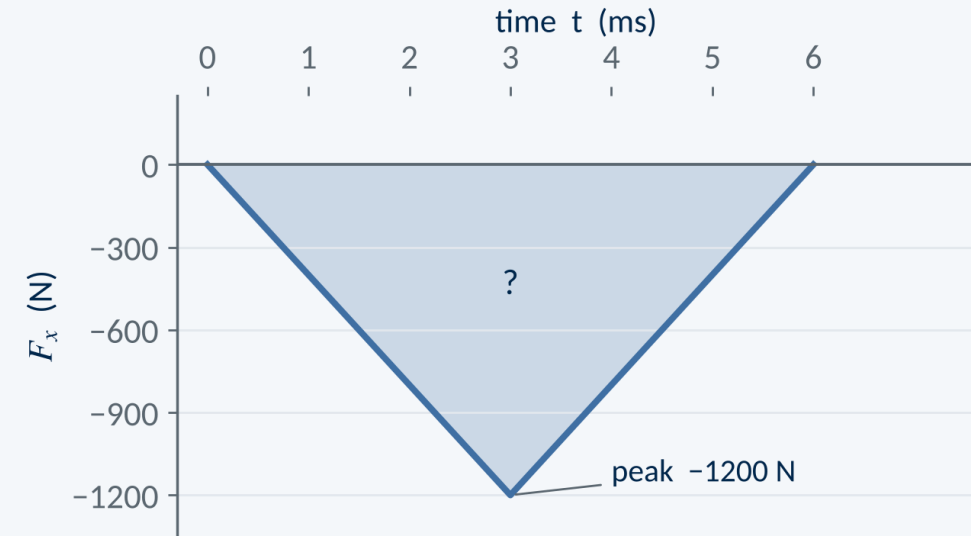
Softball Against a Wall

THE MODEL



- $m = 0.20 \text{ kg}$, $v_{x,1} = +12 \text{ m/s}$
- contact lasts $\Delta t = 6 \text{ ms}$ (0.006 s)
- triangular contact force, peak magnitude 1200 N , acting in $-x$

CONTACT FORCE ON THE BALL



$F_x < 0$: the wall pushes in $-x$, so the graph lies below the axis.

Assumptions: motion along x only. The wall's contact force is the only x -force: gravity is vertical, and air drag is negligible during 6 ms .

PREDICT

Will the ball rebound? Faster or slower than 12 m/s ?

Observe

Idealize

Model

Solve / Analyze

Validate

Report



Does the Ball Rebound?

1

Impulse = signed area

$$I_{x,1 \rightarrow 2} = -\frac{1}{2}(1200 \text{ N})(0.006 \text{ s}) = -3.60 \text{ N} \cdot \text{s}$$

2

Initial momentum

$$L_{x,1} = mv_{x,1} = (0.20 \text{ kg})(+12 \text{ m/s}) \\ = +2.40 \text{ kg} \cdot \text{m/s}$$

3

Final momentum

$$L_{x,2} = L_{x,1} + I_{x,1 \rightarrow 2} = 2.40 + (-3.60) \\ = -1.20 \text{ kg} \cdot \text{m/s}$$

4

Final velocity

$$v_{x,2} = \frac{L_{x,2}}{m} = -6.0 \text{ m/s}$$

5

Average force

$$F_{avg,x} = \frac{I_{x,1 \rightarrow 2}}{\Delta t} = -600 \text{ N}$$

WHAT THE MINUS SIGN MEANS

$v_{x,2} < 0$: the ball now moves in $-x$, away from the wall, at speed $v_{sp,2} = 6.0 \text{ m/s}$. The wall's impulse first stopped the ball ($2.40 \text{ N} \cdot \text{s}$), then pushed it back ($1.20 \text{ N} \cdot \text{s}$).



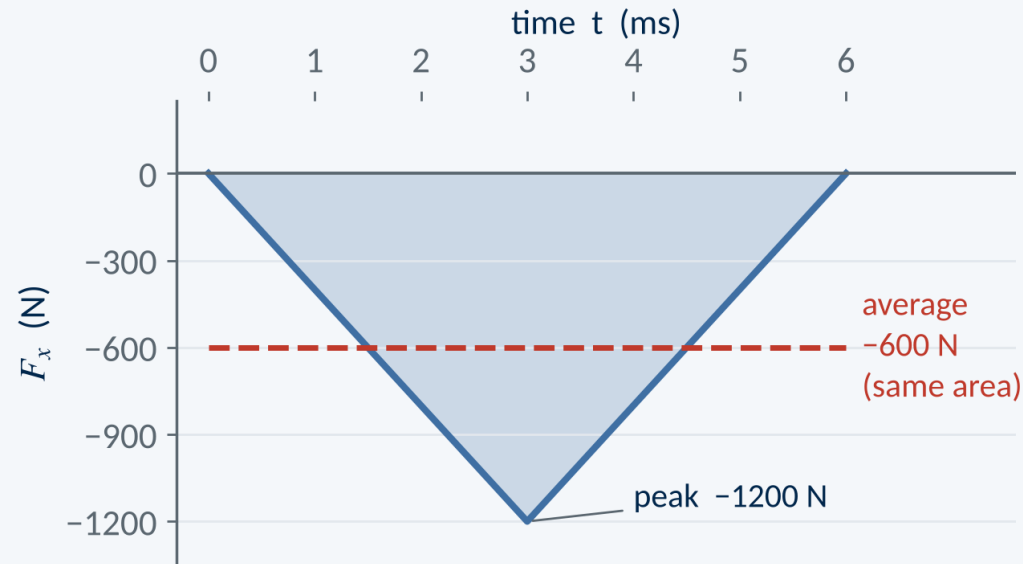
Does peak force alone decide rebound?

No. With a 1200 N triangular peak, the ball just stops when $\frac{1}{2}(1200 \text{ N})\Delta t = 2.40 \text{ N} \cdot \text{s}$, so the pulse must last at least 4 ms . Anything longer gives rebound.



Average Force Is Not Peak Force

THE SAME PULSE, ITS AVERAGE



$$\vec{F}_{avg} = \frac{\vec{I}_{1 \rightarrow 2}}{\Delta t}$$

Net force

$\sum \vec{F}$, the sum of all external forces. Its impulse changes $\vec{L}$.

Contact force

The push of a surface (here, the wall). Usually dominant in a collision.

Average force

The constant force with the same impulse over the same Δt .

Peak force

Peak force is the largest force magnitude reached during contact. It is often important in assessing damage or injury, but it is not the only determining factor.

Contact duration

$\Delta t = t_2 - t_1$, how long the surfaces touch.

Impulse fixes the area under the curve — not its shape, and not its peak.

Observe

Idealize

Model

Solve / Analyze

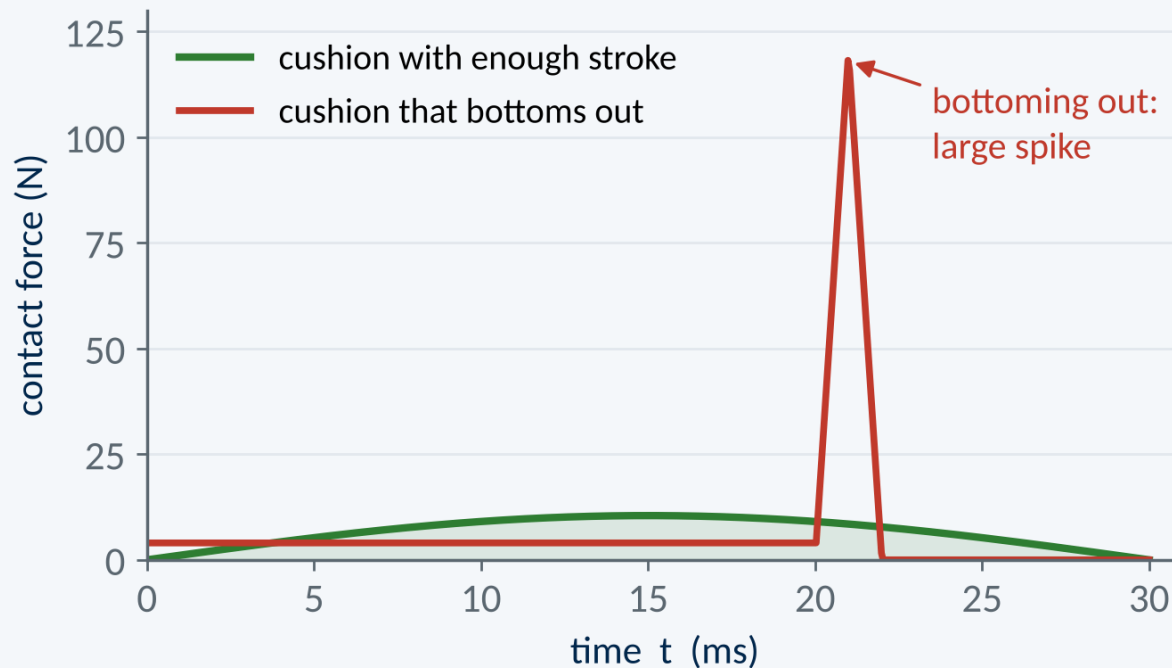
Validate

Report



Designing a Softer Stop

SAME IMPULSE, TWO CUSHIONS



Equal areas. Illustrative shapes, not measured data.



Longer stopping time

For a fixed momentum change, doubling Δt halves the average net force. It does not by itself guarantee a lower peak.



Thickness and stiffness matter

The force history and the material response set the peak. A cushion that is too thin or too soft bottoms out and spikes.



Stopping distance (Chapter 4)

The cushion must also absorb the kinetic energy T_1 over its stroke. More stroke means a lower average force over the distance.

Observe

Idealize

Model

Solve / Analyze

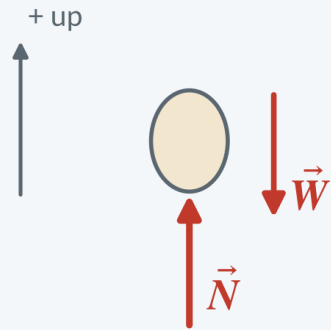
Validate

Report



Same Momentum Change, Different Contact Impulse

MODEL · 60 g, 0.5 m DROP



free-body diagram, during contact

- $m = 0.060 \text{ kg}$, $h = 0.5 \text{ m}$, no air resistance
- impact speed $v(2gh) \approx 3.13 \text{ m/s}$
- $v_{y,1} = -3.13 \text{ m/s}$, $v_{y,2} = 0$

UPWARD POSITIVE, DURING CONTACT

$$I_{y,1 \rightarrow 2}^{(N)} - mg\Delta t = m\Delta v_y$$

contact impulse – gravity impulse = net momentum change (the same 0.1878 N·s for both landings)

	Rigid plate	Foam pad
Stopping interval Δt (illustrative)	1 ms	30 ms
Net impulse $m\Delta v_y$	0.1878 N·s	0.1878 N·s
Gravity impulse $mg\Delta t$	0.0006 N·s	0.0177 N·s
Contact impulse	0.1884 N·s	0.2055 N·s
Average contact force	$\approx 188 \text{ N}$	$\approx 6.9 \text{ N}$

Same net impulse. Foam: slightly larger contact impulse, yet $\approx 27\times$ smaller average contact force.

Observe

Idealize

Model

Solve / Analyze

Validate

Report



Impulsive and Non-Impulsive Forces

COMPARE IMPULSES, NOT FORCES

Gravity's share of the velocity change during contact:

$$\frac{g\Delta t}{\Delta v_{sp}}$$

Rigid, 1 ms

$$(9.81)(0.001) / 3.13 = 0.31\%$$

neglect gravity

Foam, 30 ms

$$(9.81)(0.030) / 3.13 = 9.4\%$$

keep gravity



Non-impulsive forces

Forces whose impulse over the contact interval is small compared with $m\Delta v_{sp}$: often gravity, air drag, rolling resistance. Contact or not, the test is the impulse.



Impulsive forces

The normal contact force during a collision is usually the dominant force. It must never be neglected.



Compare within one direction

At the wall, gravity is vertical and the contact impulse is horizontal. Gravity adds nothing in x ; in y it changes v_y by only $g\Delta t = 0.059$ m/s.

Observe

Idealize

Model

Solve / Analyze

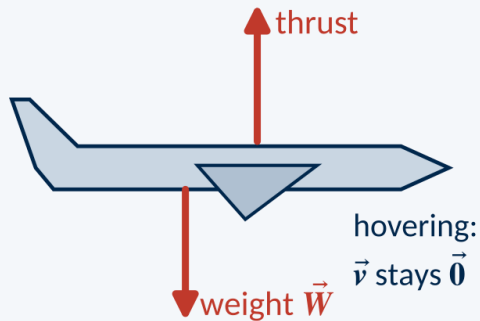
Validate

Report



Three Quick Checks

1 · A HOVERING VTOL



A 100 Mg aircraft hovers for 10 s. Find the impulse of gravity, the impulse of the thrust, and the net impulse.

Gravity: 9810 kN·s down. Thrust: 9810 kN·s up. **Net: zero**, so $L^{\rightarrow}$ does not change.

2 · TRUE OR FALSE?

“Two landings with equal momentum changes must have equal average forces.”

False, unless Δt is also equal. The average force is the impulse divided by Δt .

3 · TRUE OR FALSE?

“Zero net impulse from t_1 to t_2 means the momentum was constant the whole time.”

False. It guarantees only $L^{\rightarrow}_2 = L^{\rightarrow}_1$. A car can speed up, then brake back to its original velocity.



Is the AI Right About the Foam?



AI-GENERATED EXPLANATION

“The foam reduces the impulse on the egg, which is why it does not break.”



Your diagnosis first — 2 minutes

- What is wrong with the statement?
- Use the numbers from the landing slide.
- Write a one-sentence explanation you could defend.

A DEFENSIBLE EXPLANATION

The foam does **not** reduce the impulse. The net impulse is the same for both landings ($0.1878 \text{ N}\cdot\text{s}$), and the foam's contact impulse is slightly larger ($0.2055 \text{ N}\cdot\text{s}$).

The foam spreads that impulse over a longer time (30 ms instead of 1 ms), so the average contact force drops from about 188 N to about 6.9 N.

A lower average does not guarantee a lower peak; foam thick enough not to bottom out usually lowers the peak too, and the egg survives.

AI is a tool to critique, not an authority: test every claim against the model and the numbers.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

Report

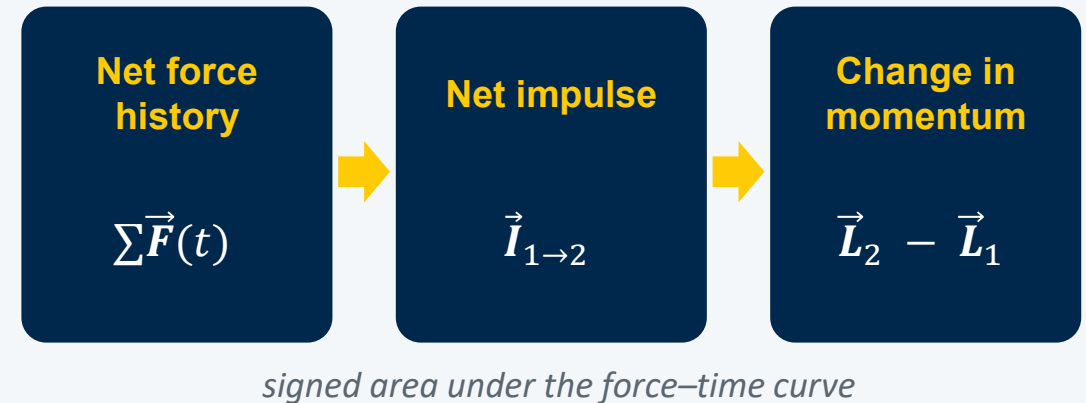


Resolving the Landing

YOUR PREDICTIONS, RESOLVED

- 1 **Larger change in momentum?**
The same. Both go from 3.13 m/s downward to rest.
- 2 **Larger peak contact force?**
In practice, the rigid plate. Its average contact force is $\approx 27\times$ larger. A lower average does not by itself guarantee a lower peak: the foam's response, and whether it bottoms out, set the peak.

THE CORE RELATIONSHIP



You should now be able to explain why equal momentum changes can come with very different forces, read impulse from a force–time graph, and decide when a force such as gravity may be neglected.

Next — Part 2: real problems have several time-varying forces acting in different directions. How do we account for all of them systematically?

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

Report

CHAPTER - 5 · PART 1

APPENDIX

Appendix — Supplemental Material

A1 data-plausibility audit · A2 pothole force record · A3 impulse from sampled data · A4 Phyphox accelerometer experiment · A5 when gravity matters. Not required for the Part 1 learning objectives.

Observe



Idealize



Model



Solve / Analyze



Validate



Report

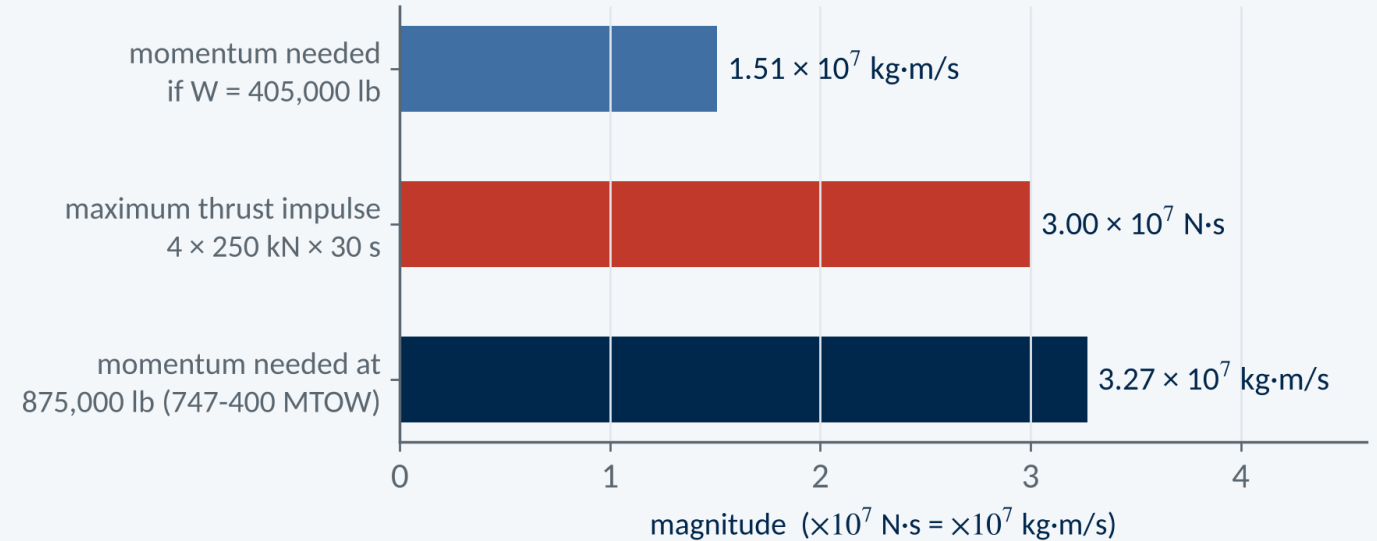


Can a 747 Take Off on These Numbers?

THE CLAIMS (UNVERIFIED)

- 4 engines, each up to about 250 kN of thrust
- about 30 s to reach takeoff speed
- takeoff speed 184 mph (82.3 m/s)
- aircraft weight stated as 405,000 lb

Momentum needed = $m \times \text{takeoff speed}$. The thrust impulse is an upper bound: all four engines at full thrust for the whole 30 s.



1

Is 405,000 lb a plausible takeoff weight? Re-check against a published maximum takeoff weight.

2

Even at full thrust, what forces reduce the net impulse below the thrust impulse?

3

Can impulse alone tell us how much fuel was burned? What else would we need?

Observe



Idealize



Model



Solve / Analyze



Validate

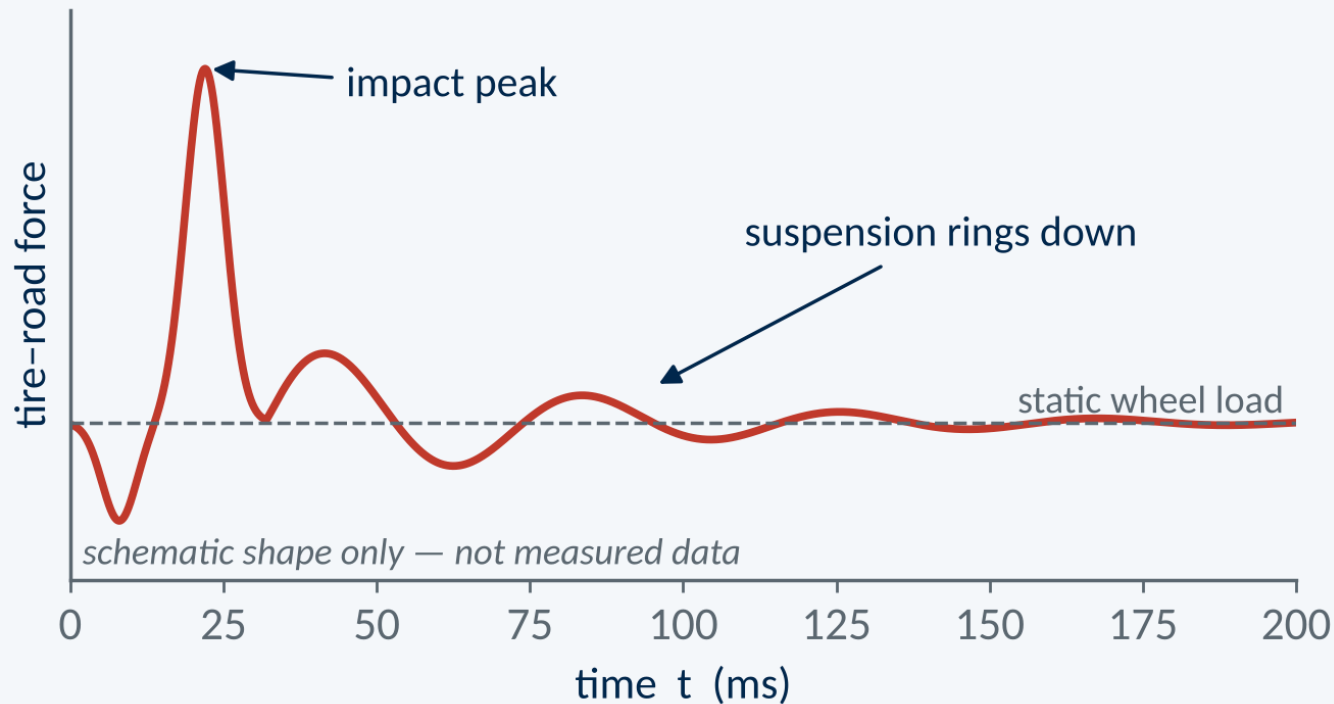


Report



A Tire Hits a Pothole

TIRE-ROAD FORCE vs TIME



Area relative to the static load

A qualitative reading: the extra road impulse. The suspension forces also act on the wheel.



The impact peak

The impact peak is an important factor in tire and rim damage. A brief, sharp peak can carry a modest impulse.



The ring-down

The suspension oscillating after the impact: the subject of Chapter 10.

Observe ›

Idealize ›

Model ›

Solve / Analyze ›

Validate ›

Report



Impulse from Sampled Force Data

TRAPEZOIDAL RULE

$$I_{x,1 \rightarrow 2} \approx \sum \frac{1}{2} (F_{x,k} + F_{x,k+1}) \Delta t_s$$

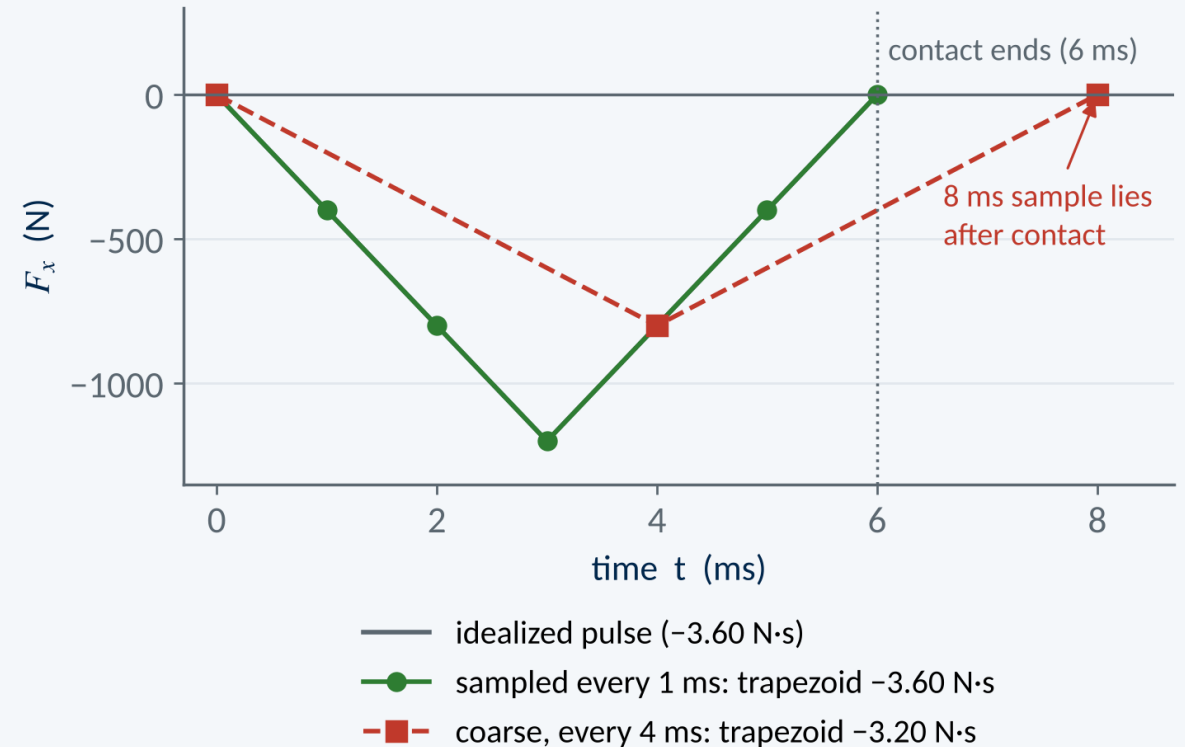
Δt_s = sampling interval; $F_{x,k}$ = the k -th force sample



AI as coding companion: ask an AI tool to write the trapezoidal sum for your sampled force data.



You validate: units, zero-force baseline, sampling interval vs pulse duration, and $m\Delta v_x$. At 4 ms the 6 ms pulse is only coarsely reconstructed.



Observe

Idealize

Model

Solve / Analyze

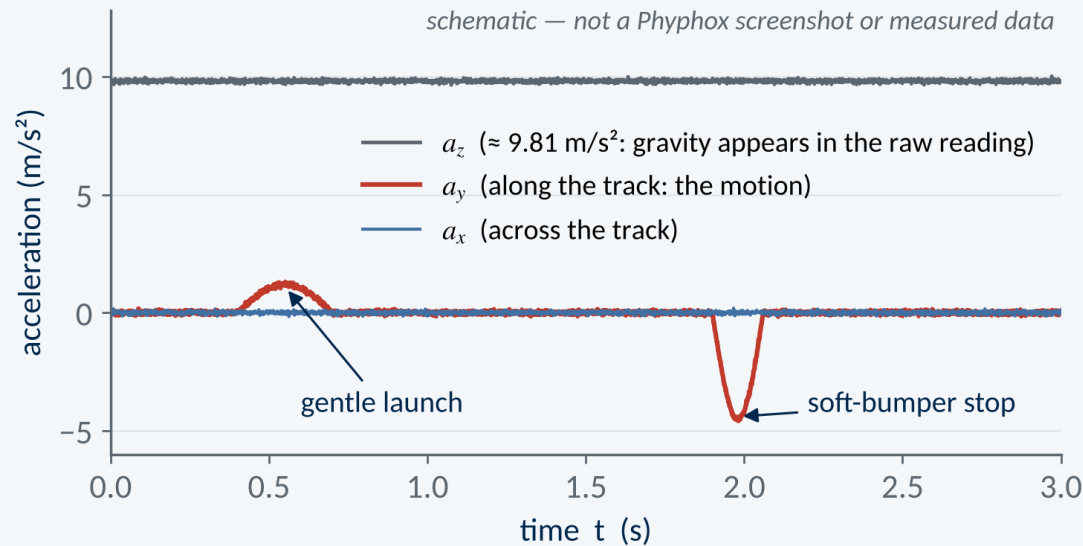
Validate

Report



A Phyphox Accelerometer Experiment

RECORDED ACCELERATION COMPONENTS



Analyze: integrate $a_y(t)$ numerically (trapezoids) over the stop to get Δv_y ; net impulse $I_{y,1 \rightarrow 2} = m \int a_y dt$.

Compare with the momentum change $m(v_{y,2} - v_{y,1})$ measured independently from video.



Set-up and axes

Phone in a padded holder, strapped flat to a cart; its long (y) axis along the track. A slow roll into a soft bumper. No drops.



Raw vs gravity-corrected

“Acceleration with g ” includes gravity ($\approx 9.81 \text{ m/s}^2$ on a_z here); “Acceleration (without g)” removes it. Use the axis along the motion.



Sampling and uncertainty

Check the sampling rate. Offsets, noise and tilt accumulate when you integrate, so report a range, not one number.

Observe

Idealize

Model

Solve / Analyze

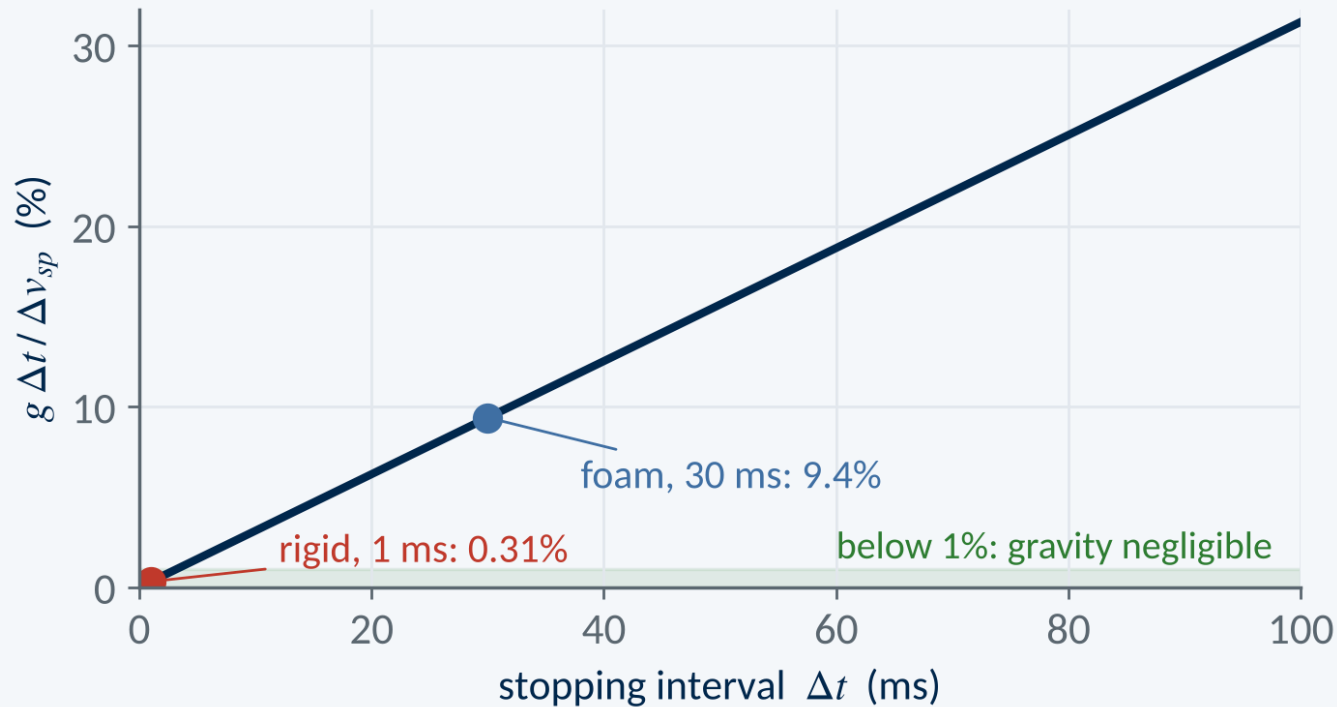
Validate

Report



How Long Before Gravity Matters?

0.5 m DROP · IMPACT AT 3.13 m/s



GRAVITY'S SHARE

$$\frac{g \Delta t}{\Delta v_{sp}}$$

grows in proportion to the stopping interval: 1 ms $\rightarrow$ 0.31%, 10 ms $\rightarrow$ 3.1%, 30 ms $\rightarrow$ 9.4%, 100 ms $\rightarrow$ 31%



At what stopping interval does gravity contribute 5% of the momentum change for this drop? How does the answer change for a 2 m drop?

Observe

Idealize

Model

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