

AI-AUGMENTED ENGINEERING DYNAMICS: A CONVERSATIONAL APPROACH

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Observe



Idealize



Model



Solve / Analyze



Validate



Report

The engineering workflow you will use throughout this book

by Taner Onsay

CHAPTER - 2

PART 7 · ≈ 65 MIN

Constraints and Relative / Dependent Motion

When one thing moves, what must another do? And what does an observer who is moving actually see? One principle each, two examples each — then the bridge to Chapter 3.

7

Observe

Idealize

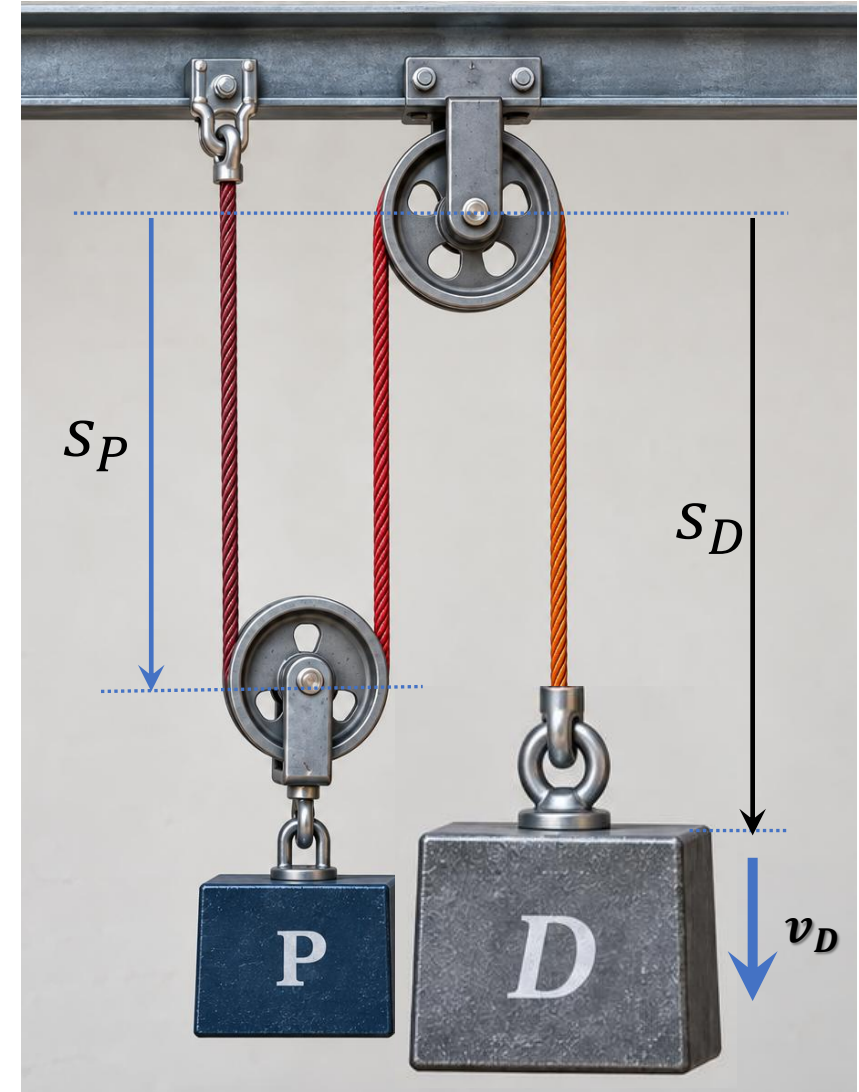
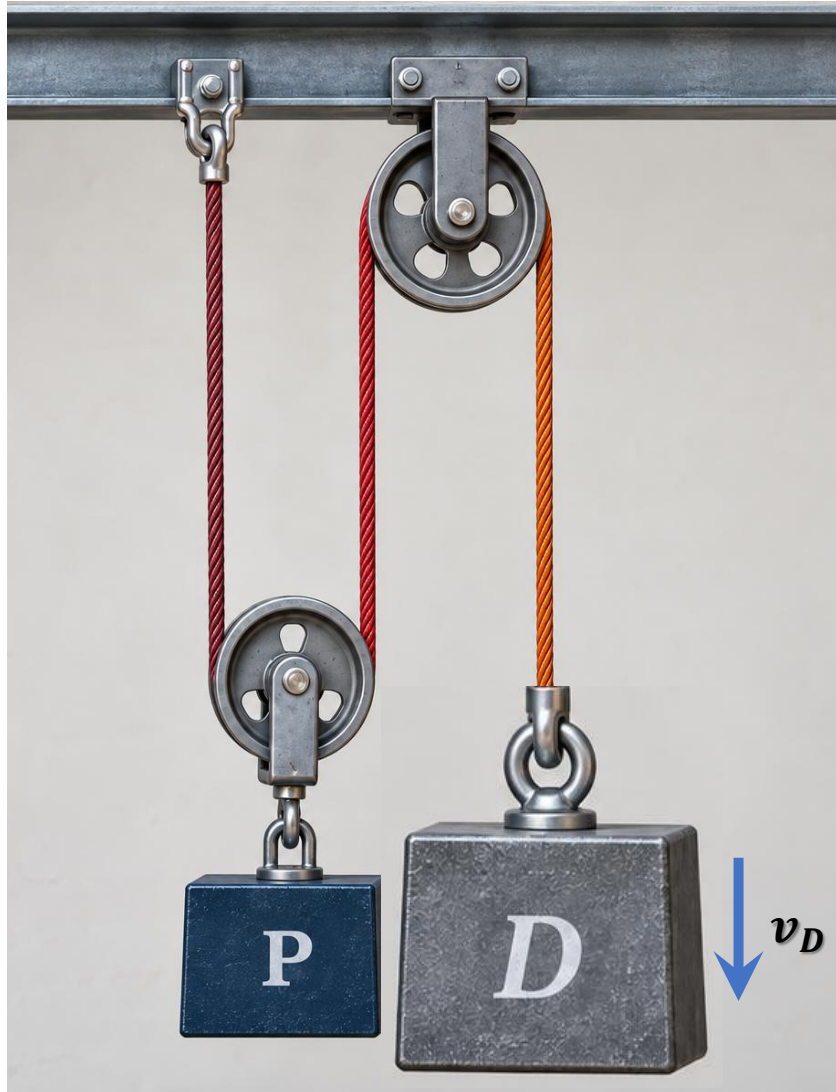
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The block-D is moving down with a speed v_D .
Is the speed of block P same as D, or less, or more?

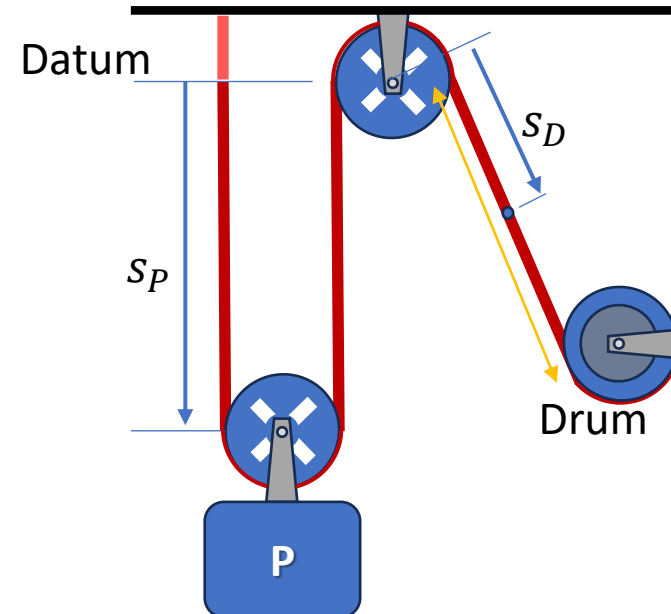
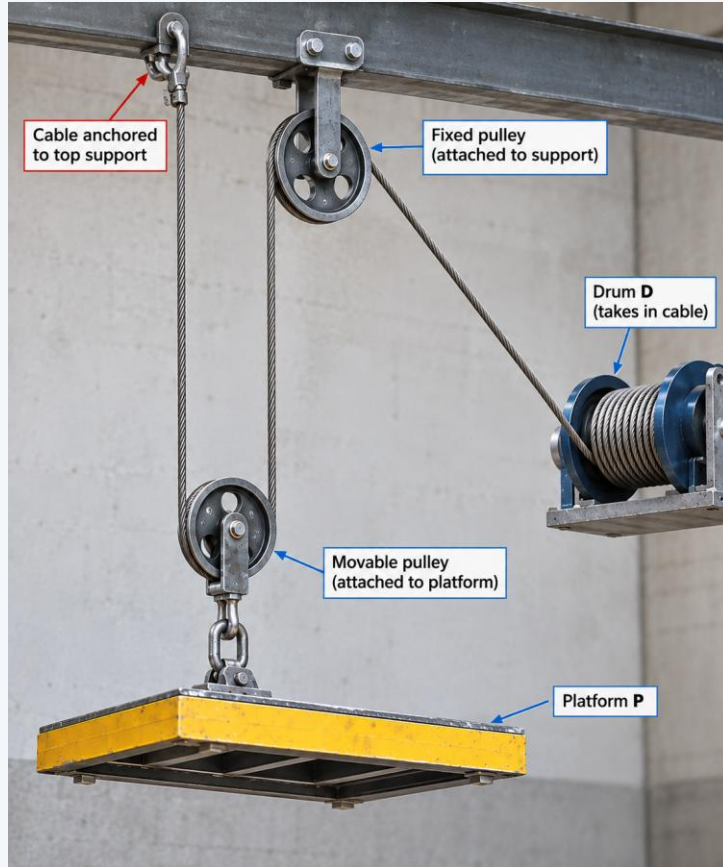




The drum pulls cable in at 1 m/s. How fast does the platform rise?

DRUM LIFT

A construction hoist uses one fixed sheave and one movable sheave attached to the platform. The drum takes in cable to lift the platform.



PREDICT

Drum pulls cable in at 1 m/s. The platform rises at:

- A) 1 m/s
- B) 0.5 m/s
- C) 2 m/s



Before any equation — say it in words

Which pieces of cable get shorter when the platform rises? How many?



Concept check — does a track's slope matter?

No: a cable along the track constrains distance ALONG the path, whatever the slope.

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Geometric constraint → position relation → differentiate → velocity relation → differentiate → acceleration relation

1 Geometric constraint

The cable does not stretch: its total length L is constant.

2 Position relation

Choose a fixed datum and positive directions. Write L as a sum of the segments that CAN change length:

$$L = 2s_P + s_D + (\text{constant arcs}).$$

3 Differentiate → velocities

$$0 = 2v_P + v_D$$

Signs follow the datum; a negative result means "opposite to the direction I assumed".

4 Differentiate → accelerations

$$0 = 2a_P + a_D$$

Same coefficients when the geometry is fixed — and NOT when it is not (next example).

Drop the segments that never change length. Keep one datum and one sign convention. Then it is Chapter 1 differentiation — twice.

Answer to the vote: $0 = 2v_P + v_D$ with $v_D = +1 \text{ m/s}$ (paid in, positive as drawn) $\rightarrow v_P = -0.5 \text{ m/s}$: the platform rises at 0.5 m/s .



Drum takes up cable at 0.6 m/s, accelerating at 0.10 m/s². Platform velocity and acceleration? Cable speed to raise it 12 m in 40 s?

THE MODEL

Particle	the platform (its sheave axle)
Datum	the fixed top sheave axis; s_p and s_D measured DOWN from it
Constraint	inextensible cable: $L = 2s_p + s_D + (\text{arcs}) = \text{const}$
Knowns	$v_D = +0.6 \text{ m/s}$, $a_D = +0.10 \text{ m/s}^2$ (cable point moving toward the drum, i.e. down)
Unknowns	v_p , a_p ; cable speed for 12 m in 40 s
Assumptions	cable taut and inextensible; sheaves ideal; vertical segments

SOLVE

$$0 = 2v_p + v_D \rightarrow v_p = -0.30 \text{ m/s (up)}$$

$$0 = 2a_p + a_D \rightarrow a_p = -0.05 \text{ m/s}^2 \text{ (speeding up)}$$

$$12 \text{ m in } 40 \text{ s} \rightarrow v_p = 0.30 \text{ m/s} \rightarrow \text{cable at } 0.60 \text{ m/s}$$



Change the datum.

Measure the platform UP from the floor:

$s' = h - s_p$. The relation becomes

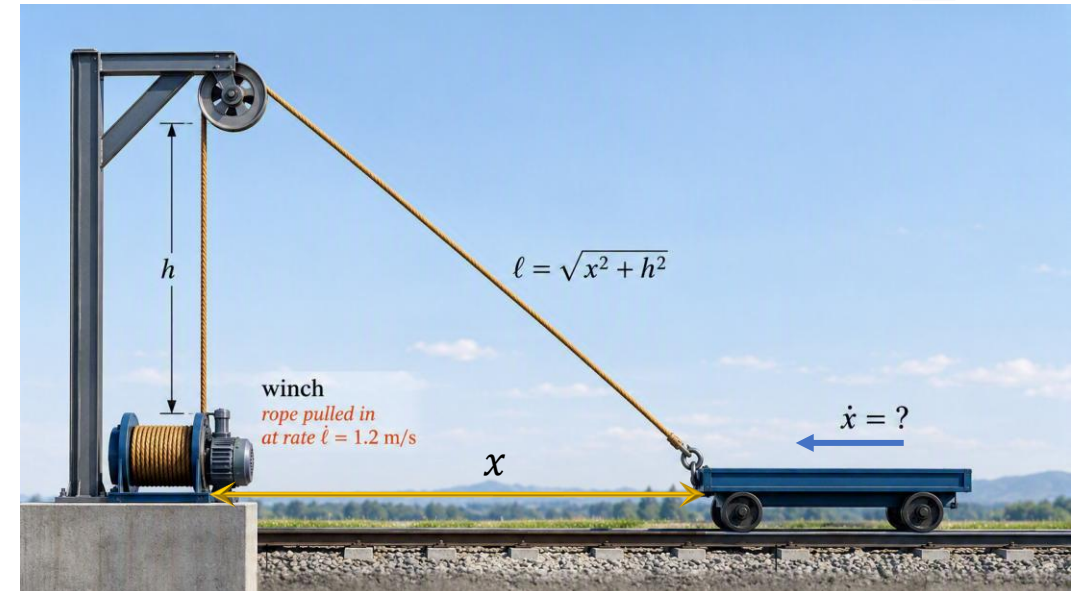
$$0 = -2v' + v_D \rightarrow v' = +0.30 \text{ up.}$$

Same physics.



PREDICT

A cart on a track is towed by a rope that runs over a high pulley to a winch. The rope is pulled in at a steady 1.2 m/s (constant speed). Does the cart move at 1.2 m/s? Always? (constant speed?)

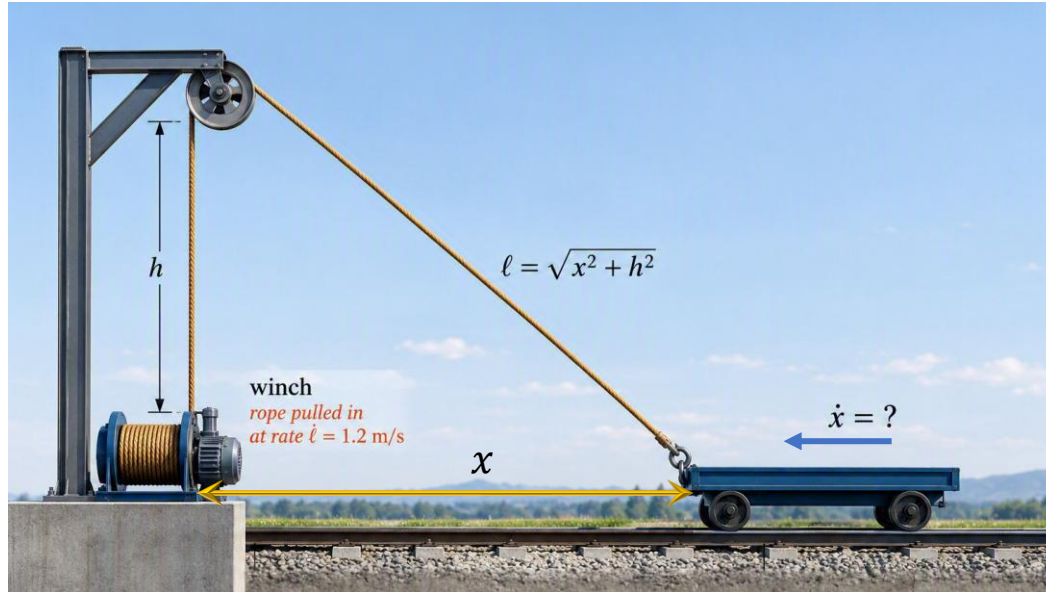


Commit: faster · slower · exactly 1.2 · it depends on where the cart is.

And a second vote: with the rope pulled at CONSTANT speed, is the cart accelerating?



Variable geometry: the rope length depends on x through Pythagoras



THE MODEL

Particle	the cart
Coordinate	x from the pole base along the track, positive away from the pole
Constraint	rope from pulley to cart: $\ell = \sqrt{x^2 + h^2}$, with $h = 4$ m
Knowns	$\ell = -1.2$ m/s (segment shortening at the winch rate), $\ddot{\ell} = 0$; instant $x = 6$ m $\rightarrow \ell = 7.21$ m
Unknowns	$\dot{x}$ and $\ddot{x}$ at this instant
Assumptions	rope taut, inextensible; pulley small; track straight and level

POSITION RELATION

$$\ell^2 = x^2 + h^2$$



The cart moves **FASTER** than the rope — and accelerates even though the rope speed is constant

SOLVE: Differentiate $\ell^2 = x^2 + h^2$

$$2\ell\dot{\ell} = 2x\dot{x} \rightarrow \dot{x} = (\ell/x)\dot{\ell} = (7.21/6)(-1.2) = -1.44 \text{ m/s}$$

$$\dot{\ell}^2 + \ell\ddot{\ell} = \dot{x}^2 + x\ddot{x} \rightarrow \ddot{x} = (\dot{\ell}^2 - \dot{x}^2)/x \quad (\ddot{\ell} = 0)$$

$$\ddot{x} = (1.44 - 2.07)/6 = -0.105 \text{ m/s}^2$$

The cart approaches the pole at 1.44 m/s — 20% faster than the rope — and its speed keeps growing at 0.105 m/s² although the winch never changes rate. The ratio ℓ/x is not a constant; it is the geometry, and the geometry is moving.



Far away ($x \gg h$): $\ell/x \rightarrow 1$, so $\dot{x} \rightarrow \dot{\ell}$ and $\ddot{x} \rightarrow 0$.
Rope and cart move together. ✓



Near the pole ($x \rightarrow 0$): the ratio blows up — the model breaks (rope near-vertical; the cart would lift). Know where your model stops.



Dimensions. $(\text{m/s})^2/\text{m} = \text{m/s}^2$. ✓ **Sign.** $\ddot{x} < 0$ with $\dot{x} < 0$: speeding up toward the pole. ✓



Why this example

Fixed geometry: constant ratios.

Variable geometry: ratios that move — and an acceleration from nowhere.



Dashcam versus overhead camera: the same two cars, two very different pictures

Dash Cam View



From car A: car B appears to drift and turn; the road slides past.

Overhead View



Both cars on the road; A straight, B on the curve; same instant.



Predict — the radar says "closing at 5 m/s"

Is the car ahead braking? Are you accelerating? Can you tell from the radar alone? (No. A closing rate is a DIFFERENCE. It does not say who is doing what.)



What each camera sees

The overhead camera sees absolute motion: $\vec{r}_A$ and $\vec{r}_B$ from a fixed origin. The dashcam sees only $\vec{r}_B - \vec{r}_A$: where B is relative to A.

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Model

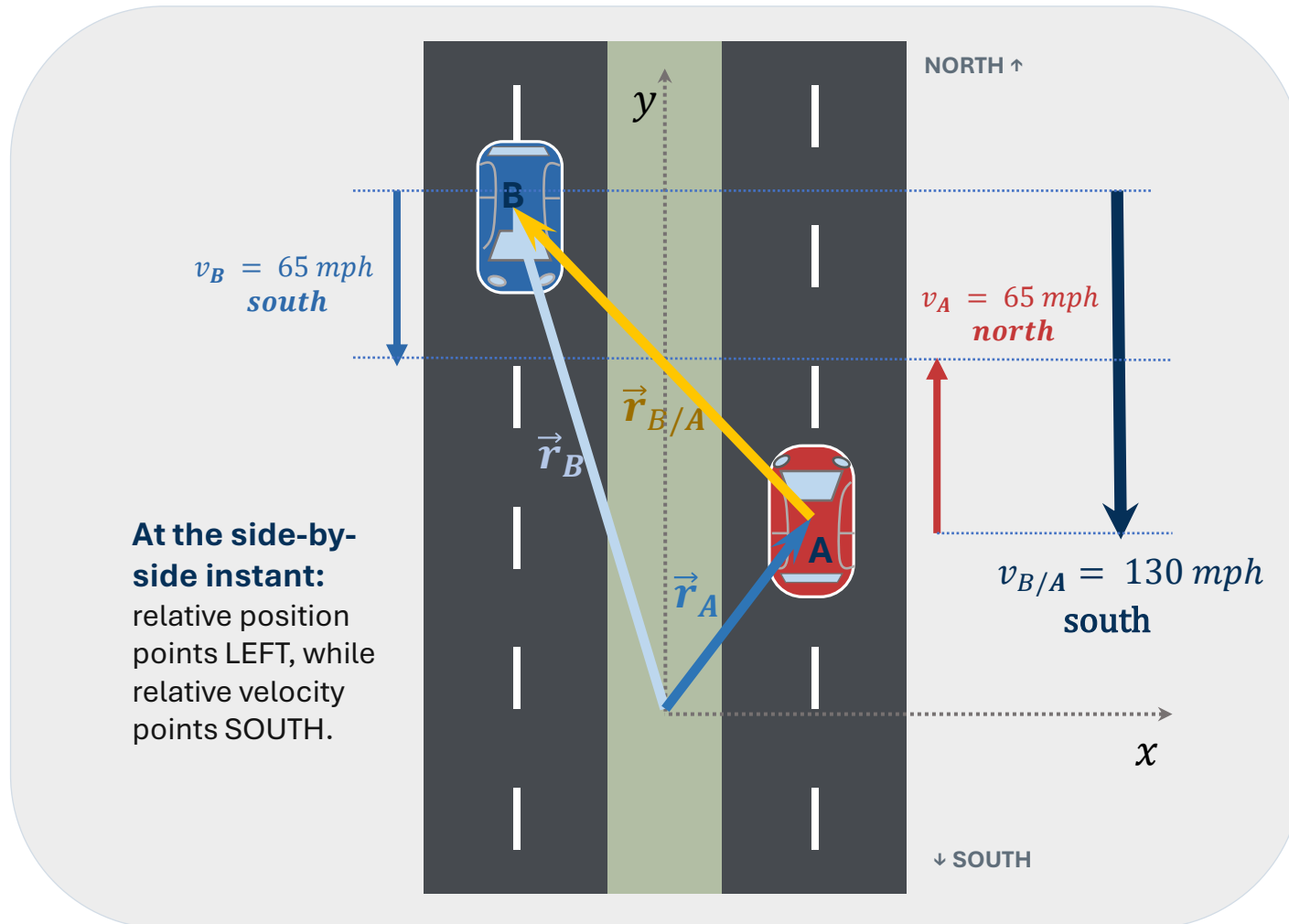
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Where B is now relative to A $\neq$ how B is moving relative to A



RELATIVE VELOCITY

$$\begin{aligned}\vec{v}_{B/A} &= \vec{v}_B - \vec{v}_A \\ &= (-65\hat{j}) - (+65\hat{j}) \\ &= -130\hat{j} \text{ mph}\end{aligned}$$

WHERE IS B?

$\vec{r}_{B/A}$ points from A to B.
Side-by-side $\rightarrow$ directly left.

HOW IS B MOVING?

$\vec{v}_{B/A}$ is tangent to B's path as seen from A $\rightarrow$ due south.

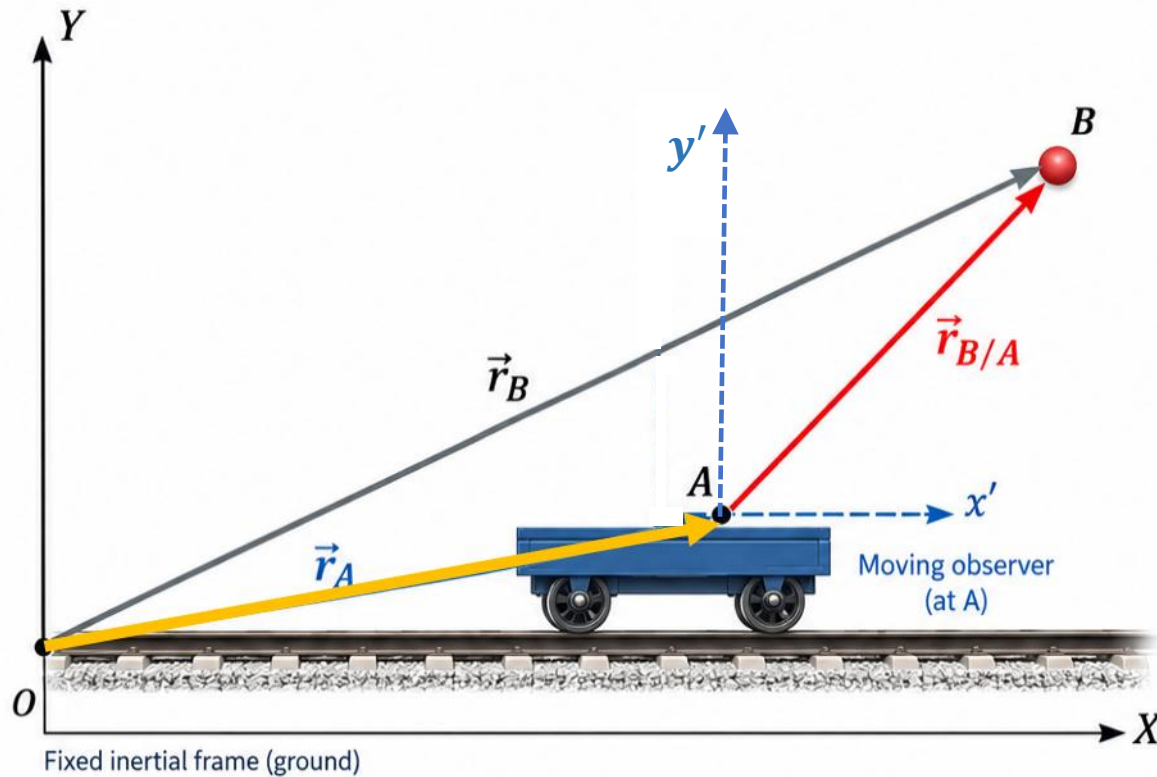
KEY IDEA

Line of sight $\vec{r}_{B/A}$ and relative velocity $\vec{v}_{B/A}$ need not point in the same direction.



Relative Position, Velocity, and Acceleration

Differentiate twice. Valid only while the observer's axes is fixed (meaning only translate, do not rotate).



OBSERVER A TRANSLATING ONLY

Position relation

$$\vec{r}_B = \vec{r}_A + \vec{r}_{B/A}$$

Velocity relation

$$\vec{v}_B = \vec{v}_A + \vec{v}_{B/A}$$

Acceleration relation

$$\vec{a}_B = \vec{a}_A + \vec{a}_{B/A}$$

$\vec{r}_{B/A}$ = "B as seen from A". $\vec{v}_{B/A} = -\vec{v}_{A/B}$
Vector differences — draw the triangle.

Caveat, stated once and meant: these differences are correct only for an observer whose axes TRANSLATE. A rotating observer (a turning car's own frame) is Chapter 6.



$\vec{v}_{B/A}$ is what A would measure with its own instruments. Nothing about it says who is "really" moving.

1

Same velocity → zero relative velocity

Two cars side by side at 25 m/s: $\vec{v}_{B/A} = 0$.
To A, B is parked. A radar on A reads 0.

2

Perpendicular velocities

A north at 25, B east at 25: $\vec{v}_{B/A} = (25, -25)$ m/s
B moves south-east at 35 m/s as seen from A.

3

Concept check

A at 3 m/s along $+x$; B at 4 m/s at angle θ .
Which θ makes $|\vec{v}_{B/A}|$ smallest? ($\theta = 0$: parallel velocities. $|\vec{v}_{B/A}| = 1$ m/s.)



Misconception — “ $\vec{v}_{A/B}$ and $\vec{v}_{B/A}$ are the same”

They are negatives of each other.
The subscript names the observer; read it every time.



Misconception — “constant closing rate ⇒ nobody is accelerating”

$\vec{a}_{B/A} = 0$ means only that $\vec{a}_B = \vec{a}_A$.
Both cars could be braking hard together.



AI AS CRITIC

“I assumed $\vec{a}_{B/A} = \vec{a}_B - \vec{a}_A$. Under what condition is this wrong?” — the AI should name rotating observers; if it does not, you have found a gap in its answer.

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What will A's radar report about B? Relative velocity and relative acceleration — with B's acceleration assembled in n–t first



The step everyone skips: B is on a curve, so B has a normal acceleration whether or not it brakes. Find its direction from the sketch (toward the center).

THE MODEL

Particles

cars A and B (mass centers)

Frames

fixed x (east), y (north); observer A translating (its lane is straight — axes do not rotate)

Car A

$\vec{v}_A = 22 \text{ m/s north}$; $\vec{a}_A = 1.5 \text{ m/s}^2 \text{ north}$

Car B

ramp $\rho = 120 \text{ m}$; heading 35° east of north; $v_B = 15 \text{ m/s}$; $a_t = -2.0 \text{ m/s}^2$ (braking); turning right (center to its right)

Unknowns

$\vec{v}_{B/A}$, $\vec{a}_{B/A}$ — what A's radar reports

Decision

Assemble $\vec{a}_B = a_t \hat{u}_t + \left(\frac{v_B^2}{\rho}\right) \hat{u}_n$ in n–t FIRST, convert to x–y, then subtract



$\vec{v}_{B/A} = 13.0 \text{ m/s}$ heading east-south-east; $\vec{a}_{B/A} = 4.2 \text{ m/s}^2$ almost straight south

SOLVE

$$\hat{u}_t = (\sin 35^\circ, \cos 35^\circ) = (0.574, 0.819); \quad \hat{u}_n = (\cos 35^\circ, -\sin 35^\circ) = (0.819, -0.574)$$

$$\vec{v}_B = 15 \hat{u}_t = (8.60, 12.29) \text{ m/s}; \quad a_n = 15^2/120 = 1.875 \text{ m/s}^2$$

$$\vec{a}_B = -2.0 \hat{u}_t + 1.875 \hat{u}_n = (0.39, -2.71) \text{ m/s}^2$$

$$\vec{v}_{B/A} = \vec{v}_B - \vec{v}_A = (8.60, -9.71) \text{ m/s} \rightarrow 13.0 \text{ m/s}, 48^\circ \text{ south of east}$$

$$\vec{a}_{B/A} = \vec{a}_B - \vec{a}_A = (0.39, -4.21) \text{ m/s}^2 \rightarrow 4.2 \text{ m/s}^2, 5^\circ \text{ east of south}$$

Three descriptions in one problem: n-t to build $\vec{a}_B$, Cartesian to subtract, and a stated observer to give the result its meaning.



Interpret — what the radar reports

B is moving away sideways (east) at 8.6 m/s and falling back at 9.7 m/s. Relative to A, B is "accelerating backward" at 4.2 m/s²: A speeding up (1.5), B braking (2.0 along its heading) and B turning (1.9 toward its center) all add up.



Which part is the turn?

Remove a_n and recompute: $\vec{a}_{B/A} = (-1.15, -3.14)$. The turn contributed (1.54, -1.08) — over a third of the reported relative acceleration. Skipping it is the classic error.



Limits, directions, and the sketch



Limit $\rho \rightarrow \infty$. $a_n \rightarrow 0$; $\vec{a}_B \rightarrow -2 \hat{u}_t$;
 $\vec{a}_{B/A} \rightarrow (-1.15, -3.14)$.
 Pure braking difference. Sensible.



Limit same heading, same
 speed. $\vec{v}_{B/A} \rightarrow 0$: B looks parked
 to A. Sensible.



Direction of $\hat{u}_n$. Toward the
 center, on B's right. Put it on the
 left and $\vec{a}_{B/A}$ changes by
 $(-3.07, 2.15)$. Draw it.



AI as Coding Companion

"Animate two cars — one straight,
 one on a 120 m arc — from a fixed
 frame and from car A's frame side by
 side."* Does B's path in A's frame
 curve the way the numbers say (east
 and falling back)?



AI as Validator

"Check the sign convention in my
 relative-acceleration solution: I took
 $\hat{u}_n$ to the right of B's heading for a
 right turn. Confirm, and tell me what
 changes for a left turn."



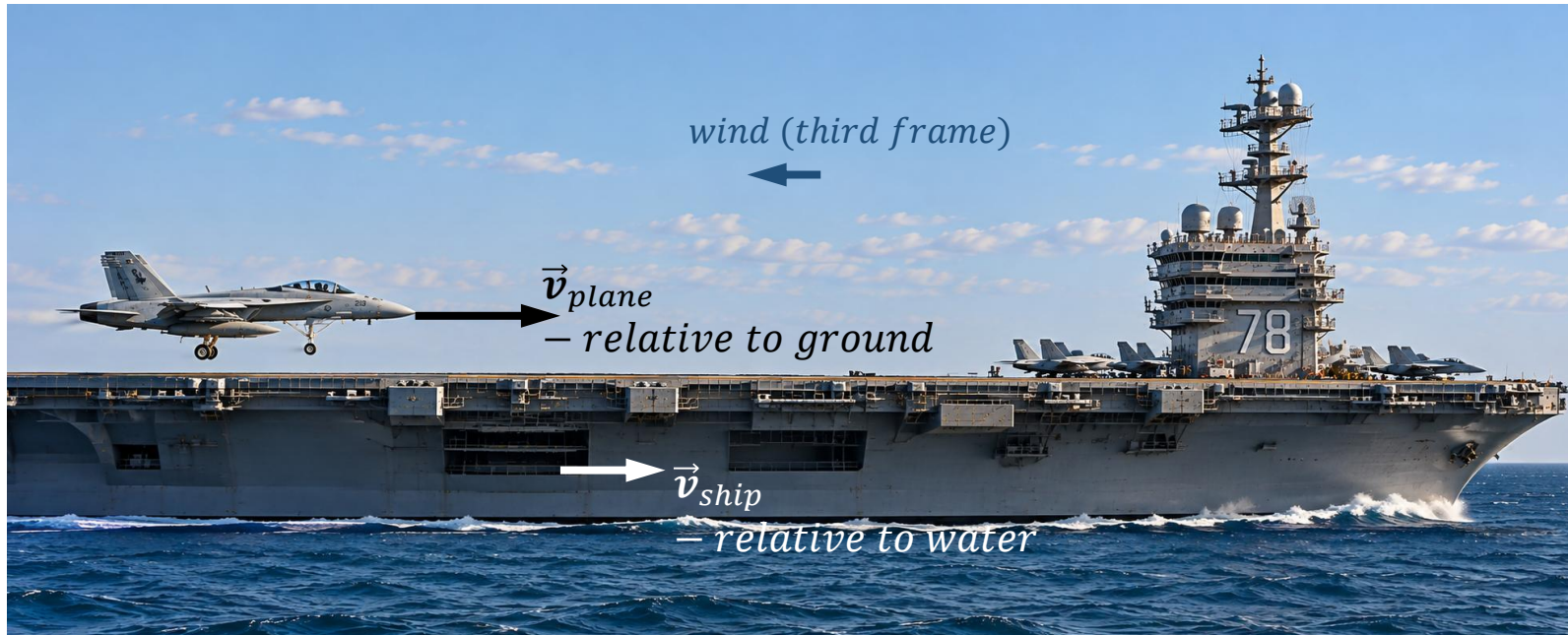
The engineering point

A radar reports $\vec{v}_{B/A}$ and $\vec{a}_{B/A}$. The
 controller must decide whether B is
 braking or A is accelerating — and it
 cannot, from the radar alone. It needs
 A's own speedometer and
 accelerometer: the absolute half of
 the relation

Relative motion is a DIFFERENCE. To recover what each body is doing, you must know the observer's own motion. Sensors that ride on the observer never tell you that.



Airspeed, ground speed, deck speed — which one does each instrument report?



Ground speed

relative to the earth — what GPS reports.



Deck speed

$\vec{v}_{\text{plane}} - \vec{v}_{\text{ship}}$
This is what the deck crew sees.



Airspeed

relative to the air — what the wing feels and the indicator reads.
Wind is a third moving frame.



Try it

Ship 25 kn into a 15 kn headwind; plane at 150 kn ground speed, same direction. Airspeed? Deck speed as it leaves the deck?
Which observer matters to the wing, and which to the deck crew? (knot: 1 kn = 1.15mph)

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Part 7 — what you can now explain and do



You can now EXPLAIN

- The five-step constraint chain, and why segments of constant length drop out
- Why a fixed-geometry cable gives constant velocity ratios, and a variable-geometry cable gives ratios that move — and therefore an acceleration
- What $\vec{v}_{B/A}$ means (what A measures), why $\vec{v}_{B/A} = -\vec{v}_{A/B}$, and why a closing rate alone cannot tell you who is accelerating
- Why the difference formulas hold only for a translating observer — and what waits in Chapter 6



You can now DO

- Write a cable-length relation from a stated datum, differentiate twice, and interpret negative results
- Solve a variable-geometry constraint to the acceleration and check its limits
- Assemble a body's absolute acceleration in n–t before subtracting it from another body's — and validate by limiting cases
- Name the observer for every relative quantity: ground, deck, air, radar

Chapter 2 → Chapter 3: we can now DESCRIBE acceleration in any coordinate language, connected or relative. Chapter 3 asks what FORCES produce it — starting with the a_n every curve demands.

One motion, many languages

**You can now describe the acceleration of anything that moves:
on a curve, from a point, along a cable, or seen from a moving
observer.**

Chapter 3 asks what forces produce it.

Part 1: acceleration from speed, direction, or both. Parts 2, 4, 5: three descriptions of one motion. Part 3: a model, measured.
Part 6: the engineer chooses. Part 7: connected and relative.