

AI-AUGMENTED ENGINEERING DYNAMICS: A CONVERSATIONAL APPROACH

HOMEWORK 4 · CHAPTER 2 · PARTS 5–7

Engineering Assignment 4

Virtual Engineering Laboratory — Polar Motion, Coordinate Choice, and Connected Motion

Polar r - θ Kinematics → Choosing the Description → Constraints & Relative Motion

Suggested Assessment · 100 points

target effort ≈ 2.5 hours (3 hours maximum)

type all answers and paste all VEL screenshots directly into this document



AI First Engineering

Figure: AI First Engineering (AIFE) course logo

Taner Onsay, Ph.D. · © 2026 AI First Engineering ·

AI use is allowed and encouraged — as an assistant. AI may help you operate the Virtual Engineering Laboratory, check an equation, help you read a readout, debug a calculation, or challenge your reasoning. But the predictions, the VEL runs and screenshots, the hand calculations, the validation tables, and the final engineering judgment must be YOUR OWN work — not an AI transcript. Assessment rewards evidence + reasoning + validation, not polished prose.

VEL IS THE EXPERIMENT — NOT THE ANSWER KEY

In this homework you will use one tool from the AIFE Virtual Engineering Laboratory — the Polar $r - \theta$ Motion Animator at lab.aifirstengineering.org/pma/polar — to conduct three connected numerical experiments.

The animator has a **PREDICTION MODE** that hides $\dot{r}$, a_r , a_θ , $|a|$ and the four acceleration contributions behind a question mark until you press REVEAL. You will use it in every experiment: commit your prediction, do your own calculation, and only then reveal. The VEL displays numbers; it does not tell you whether they are right.

PREDICT → OBSERVE → CALCULATE → REVEAL → VALIDATE → EXPLAIN

the ME345 course loop: OBSERVE → IDEALIZE → MODEL → SOLVE / ANALYZE → VALIDATE → REPORT

NOTATION — the lecture and the animator use the same quantities under two names

Chapter 2 Part 5 writes $\dot{\theta}$ and $\ddot{\theta}$; the animator writes ω and α . They are the same things: $\omega = d\theta/dt$ (rad/s) and $\alpha = d\omega/dt$ (rad/s²). This assignment uses ω and α throughout. The basis vectors are $\hat{u}_r$ and $\hat{u}_\theta$. Radial rates are written $\dot{r} = dr/dt$ and $\ddot{r} = d^2r/dt^2$. Keep every angle in radians in your calculations.

$$\mathbf{v} = \dot{r} \hat{u}_r + r \omega \hat{u}_\theta \quad \mathbf{a} = (\ddot{r} - r \omega^2) \hat{u}_r + (r \alpha + 2 \dot{r} \omega) \hat{u}_\theta$$

PERSONALIZED PARAMETERS — read before you start

Wherever a parameter is given as a range, select your own value to ONE decimal place inside that range (for example 1.4 rad/s, not 1.45 and not 1). Record your selected values in the parameter table at the start of each Part before you begin that investigation. To select a value, use **Engineering Utilities** → **Random Number Generator** posted on the course webpage (ME345-Random-Number-Generator.xlsx). Enter the lower and upper limits of the specified range and record the generated value. Do not change a recorded value unless the question asks for a parameter study. Every student therefore runs a different virtual experiment; the instructor grades your method, your evidence and your validation — not agreement with a single answer.

Evidence. This homework requires exactly THREE screenshots (A2, A3, B2). Paste them into the dashed boxes (Windows: Win+Shift+S · Mac: Cmd+Shift+4, then Ctrl+V / Cmd+V). A screenshot must show the parameter settings and the numerical readouts, not only the picture. Run the VEL in a maximized browser window so the controls, the scene and the CURRENT STATE panel fit one screenshot.

Time guide: Part A ≈ 70 min · Part B ≈ 25 min · Part C ≈ 60 min. Part A follows the cycle PREDICT → OBSERVE → CALCULATE → REVEAL → VALIDATE → EXPLAIN. Every question tells you what to determine and what to submit; the ANSWER lines and dashed boxes are where your work goes.

PART A · The Rotary Painting Machine — Three Experiments in Polar Coordinates (45 points · ≈ 70 min)

One machine. Three experiments. The polar acceleration equation, one contribution at a time.

Open the Polar $r - \theta$ Motion Animator (lab.aifirstengineering.org/pma/polar). The tool models a slotted arm that pivots about a fixed point O. A motor imposes the arm angle $\theta(t)$; the slot geometry imposes the radius $r = f(\theta)$. A slider carrying a marker rides in the slot and paints the pattern. Every experiment in Part A uses this same machine — between experiments you change exactly ONE thing.

Set-up (do this once).

Press ⌵ RESET PARAMETERS.

In 4. DISPLAY OPTIONS switch ON: Velocity v , Total acceleration a , Radial velocity, Transverse velocity, Radial acceleration, Transverse acceleration, Moving frame e_r e_θ , Four acceleration contributions (advanced), Fixed x–y frame, r and θ indicators, Geometric pattern $r = f(\theta)$, and PREDICTION MODE. Set GRAPH DISPLAY to Acceleration.

Keep MATH / EQUATIONS collapsed throughout Part A. You will open and use this panel for the first time in Part B.

With PREDICTION MODE on, the CURRENT STATE panel still shows t , r , θ , $\dot{r}$, ω , α , v_r , v_θ and $|v|$ — but it replaces $\ddot{r}$, a_r , a_θ , $|a|$ and the four contributions with a question mark. That is deliberate: you produce those numbers yourself, and only then press REVEAL full result.

Reaching $t^* = 1.50$ s exactly. Every student evaluates every experiment at the same instant, $t^* = 1.50$ s. After APPLY / GENERATE MOTION, press ↺ RESET under the scene, then press the 0.1 s ► button fifteen times. The time readout must read $t = 1.50$ s before you record anything.

A0 — Record your parameters. (3 points) Generate the four personalized values with Engineering Utilities → Random Number Generator and record them here. Everything else in the table is the same for every student.

Parameter (VEL field)	Allowed range	MY VALUE (one decimal place)
Circle radius R (Radius R)	1.2 to 2.4 m	
Angular velocity ω_0 (Angular velocity ω_0)	1.0 to 1.8 rad/s	
Spiral start radius r_1 (Start radius r_1)	0.8 to 1.6 m	
Angular acceleration α (Angular accel. $ \alpha $)	0.2 to 0.5 rad/s ²	
Spiral end radius r_2 (End radius r_2)	2.8 m (keep)	2.8 m
Turns N	1 (keep)	1
Inner stop $r_{\min}$ · Outer stop $r_{\max}$	0.5 m · 3.0 m (keep)	0.5 m · 3.0 m
Start angle θ_0 · Duration T	0.0° · 8 s (keep)	0.0° · 8 s
Evaluation instant t^*	1.50 s (same for everyone)	1.50 s

A1 — EXPERIMENT 1 · Circular motion: the limiting case. (10 points · ≈ 15 min)

The slider sits at a fixed radius while the arm turns at a constant rate.

This is the baseline against which the next two experiments are read.

VEL settings.

Preset Circle — constant ω .

Pattern Circle;

Radius R = your R;

Inner stop 0.5 m;

Outer stop 3.0 m.

Motor: CONSTANT ω ;

Angular velocity ω_0 = your ω_0 ;

Start angle $\theta_0 = 0$;

Duration T = 8 s.

Do not press APPLY until you have written A1.1.

A1.1 PREDICT (3 points). Complete BEFORE you press APPLY / GENERATE MOTION. On a circle about O the radius never changes, so $\dot{r} = 0$ and $\ddot{r} = 0$; the motor rate is constant, so $\alpha = 0$.

1. Is v_r zero or non-zero? Is v_θ zero or non-zero?
2. Is a_r zero or non-zero? Is a_θ zero or non-zero?
3. In which direction does the TOTAL acceleration a point? Answer in words (for example: along the arm, outward / toward O / perpendicular to the arm).
4. r is constant AND ω is constant. Is the acceleration therefore zero? Answer YES or NO with one sentence of reasoning.
5. In the VEL's own PREDICTION panel, select a_θ is: zero / non-zero and a_r points: toward O / away from O.

ANSWER A1.1:

A1.2 CALCULATE, then REVEAL and VALIDATE (5 points).

Press APPLY / GENERATE MOTION and step to $t^* = 1.50$ s.

Record the visible readouts.

Then, BEFORE pressing REVEAL, calculate the four quantities below from the polar equations with $\dot{r} = \ddot{r} = 0$ and $\alpha = 0$, writing each equation and its substitution. Also calculate them a second way in n-t: on a circle about O the path radius of curvature is $\rho = R$, so $a_n = |v|^2 / \rho$ and $a_t = \rho \alpha$.

Then press REVEAL full result and complete the table.

Quantity at $t^* = 1.50$ s	Polar VEL	Polar hand calculation	n-t hand calculation	% diff
Speed $ v $ (m/s)		$ v = R \omega_0 =$	$ v = \rho \omega_0 =$	
Radial / normal (m/s ²)	$a_r =$	$a_r = -R \omega_0^2 =$	$a_n = v ^2 / \rho =$	
Transverse / tangential (m/s ²)	$a_\theta =$	$a_\theta = r \alpha + 2 \dot{r} \omega =$	$a_t = \rho \alpha =$	
Magnitude $ a $ (m/s ²)				

% difference = $|VEL - hand| / |hand| \times 100$ %. Validation statement: state whether every row agrees within 1 %. If a row does not, name the input you would check first.

ANSWER A1.2 (validation statement + your substitutions, typed here or attached as a photo):

A1.3 EXPLAIN (2 points).

In two or three sentences:

- (a) why the acceleration is not zero even though the speed never changes;
- (b) the polar result is $a_r = -R \omega_0^2$ while Part 4 gives $a_n = +|v|^2 / \rho$ — explain why the SIGNS differ although the arrow is the same, and state what u_n is here in terms of u_r . Was your A1.1 item 4 prediction correct?

ANSWER A1.3:

A2 — EXPERIMENT 2 · The slider moves out while the motor rate stays constant.
(20 points · ≈ 30 min) Change ONE thing: the slot is now a spiral, so the slider moves radially while the arm turns. The motor rate is exactly as before.

VEL settings.

Preset Expanding spiral — constant ω .

Start radius r_1 = your r_1 ;

End radius r_2 = 2.8 m;

Turns N = 1; stops 0.5 m and 3.0 m.

Motor: CONSTANT ω ;

ω_0 = your ω_0 (the SAME value as Experiment 1);

θ_0 = 0; T = 8 s.

The slot geometry is the Archimedean spiral $r = r_1 + b\theta$, where $b = (r_2 - r_1) / (2\pi N)$. The run ends when the slider reaches r_2 — your run will end somewhere between 3.5 s and 6.3 s, so $t^* = 1.50$ s is always inside it.

A2.1 PREDICT (5 points).

Complete BEFORE you press APPLY / GENERATE MOTION.

1. Does v_r point outward or inward? Does v_θ point with the arm's rotation or against it?
2. Does a_r point toward O or away from O?
3. The motor rate is EXACTLY constant, so $\alpha = 0$. Can the transverse acceleration a_θ still be non-zero? Answer YES or NO and give one sentence of reasoning. Commit before you calculate.
4. Tick the contributions you expect to be PRESENT (non-zero) at t^* : ☐ $\ddot{r}$ ☐ $-r\omega^2$ ☐ $r\alpha$ ☐ $2\dot{r}\omega$
5. Record the same two answers in the VEL's PREDICTION panel (a_θ is: zero / non-zero; a_r points: toward O / away from O).

ANSWER A2.1:

A2.2 CALCULATE — before you REVEAL (7 points).

Press APPLY / GENERATE MOTION and step to $t^* = 1.50$ s. Keep MATH / EQUATIONS collapsed and do not press REVEAL yet.

For the Archimedean spiral:

$$r = r_1 + b\theta, \quad b = \frac{r_2 - r_1}{2\pi N}$$

and constant motor rate $\dot{\theta} = \omega_0$, calculate the following quantities at $t^* = 1.50$ s

$$\theta = \omega_0 t^2, \quad \dot{\theta} = \omega_0, \quad \ddot{\theta} = 0$$

$$r = r_1 + b\theta, \quad \dot{r} = b\dot{\theta}, \quad \ddot{r} = 0$$

record these six kinematic quantities:

$$r, \theta, \dot{r}, \dot{\theta}, \ddot{r}, \ddot{\theta}$$

Then use them to calculate the polar components of velocity and acceleration:

$$v_r = \dot{r}, \quad v_\theta = r\dot{\theta}, \quad |v| = \sqrt{v_r^2 + v_\theta^2},$$

$$a_r = \ddot{r} - r \dot{\theta}^2, \quad a_\theta = r \ddot{\theta} + 2 \dot{r} \dot{\theta}, \quad |a| = \sqrt{a_r^2 + a_\theta^2}.$$

Write every equation with your own numbers substituted, include units, and keep θ in radians. Complete this work before pressing REVEAL

WRITE YOUR SIX KINEMATIC QUANTITIES, VELOCITY COMPONENTS, ACCELERATION COMPONENTS, AND FINAL $\mathbf{v}$ AND $\mathbf{a}$ VECTORS HERE (A2.2)

(equations, substitutions, results and units — typed, or a photo of your work. Complete this BEFORE pressing REVEAL.)

A2.3 REVEAL and VALIDATE (5 points). Now press REVEAL full result and complete the table. The VEL displays two decimals.

Quantity at $t^* = 1.50$ s	VEL	Hand calculation	% difference
r (m)			
$\dot{r}$ (m/s)			
v_r (m/s)			
v_θ (m/s)			
$ v $ (m/s)			
a_r (m/s ²)			
a_θ (m/s ²)			
contribution $2 \dot{r} \dot{\theta}$ (m/s ²)			
$ a $ (m/s ²)			

Validation statement: does every row agree within 1 %? The a_θ row is the one to watch, because a_θ is the smallest number in the table. If that row exceeds 1 %, compute the display-rounding bound $(0.005 / a_\theta) \times 100$ % and state whether your difference lies inside it. Also state whether your A2.1 item 3 prediction was correct.

ANSWER A2.3 (validation statement):

Required evidence (SCREENSHOT 1 of 3): the VEL window AFTER REVEAL at $t = 1.50$ s, showing the pattern and motor parameter boxes, the scene with the moving e_r ,

e_θ frame, the CURRENT STATE panel including the contributions block, and the REVEAL line that begins YOUR PREDICTION: ... ACTUAL ...

PASTE VEL EVIDENCE FOR EXPERIMENT 2 (A2.3) HERE

(parameter boxes + scene with the moving frame + CURRENT STATE with the contributions block + the REVEAL line — click here and paste — Ctrl+V / Cmd+V)

A2.4 EXPLAIN (3 points). The motor rate never changed, yet a_θ is not zero.

1. Explain why, in your own words, using BOTH pictures from Part 5:

(i) $v_\theta = r \omega$ grows because r grows, at the rate $\dot{r}$ ω ;

(ii) the vector $\dot{r} \mathbf{u}_r$ has a fixed length but its direction turns with the arm, contributing another $\dot{r} \omega$. State how they combine.

2. What changes if the slider moves INWARD instead of outward (a contracting spiral, same motor)? State what happens to the sign of a_θ and why.

ANSWER A2.4:

A3 — EXPERIMENT 3 · The arm accelerates: two contributions to a_θ .

(12 points · ≈ 20 min)

Change ONE thing again: the same spiral, but now the motor speeds up.

Both terms of $a_\theta = r \alpha + 2 \dot{r} \omega$ are alive at once.

VEL settings.

Preset Expanding spiral — accelerating arm.

Pattern fields exactly as in Experiment 2 ($r_1 =$ your r_1 , $r_2 = 2.8$ m, $N = 1$).

Motor: ACCELERATING ARM;

$\omega_0 =$ your ω_0 ;

Angular accel. $|\alpha| =$ your α ;

$\theta_0 = 0$;

$T = 8$ s.

Now $\omega = \omega_0 + \alpha t$ and $\theta = \omega_0 t + \frac{1}{2} \alpha t^2$.

A3.1 PREDICT (2 points). Before calculating anything: at $t^* = 1.50$ s, which of the two contributions to a_θ do you expect to be LARGER — $r \alpha$ (the arm speeding up)

or $2 \dot{r} \omega$ (the slider moving out while the arm turns)? Commit, and give one sentence of reasoning.

ANSWER A3.1:

A3.2 CALCULATE, REVEAL and VALIDATE (5 points). Step to $t^* = 1.50$ s. Calculate $\omega = \omega_0 + \alpha t^*$, $\theta = \omega_0 t^* + \frac{1}{2} \alpha t^{*2}$, $r = r_1 + b\theta$, $\dot{r} = b \omega$ and $\ddot{r} = b \alpha$. Then compute each contribution SEPARATELY. Only then press REVEAL and read the four-contribution block.

Contribution at $t^* = 1.50$ s	Hand calculation	VEL (contributions block)	% difference
$r \alpha$ (arm speeding up)			
$2 \dot{r} \omega$ (radial motion while turning)			
TOTAL a_θ (m/s ²)			
$\ddot{r}$ (slider along the slot)			
$-r \omega^2$ (turning the velocity toward O)			
TOTAL a_r (m/s ²)			

Ratio at this instant: $(r \alpha) / (2 \dot{r} \omega) = \underline{\hspace{2cm}}$ (dimensionless). Which contribution is larger? Was your A3.1 prediction correct?

Required evidence (SCREENSHOT 2 of 3): the VEL AFTER REVEAL at $t = 1.50$ s in ACCELERATING ARM mode, showing the parameter boxes (including $|\alpha|$), the four-contribution block with $r \alpha$ and $2 \dot{r} \omega$ both non-zero, and the scene with the contribution vectors drawn.

PASTE VEL EVIDENCE FOR EXPERIMENT 3 (A3.2) HERE

(parameter boxes including $|\alpha|$ + the four-contribution block + the scene — click here and paste — Ctrl+V / Cmd+V)

A3.3 PARAMETER STUDY — does turning α up change the balance? (3 points)

A common expectation is: “to make $r \alpha$ the dominant contribution, increase α .” Test it.

1. PREDICT first, in one sentence: if you DOUBLE $|\alpha|$ and look again at $t^* = 1.50$ s, what do you expect the ratio $(r \alpha) / (2 \dot{r} \omega)$ to do?
2. Set Angular accel. $|\alpha| = 2 \times$ your α (leave everything else alone), press APPLY / GENERATE MOTION, step to $t^* = 1.50$ s, press REVEAL, and complete the table.

Contribution at $t^* = 1.50$ s	$ \alpha = \text{your } \alpha$	$ \alpha = 2 \times \text{your } \alpha$
ω at t^* (rad/s)		
$r \alpha$ (m/s ²)		
$2 \dot{r} \omega$ (m/s ²)		
ratio $(r \alpha) / (2 \dot{r} \omega)$		

3. EXPLAIN in two or three sentences why doubling α moves the ratio far less than expected. Use $\omega = \omega_0 + \alpha t$ and $\dot{r} = b \omega$ to show that $2 \dot{r} \omega = 2 b \omega^2$ grows with the SQUARE of the motor rate, while $r \alpha$ grows roughly in proportion to α . Raising α raises ω as well.

ANSWER A3.3:

A3.4 CLOSURE — back to the circle (2 points). Return $|\alpha|$ to your own α value. Now change the GEOMETRY instead of the motor.

1. PREDICT before you run it: if the slot is a CIRCLE (r constant) and the arm accelerates, what happens to the $2 \dot{r} \omega$ contribution, and what is left of a_θ ? One sentence.
2. Select Preset Circle — accelerating arm. Radius $R =$ your R (the Experiment 1 value); $\omega_0 =$ your ω_0 ; $|\alpha| =$ your α ; $\theta_0 = 0$; $T = 8$ s. APPLY, step to $t^* = 1.50$ s, REVEAL, and record:

$$\omega \text{ at } t^* = \underline{\hspace{2cm}} \text{ rad/s} \quad \dot{r} = \underline{\hspace{2cm}} \text{ m/s} \quad 2 \dot{r} \omega = \underline{\hspace{2cm}} \text{ m/s}^2 \quad r \alpha = \underline{\hspace{2cm}} \text{ m/s}^2$$

$$\underline{\hspace{2cm}} \text{ m/s}^2 \quad a_{\theta} = \underline{\hspace{2cm}} \text{ m/s}^2$$

3. Confirm by hand that $a_{\theta} = R \alpha$ for this case, and state in one sentence why the other contribution vanished. No screenshot is required — the numbers above are the evidence.

ANSWER A3.4:

ONE VELOCITY VECTOR. ONE ACCELERATION VECTOR.

The animator draws the fixed x–y frame and the moving r– θ frame in the same picture. Between the two frames the COMPONENTS look completely different; the ARROWS do not move at all. Part B asks why — and makes you prove it with your own numbers.

PART B · One State, Three Languages — Choosing and Cross-Checking the Description (20 points · $\approx$ 25 min)

The motion never changed. Only our description changed.

Part B uses the state you already produced in Experiment 2 — the same instant, the same numbers. No new motion is generated. Re-load your Experiment 2 settings (Preset Expanding spiral — constant ω , your r_1 , your ω_0 , CONSTANT ω , $\theta_0 = 0$, $T = 8$ s), press APPLY / GENERATE MOTION and step to $t^* = 1.50$ s.

B1 — Choose a description and justify it (3 points). The machine's controller commands the slot geometry $r = f(\theta)$ and the motor law $\theta(t)$; the question asks for the slider's velocity and acceleration. Which of the three descriptions — Cartesian x–y, normal–tangential n–t, or polar r– θ — is the natural one to COMPUTE in? Answer in one or two sentences using the three questions: what do I know · what am I asked · what did the instrument measure.

ANSWER B1:

B2 — The same two vectors in the fixed x–y frame (7 points). Do the hand calculation FIRST. Rotating components between two frames at an instant is the Part 6 just-in-time result; here the rotation angle is θ itself.

$$\begin{aligned} v_x &= v_r \cos\theta - v_{\theta} \sin\theta & v_y &= v_r \sin\theta + v_{\theta} \cos\theta \\ a_x &= a_r \cos\theta - a_{\theta} \sin\theta & a_y &= a_r \sin\theta + a_{\theta} \cos\theta \end{aligned}$$

Use your A2 values of v_r , v_{θ} , a_r , a_{θ} and θ (in radians). Then — and only then — press SHOW under MATH / EQUATIONS. This is the first time you open this panel. Read the line “same vectors in the fixed x–y frame” and complete the table.

Quantity at $t^* = 1.50$ s	VEL x–y line	Hand rotation	% difference
v_x (m/s)			
v_y (m/s)			
a_x (m/s ²)			
a_y (m/s ²)			
$ v $ from x–y (m/s)			
$ a $ from x–y (m/s ²)			

Required evidence (SCREENSHOT 3 of 3): the MATH / EQUATIONS — at the current instant panel EXPANDED at $t = 1.50$ s, showing the six-number line, the polar components, and the “same vectors in the fixed x–y frame” line.

PASTE THE MATH / EQUATIONS PANEL (B2) HERE

(the expanded panel at $t = 1.50$ s including the fixed x–y line — click here and paste — Ctrl+V / Cmd+V)

B3 — The same two vectors in n–t (6 points). The animator displays no n–t quantity at all, so this calculation is yours alone. The velocity is tangent to the path, so $u_t = v / |v|$. Project the acceleration onto it:

$$a_t = \mathbf{a} \cdot \hat{\mathbf{u}}_t = (v_r a_r + v_\theta a_\theta) / |v| \quad a_n = \sqrt{|\mathbf{a}|^2 - a_t^2} \quad \rho = \frac{|v|^2}{a_n}$$

$$a_t = \underline{\hspace{2cm}} \text{ m/s}^2 \quad a_n = \underline{\hspace{2cm}} \text{ m/s}^2$$

$$\rho = \underline{\hspace{2cm}} \text{ m} \quad (\text{your } r \text{ at } t^* \text{ was } \underline{\hspace{2cm}} \text{ m})$$

1. Compare ρ with r at this instant. Are they equal? Should they be? What single change to the experiment would make them equal? One or two sentences.

ANSWER B3:

B4 — Validate: one motion, three descriptions (2 points). Fill in the magnitudes from your own three calculations and write the validation statement.

Description	$ v $ (m/s)	$ a $ (m/s ²)
Polar r– θ (A2)		
Cartesian x–y (B2)		
Normal–tangential n–t (B3)		

Validation statement: do the three rows agree to the precision of your numbers? Write one sentence saying what it would mean if they did not.

ANSWER B4:

B5 — Engineering judgment (2 points).

1. Suppose the only data you had were a Tracker export giving (t, x, y) of the painted dot and nothing else. Which description would you compute in FIRST, and which would you convert to in order to answer “how hard is the slider pushing sideways on the slot?” One sentence each.

2. Name the single piece of information that would flip your B1 choice, and say what you would choose instead.

ANSWER B5:

SAME MOTION. SAME v. SAME a. DIFFERENT LANGUAGE. Cartesian tells you WHERE the vector points. Polar and n-t tell you WHY it points there — range versus bearing, speed change versus direction change. The wrong description does not give a wrong answer; it gives the right answer slowly, and hides the meaning.

PART C · Connected Motion — A Cable Constraint and a Moving Observer (35 points · ≈ 60 min)

When one thing moves, what must another do? And what does an observer who is moving actually see?

C0 — Record your parameters. Generate the five personalized values with Engineering Utilities → Random Number Generator, to one decimal place.

Parameter	Allowed range	MY VALUE (one decimal place)
C1 Drum take-up speed v_D	0.4 to 1.2 m/s	
C1 Drum acceleration a_D	0.10 to 0.40 m/s ²	
C1 Required lift height H	6.0 to 10.0 m	
C2 Aircraft A speed v_A	30.0 to 36.0 m/s	
C2 Drone B speed v_B	24.0 to 30.0 m/s	
C2 Bearing of B from A · range r	030° · 900 m (same for everyone)	030° · 900 m

C1 — Dependent motion: the battery-module lift. (18 points · ≈ 30 min) A servo winch raises a tooling carriage inside an EV final-assembly cell. You are NOT given the velocity relation. You will build it from the geometry.

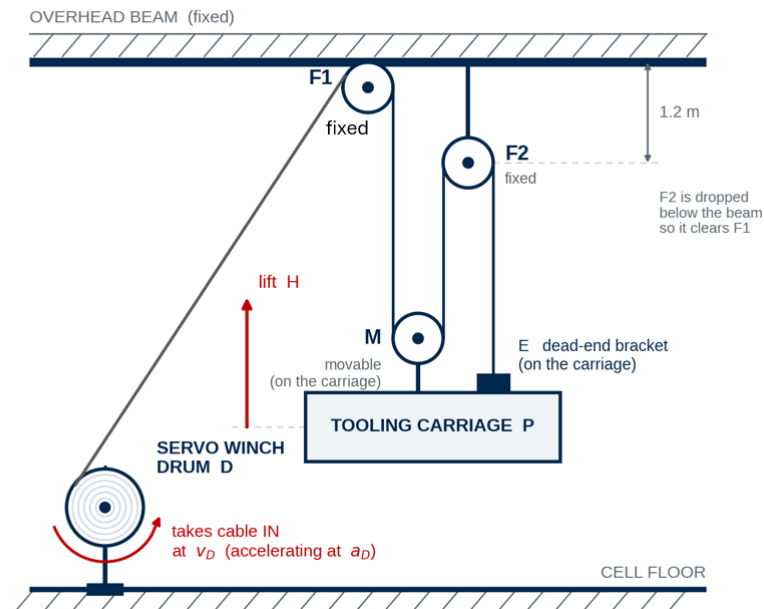


Figure C1 — battery-module lift. The cable leaves the drum D, rises over the fixed sheave F1, drops round the movable sheave M on the carriage, rises over the fixed sheave F2, and ends at the dead-end bracket E bolted to the carriage.

Model assumptions (stated, and meant): the cable is taut and inextensible; the sheaves are ideal and their radii are negligible; all three falls between the overhead structure and the carriage are vertical; the carriage P moves vertically. At the instant considered the drum is taking cable in at your v_D and is accelerating at your a_D .

C1.1 PREDICT (3 points). Before you write a single equation: does the carriage rise FASTER than, SLOWER than, or at the SAME speed as the cable is drawn in at the drum? Commit to one answer and give one sentence of physical reasoning. (Think about how the cable that disappears at the drum is shared among the falls that shorten.)

ANSWER C1.1:

C1.2 MODEL — datum, directions, and the constant-length relation (5 points).

Work through the constraint chain of Part 7 and write each step explicitly.

1. State your datum and your positive direction, and mark them on the figure (or describe them unambiguously in words).
2. Define a position coordinate for the carriage and a position coordinate for the cable point at the drum. Name them.
3. List EVERY cable segment in the figure and mark which ones change length as the carriage rises and which ones do not. State how many change.
4. State explicitly what happens to the 1.2 m by which F2 sits below the beam, and why.
5. Write the constant-length relation $L = \dots = \text{constant}$.

SKETCH YOUR DATUM AND WRITE YOUR CONSTANT-LENGTH RELATION HERE (C1.2)

(an annotated copy of Figure C1 or a clear hand sketch is fine — the datum, the positive direction, the named coordinates and the relation must all be visible)

C1.3 DIFFERENTIATE (4 points). Differentiate your relation once with respect to time to obtain the velocity relation, and again to obtain the acceleration relation. Show both lines.

Velocity relation: _____ Acceleration relation: _____

C1.4 CALCULATE (4 points). Using your own v_D , a_D and H , and showing each substitution:

1. the velocity of the carriage, $v_P =$ _____ m/s;
2. the acceleration of the carriage, $a_P =$ _____ m/s²;
3. the length of cable the drum must take in to raise the carriage by H , = _____ m;
4. the time to raise the carriage by H if the drum ran at a constant v_D , = _____ s.

ANSWER C1.4 (equations and substitutions):

C1.5 INTERPRET THE SIGNS (1 point). Your v_P and a_P carry signs that depend on the datum you chose in C1.2. State, in one sentence each, what the sign of v_P means physically and what the sign of a_P means physically (is the carriage speeding up or slowing down?).

ANSWER C1.5:

C1.6 VALIDATE BY CHANGING THE DATUM (1 point). Now measure the carriage UPWARD from the cell floor instead. Write the new position coordinate in terms of the old one, differentiate, and show that the new velocity relation gives the SAME physical answer with the opposite sign. One line of algebra plus one sentence.

ANSWER C1.6:

C2 — Relative motion: the airspace conflict check. (17 points · $\approx$ 30 min) A survey aircraft A and an uncrewed survey drone B are operating in the same block of airspace.

A's traffic sensor reports what A sees. You will work out what that is — and what it means.

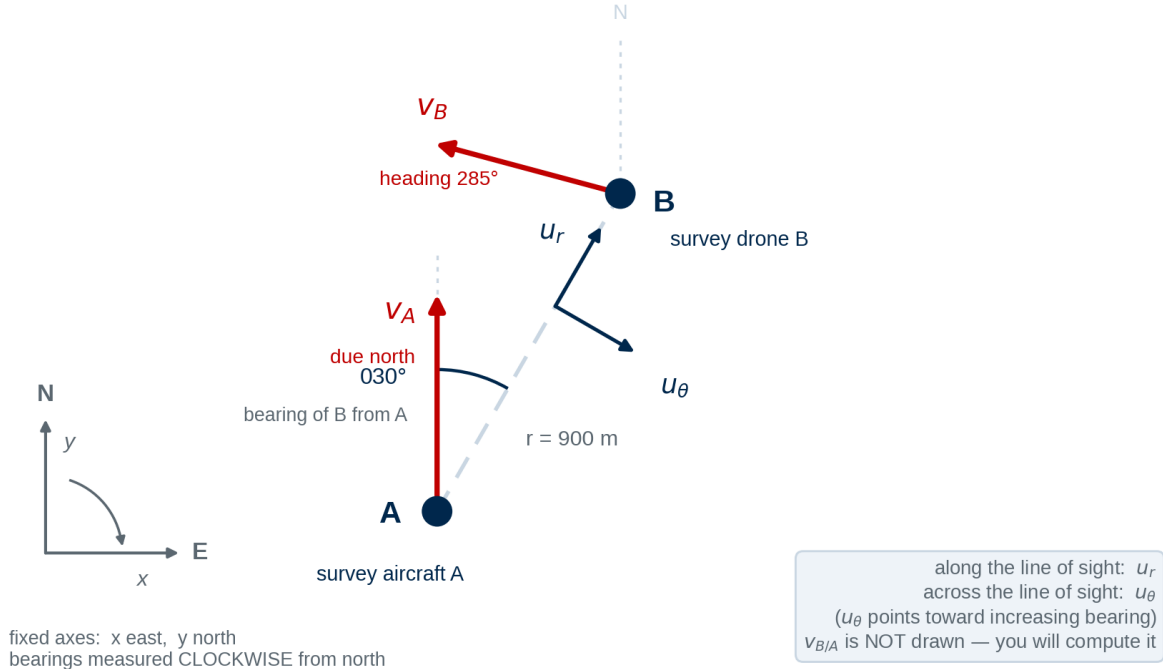


Figure C2 — the instant analysed. Bearings are measured clockwise from north. The relative velocity $v_{B/A}$ is deliberately NOT drawn.

The situation. Work in fixed axes with x to the EAST and y to the NORTH. Aircraft A flies due north (bearing 000°) at your v_A . Drone B flies on heading 285° at your v_B . At the instant considered, B bears 30° from A at a range of $r = 900$ m. Treat both as particles, and treat observer A as TRANSLATING — its axes do not rotate, so the Part 7 difference relations apply.

C2.1 SET UP (3 points). Write v_A and v_B as x–y component vectors, showing the substitution. Remember that a bearing β measured clockwise from north gives the direction $(\sin\beta, \cos\beta)$ in (east, north) components. Then sketch both absolute velocity vectors and the line of sight on a north-up diagram (annotating Figure C2 is fine).

$$v_A = (\quad , \quad) \text{ m/s} \quad v_B = (\quad , \quad) \text{ m/s}$$

C2.2 RELATIVE VELOCITY (5 points). Using the Part 7 relation for a translating observer:

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

1. Compute $\vec{v}_{B/A}$ in x–y components, its magnitude, and its direction as a compass bearing (clockwise from north).
2. State in one sentence what A's sensor reports.
3. Write $\vec{v}_{B/A}$ and state its relation to $\vec{v}_{B/A}$. What would B's own sensor report?

$$\vec{v}_{B/A} = (\quad , \quad) \text{ m/s}$$

$$|\vec{v}_{B/A}| = \quad \text{ m/s} \quad \text{bearing} = \quad ^\circ$$

ANSWER C2.2:

C2.3 ALONG AND ACROSS THE LINE OF SIGHT (5 points). A traffic sensor does not report x and y — it reports RANGE RATE and BEARING RATE. Those are the polar components of the relative velocity, resolved on the line of sight. Build the two unit vectors for the line of sight from A to B (bearing 30°), then project:

$$\hat{u}_r = (\sin 30^\circ, \cos 30^\circ) \quad u_\theta = (\cos 30^\circ, -\sin 30^\circ)$$

$$\text{range rate } \dot{r} = \mathbf{v}_{B/A} \cdot \mathbf{u}_r \quad \text{transverse rate } r \omega = \mathbf{v}_{B/A} \cdot \mathbf{u}_\theta \quad \omega = (r \omega) / r$$

1. $\dot{r} =$ _____ m/s — is the range opening or closing? One word.
2. $r \omega =$ _____ m/s, and the bearing rate $\omega =$ _____ rad/s = _____ $^\circ$ /s. State whether the bearing of B from A is increasing or decreasing.
3. Compute the angle between $\mathbf{v}_{B/A}$ and the line of sight. State explicitly whether the two are parallel.
4. VALIDATE. The relative velocity has one magnitude, however you resolve it. Check that $\sqrt{(\dot{r})^2 + (r \omega)^2}$ equals your $|\mathbf{v}_{B/A}|$ from C2.2, and say in one sentence why this identity must hold.

ANSWER C2.3:

C2.4 WHAT DOES A ACTUALLY SEE? (2 points). In two or three sentences, describe the picture from A's cockpit: at what rate is B closing, and at what rate and in which sense is B drifting across the windscreen? A collision-avoidance engineer watches for a bearing that stays nearly CONSTANT while the range decreases. Using your own bearing rate, say whether this geometry looks like a collision course or a safe pass, and justify it with your number.

ANSWER C2.4:

C2.5 RELATIVE POSITION IS NOT RELATIVE VELOCITY (2 points). B is located to the north-east of A at this instant, while $\mathbf{v}_{B/A}$ points approximately to the south-west. Explain why the relative-position vector and the relative-velocity vector do not have to point in the same direction. Refer to your own numbers.

ANSWER C2.5:

RELATIVE MOTION IS A DIFFERENCE. $\mathbf{v}_{B/A}$ is what A would measure with A's own instruments, and nothing about it says who is “really” moving. Where B IS (the line of sight) and how B is MOVING as seen from A are two different vectors — which is exactly why a sensor that reports only a closing rate cannot, by itself, tell a controller what to do.

OPTIONAL · Reflection (ungraded)

In three to five sentences: which of the three polar experiments changed how you read the acceleration equation, and which hand calculation made you least willing to trust a displayed number?

REFLECTION (optional):

SUBMIT · Evidence Checklist & Human Review

Submit ONE completed Word document — this file — containing:

- Parameter tables A0 and C0 completed according to the stated parameter rules and ranges.
- Predictions made before the experiment — A1.1 (five items), A2.1 (five items), A3.1, A3.3 item 1, A3.4 item 1, C1.1.
- VEL screenshots (3 in total) — A2.3 (after REVEAL, with the contributions block and the REVEAL line), A3.2 (accelerating arm, both transverse contributions), B2 (the MATH / EQUATIONS panel with the fixed x–y line).
- Hand calculations with equations, substitutions, units and signs — A1.2, A2.2, A3.2, A3.4, B2, B3, C1.3, C1.4, C1.6, C2.1, C2.2, C2.3.
- Completed validation tables and statements — A1.2, A2.3, A3.2, B2, B4, C1.6, C2.3 item 4.
- Explanations — A1.3, A2.4, A3.3, A3.4, B1, B3, B5, C1.5, C2.4, C2.5.
- Human review statement signed and dated (below).

SUBMIT ONE COMPLETED HOMEWORK DOCUMENT. Keep all required answers and VEL evidence in this document rather than as separate screenshot, video or image files. Follow your instructor's submission and file-naming requirements.

HUMAN REVIEW: (Part A: 45 · Part B: 20 · Part C: 35 · Total: 100 points)

“I reviewed the VEL experiments, predictions, hand calculations, validation tables and engineering conclusions in this submission and confirm that they represent the work I performed and reviewed.”

Human reviewed and approved: _____

Student name: _____ Date: _____

AI assists. Humans observe. Humans verify. Humans decide. Humans approve.

Suggested Assessment Rubric — 100 points

Used by the instructor and, where applicable, by an AI grading agent. All required evidence must appear inside this document. Student parameters differ; the grader checks the method, the internal consistency of each student's own numbers and the validation reasoning, not agreement with one universal answer.

Criterion	What full credit looks like	Pts
Part A — Experiment 1 (A0, A1)	Four personalized parameters in range, one decimal (A0: 3). Five predictions committed before APPLY, including the VEL PREDICTION panel (A1.1: 3). $ v = R \omega_0$ and $a_r = -R \omega_0^2$ with substitutions, $a_\theta = 0$, the n–t column reproduced with $\rho = R$, all rows within 1 %, validation statement (A1.2: 5). Explanation that constant speed still turns the velocity vector, and that $a_r = -R \omega_0^2$ and $a_n = + v ^2/\rho$ are the same arrow because $u_n = -u_r$ (A1.3: 2).	13

Criterion	What full credit looks like	Pts
Part A — Experiment 2 (A2)	Five predictions committed before APPLY, including the $\alpha = 0$ but $a_\theta \neq 0$ commitment and the contribution checklist (A2.1: 5). Six kinematic quantities $r, \theta, \dot{r}, \omega, \dot{\theta}, \alpha$ calculated using $b = (r_2 - r_1)/(2\pi N)$ and the chain rule; $v_r, v_\theta, \vec{v} , a_r, a_\theta, \vec{a} $ then calculated with equations, numerical substitutions, results, and units BEFORE REVEAL. Nine-row validation table completed after REVEAL, rows within 1 % (or inside the stated display-rounding bound for a_θ), screenshot showing the parameter boxes, the contributions block and the REVEAL line (A2.3: 5). Explanation giving BOTH pictures of the $2 \dot{r} \omega$ contribution and the inward-motion sign change (A2.4: 3).	20
Part A — Experiment 3 (A3)	Prediction committed before the arithmetic (A3.1: 2). Six numbers for the accelerating arm, both transverse contributions computed separately, both radial contributions computed separately, ratio reported, screenshot with $ a $ and the contributions block (A3.2: 5). Doubled- α prediction made before the rerun, table completed, and the explanation that $\omega = \omega_0 + \alpha t$ makes $2 \dot{r} \omega = 2 b \omega^2$ grow with the square of the motor rate (A3.3: 3). Circle closure predicted, run and confirmed: $\dot{r} = 0$ so the $2 \dot{r} \omega$ contribution vanishes and $a_\theta = R \alpha$ (A3.4: 2).	12
Part B — Choosing the description (B1–B5)	Polar chosen and justified with the three questions (B1: 3). Hand rotation of BOTH vectors into x–y done before the panel is opened, table within 1 %, screenshot of the expanded MATH / EQUATIONS panel (B2: 7). a_t, a_n and p computed independently — no VEL readout exists for these — and p compared with r with the correct reason (B3: 6). Three magnitudes tabulated and the invariance stated (B4: 2). Tracker question answered Cartesian-first then n–t or polar, and one flipping piece of information named (B5: 2).	20

Criterion	What full credit looks like	Pts
Part C — Cable constraint (C1)	Prediction committed before any equation (C1.1: 3). Datum and positive direction stated, coordinates named, THREE changing segments identified, the 1.2 m offset correctly declared a constant, constant-length relation written (C1.2: 5). Both differentiations shown (C1.3: 4). v_P , a_P , the cable length and the lift time computed with substitutions (C1.4: 4). Signs interpreted against the student's own datum (C1.5: 1). Datum inversion carried out and shown to give the same physical answer (C1.6: 1).	18
Part C — Relative motion (C2)	v_A and v_B resolved with the bearing convention, sketch present (C2.1: 3). $v_{B/A}$ computed, magnitude and compass bearing reported, $v_{A/B}$ related by a sign (C2.2: 5). Line-of-sight unit vectors built, range rate and bearing rate projected, angle between $v_{B/A}$ and the line of sight computed, and the identity $ v_{B/A} ^2 = \dot{r}^2 + (r \dot{\omega})^2$ verified (C2.3: 5). Cockpit description with the student's own closing and bearing rates and a justified collision-course verdict (C2.4: 2). Relative position versus relative velocity explained with the student's own numbers (C2.5: 2).	17
	TOTAL	100