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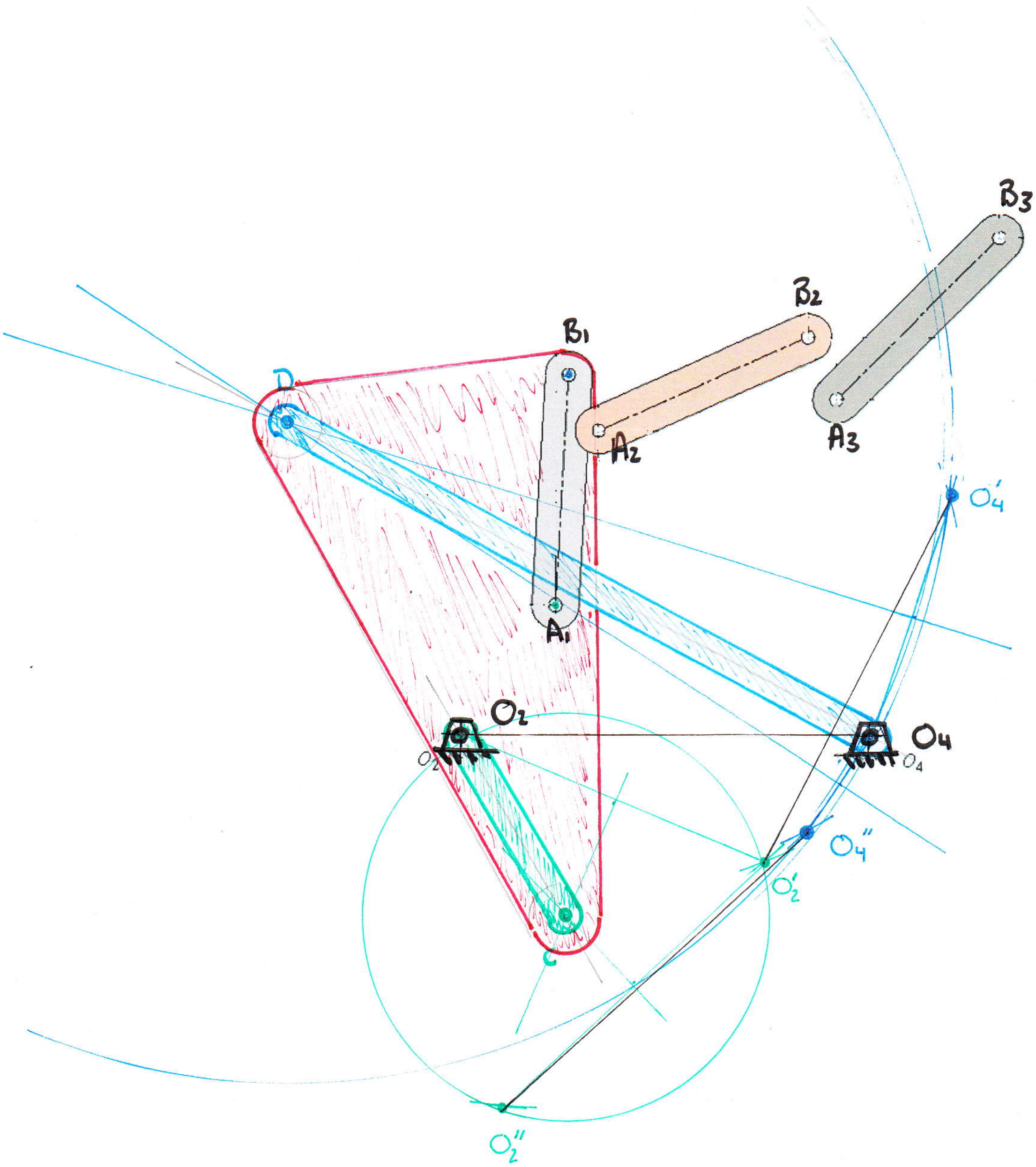
Signature: ____________________

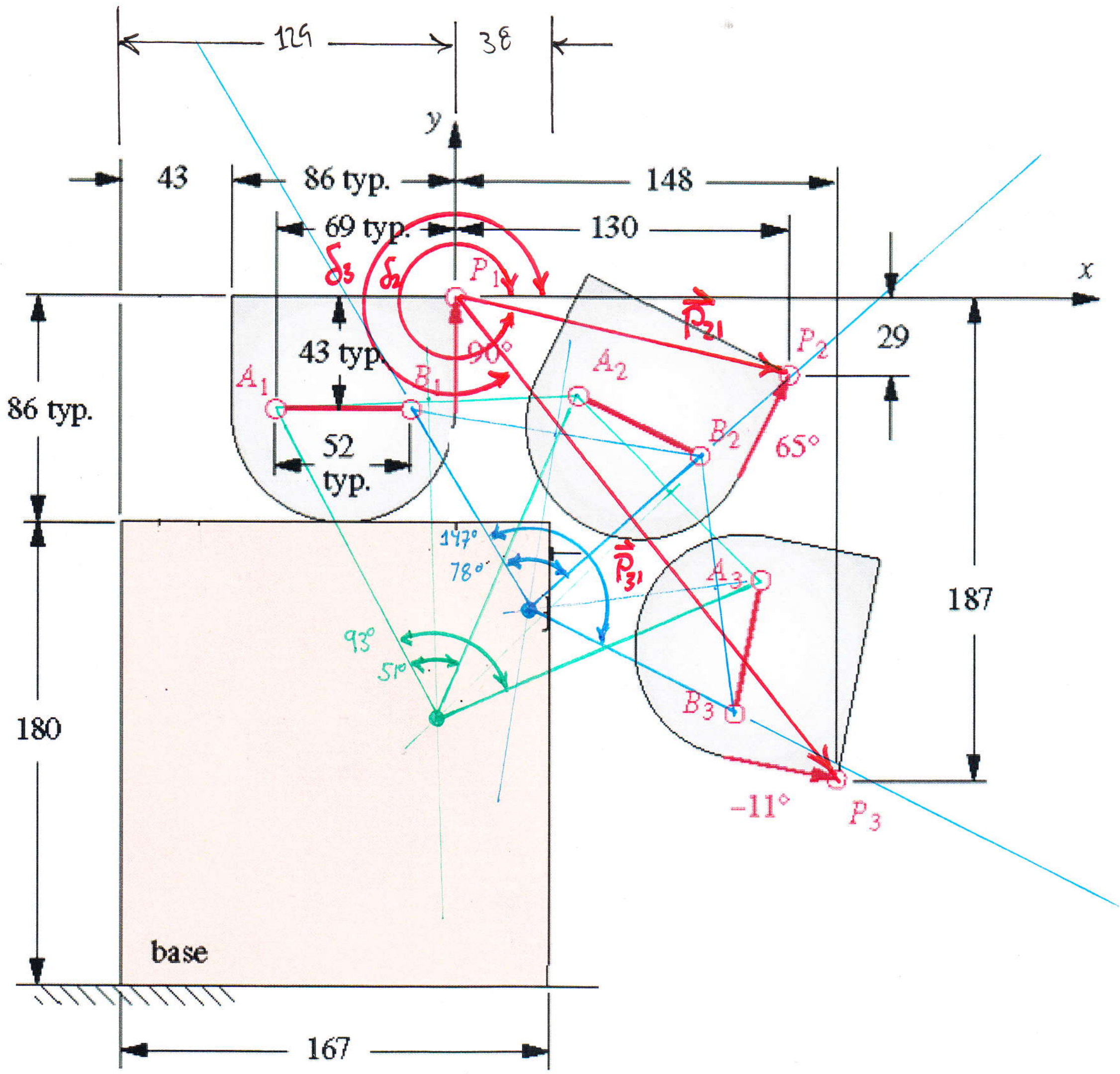
Print Name: SOLUTION

Exam Date: 15 MARCH 2016

PROBLEM 1: A mechanism needs to travel starting at the left position, moving through the middle positon, and ending at the right position as shown below below. Design the mechanism such that it attaches to the ground pivots shown.



PROBLEM 2: Using your three position algorithm, synthesize a mechanism that will take the bucket through the three positions shown. Make sure to use to pivots A and B. The ground pivots must be on the base. All dimensions are in millimeters.



$(P_{1x}, P_{1y}) = (0mm, 0mm)$
$(P_{2x}, P_{2y}) = (130mm, -29mm)$
$(P_{3x}, P_{3y}) = (148mm, -187mm)$

GIVENS (CALCULATED)

$p_{21} = \sqrt{(29mm)^2 + (130mm)^2} = 133.20mm$

$p_{31} = \sqrt{(148mm)^2 + (187mm)^2} = 238.48mm$

$\delta_2 = 360° - \tan^{-1}\frac{29}{130} = 347.43°$

$\delta_3 = 360° - \tan^{-1}\frac{187}{148} = 308.36$

$\alpha_2 = 360° - (90° - 65°) = 335°$

$\alpha_3 = 360° - (90° + 11°) = 259°$

FREE CHOICES (MEASURED)

$\beta_2 = 360° - 51° = 309°$

$\beta_3 = 360° - 93° = 267°$

$\gamma_2 = 360° - 78° = 282°$

$\gamma_3 = 360° - 147° = 213°$

First Dyad

FIRST DYAD

GIVEN:		CHOSEN:		FIND:	
P12	133.20	β2	309.00	w	136.303
P13	238.48	β3	267.00	θ	118.160
δ2	347.43			z	84.848
δ3	308.36			φ	32.852
α2	335.00			W1x	-64.327
α3	259.00			W1y	120.168
				Z1x	71.279
				Z1y	46.028

	x-coord	y-coord.
O2	-6.952	-166.197
A1	-71.279	-46.028
A2	45.955	-40.581
A3	116.419	-108.247
P1	0.000	0.000
P2	130.007	-28.989
P3	148.001	-186.999

$$\begin{bmatrix} -0.3707 & 0.7771 & -0.0937 & 0.4226 \\ -0.7771 & -0.3707 & -0.4226 & -0.0937 \\ -1.0523 & 0.9986 & -1.1908 & 0.9816 \\ -0.9986 & -1.0523 & -0.9816 & -1.1908 \end{bmatrix} \begin{Bmatrix} W1x \\ W1y \\ Z1x \\ Z1y \end{Bmatrix} = \begin{Bmatrix} 130.0073 \\ -28.9886 \\ 148.0008 \\ -186.9986 \end{Bmatrix}$$

Second Dyad

SECOND DYAD

GIVEN:		CHOSEN:		FIND:	
P12	133.20	γ2	282.00	u	91.807
P13	238.48	γ3	213.00	σ	120.114
δ2	347.43			s	44.739
δ3	308.36			ψ	67.387
α2	335.00			U1x	-46.062
α3	259.00			U1y	79.416
				S1x	17.203
				S1y	41.300

	x-coord	y-coord.
O4	28.859	-120.715
B1	-17.203	-41.300
B2	96.962	-59.149
B3	110.742	-162.232
P1	0.000	0.000
P2	130.007	-28.989
P3	148.001	-186.999

$$\begin{bmatrix} -0.7921 & 0.9781 & -0.0937 & 0.4226 \\ -0.9781 & -0.7921 & -0.4226 & -0.0937 \\ -1.8387 & 0.5446 & -1.1908 & 0.9816 \\ -0.5446 & -1.8387 & -0.9816 & -1.1908 \end{bmatrix} \begin{Bmatrix} U1x \\ U1y \\ S1x \\ S1y \end{Bmatrix} = \begin{Bmatrix} 130.0073 \\ -28.9886 \\ 148.0008 \\ -186.9986 \end{Bmatrix}$$

THESE RESULTS SHOW THE FIXED ROTO-POLES O_2 AND O_4 ARE ON THE BASE

PROBLEM 3: Design a cam to move a follower from 0 to 4 inches in 60°, dwell for 90°, fall 4 inches in 60°, and dwell for the remainder of the cycle. The total cycle time must take 4 seconds. Use CYCLOIDAL FUNCTIONS to accomplish the task.

Rise

$$s = y = h \cdot \left[\frac{\theta}{\beta} - \frac{1}{2\pi} \sin\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

$$y' = \frac{h}{\beta} \cdot \left[1 - \cos\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

$$y'' = \frac{2\pi \cdot h}{\beta^2} \cdot \sin\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

$$y''' = \frac{4 \cdot \pi^2 \cdot h}{\beta^3} \cdot \cos\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

Fall

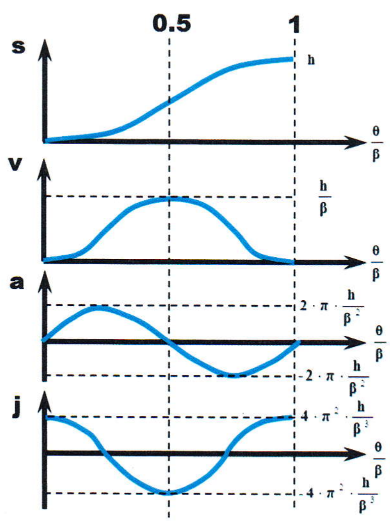
$$s = y = h - h \cdot \left[\frac{\theta}{\beta} - \frac{1}{2\pi} \sin\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

$$y' = -\frac{h}{\beta} \cdot \left[1 - \cos\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

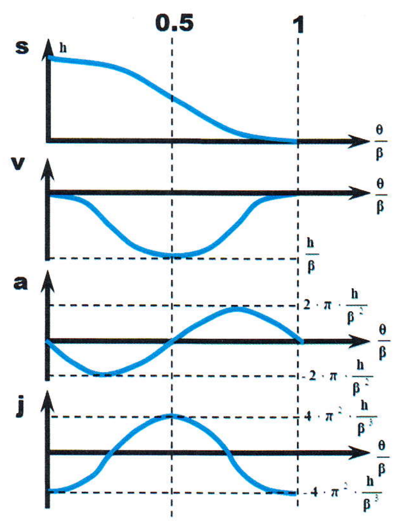
$$y'' = -\frac{2\pi \cdot h}{\beta^2} \cdot \sin\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

$$y''' = -\frac{4 \cdot \pi^2 \cdot h}{\beta^3} \cdot \cos\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

RISE

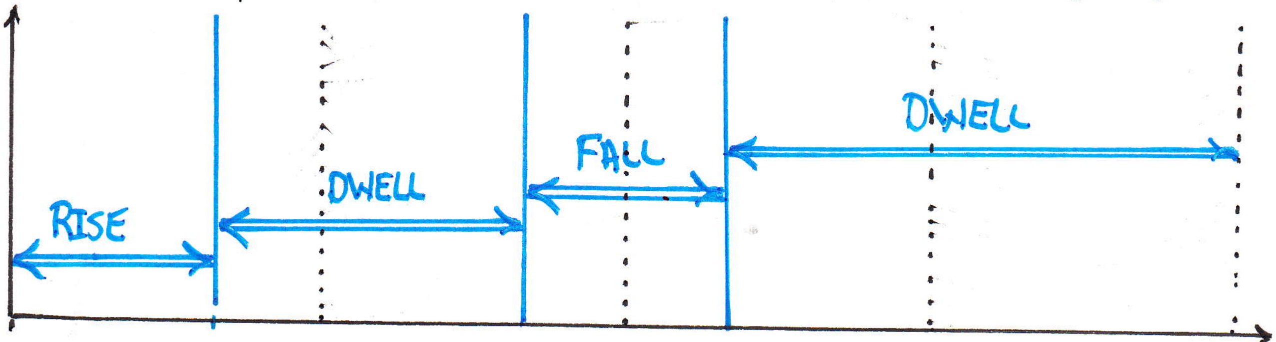


FALL

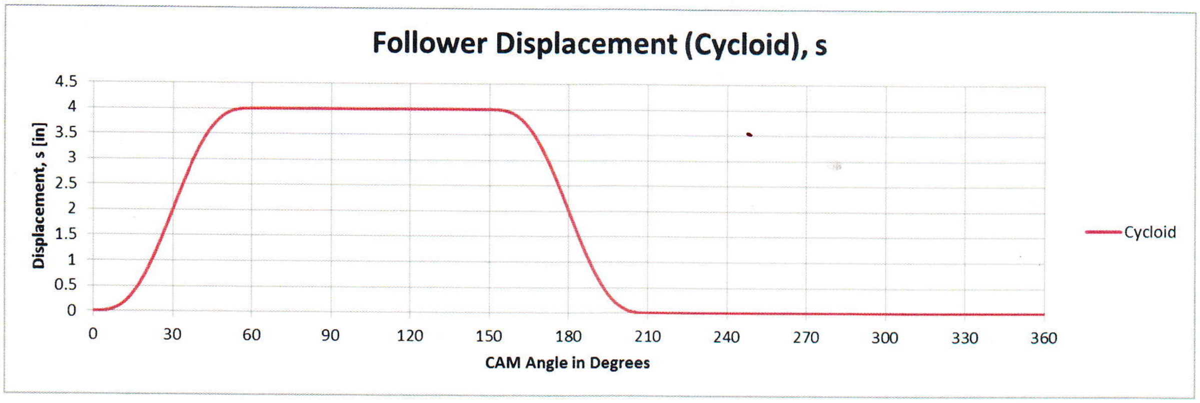


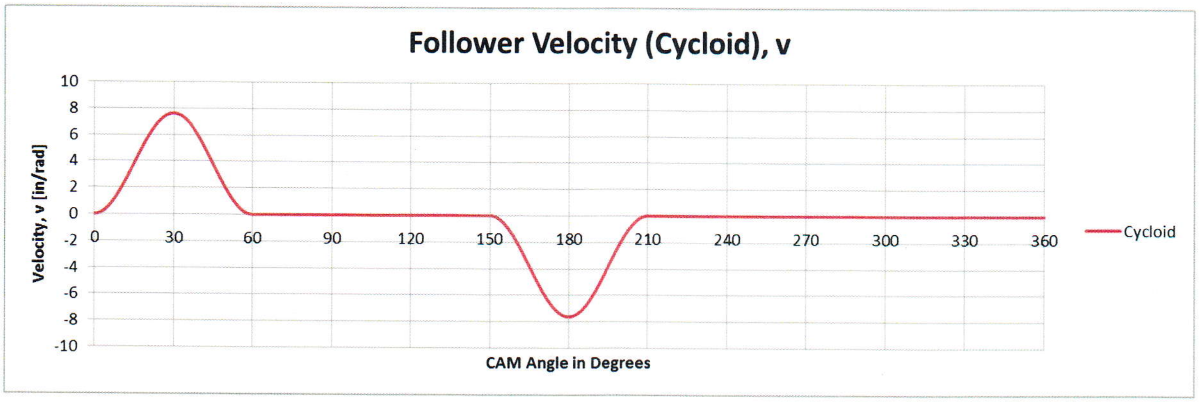
3a: Design this cam using the CYCLOIDAL function for all the rises and falls.

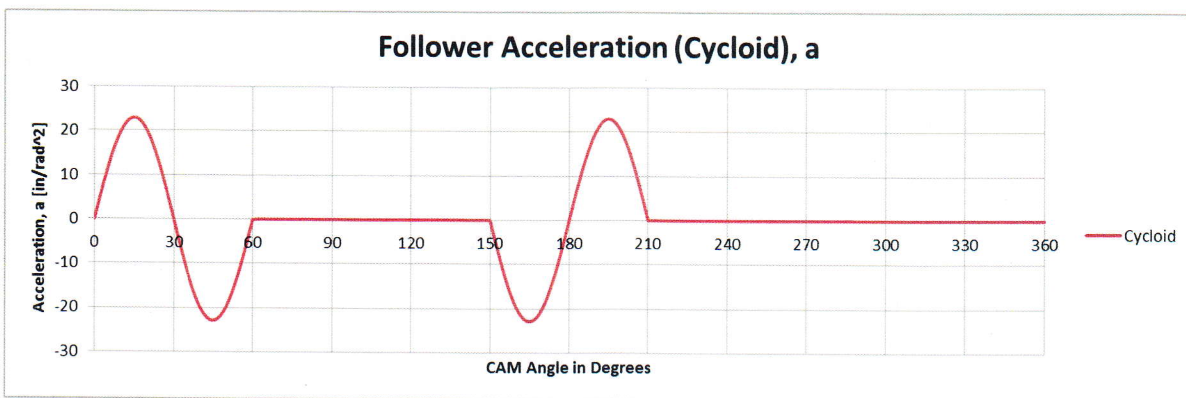
3b: Use your program to plot the s, s', s'', and s''' diagrams and attach them after the last page of this problem.

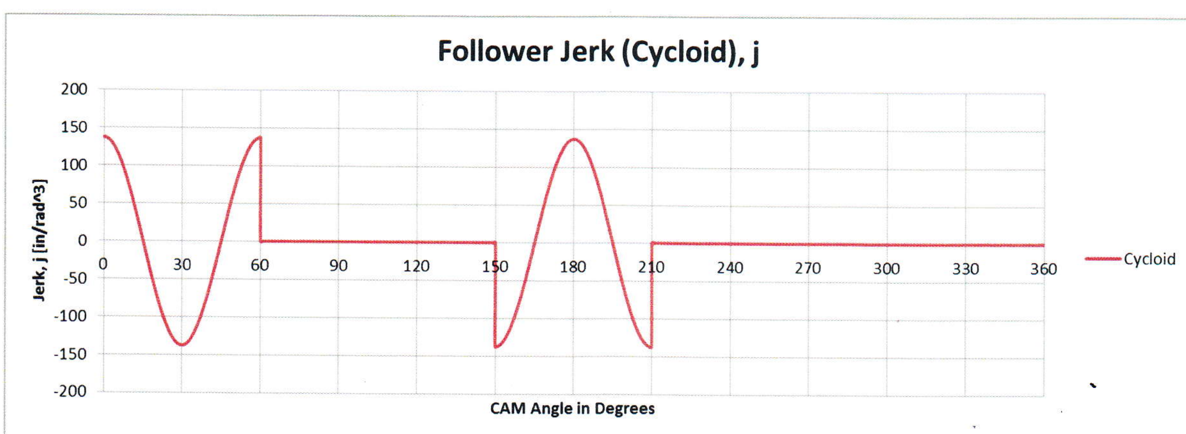


Θ [DEG]	0	60°	90	150°	180	210	270	360
Θ [RAD]	0	$\pi/3$	$\pi/2$	$5\pi/6$	π	$7\pi/6$	$3\pi/2$	2π
t [s]	0	0.667s	1s	1.667s	2s	2.333s	3s	4s
S [in]	0	4in		4in		0		0
S' [in/RAD]	0	0		0		0		0
S'' [in/RAD^2]	0	0		0		0		0
S''' [in/RAD^3]	0	–		–		–		–


Follower Displacement (Cycloid), s
Displacement, s [in]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
30
60
90
120
150
180
210
240
270
300
330
360
CAM Angle in Degrees
Cycloid


Follower Velocity (Cycloid), v
Velocity, v [in/rad]
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
30
60
90
120
150
180
210
240
270
300
330
360
CAM Angle in Degrees
Cycloid


Follower Acceleration (Cycloid), a
Acceleration, a [in/rad^2]
30
20
10
0
-10
-20
-30
0
30
60
90
120
150
180
210
240
270
300
330
360
CAM Angle in Degrees
Cycloid


Follower Jerk (Cycloid), j
Jerk, j [in/rad^3]
200
150
100
50
0
-50
-100
-150
-200
0
30
60
90
120
150
180
210
240
270
300
330
360
CAM Angle in Degrees
Cycloid

PROBLEM 4: Design a cam to move a follower from 0 to 6 inches in 45°, dwell for 90°, fall 3 inches in 45°, dwell for 60°, fall 3 more inches in 60°, and dwell the remainder of the cycle. The total cycle time must take 5 seconds. Use POLYNOMIAL FUNCTIONS to accomplish the task.

$$s = C_0 + C_1\cdot\left(\frac{\theta}{\beta}\right) + C_2\cdot\left(\frac{\theta}{\beta}\right)^2 + C_3\cdot\left(\frac{\theta}{\beta}\right)^3 + C_4\cdot\left(\frac{\theta}{\beta}\right)^4 + C_5\cdot\left(\frac{\theta}{\beta}\right)^5 + C_6\cdot\left(\frac{\theta}{\beta}\right)^6 + C_7\cdot\left(\frac{\theta}{\beta}\right)^7$$

$$= C_0 + \frac{C_1}{\beta}\cdot\theta + \frac{C_2}{\beta^2}\cdot\theta^2 + \frac{C_3}{\beta^3}\cdot\theta^3 + \frac{C_4}{\beta^4}\cdot\theta^4 + \frac{C_5}{\beta^5}\cdot\theta^5 + \frac{C_6}{\beta^6}\cdot\theta^6 + \frac{C_7}{\beta^7}\cdot\theta^7$$

$$s' = \frac{C_1}{\beta} + 2\cdot\frac{C_2}{\beta^2}\cdot\theta + 3\cdot\frac{C_3}{\beta^3}\cdot\theta^2 + 4\cdot\frac{C_4}{\beta^4}\cdot\theta^3 + 5\cdot\frac{C_5}{\beta^5}\cdot\theta^4 + 6\cdot\frac{C_6}{\beta^6}\cdot\theta^5 + 7\cdot\frac{C_7}{\beta^7}\cdot\theta^6$$

$$= \frac{1}{\beta}\left[C_1 + 2\cdot C_2\cdot\left(\frac{\theta}{\beta}\right) + 3\cdot C_3\cdot\left(\frac{\theta}{\beta}\right)^2 + 4\cdot C_4\cdot\left(\frac{\theta}{\beta}\right)^3 + 5\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^4 + 6\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^5 + 7\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^6\right]$$

$$s'' = 2\cdot\frac{C_2}{\beta^2} + 6\cdot\frac{C_3}{\beta^3}\cdot\theta + 12\cdot\frac{C_4}{\beta^4}\cdot\theta^2 + 20\cdot\frac{C_5}{\beta^5}\cdot\theta^3 + 30\cdot\frac{C_6}{\beta^6}\cdot\theta^4 + 42\cdot\frac{C_7}{\beta^7}\cdot\theta^5$$

$$= \frac{1}{\beta^2}\left[2\cdot C_2 + 6\cdot C_3\cdot\left(\frac{\theta}{\beta}\right) + 12\cdot C_4\cdot\left(\frac{\theta}{\beta}\right)^2 + 20\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^3 + 30\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^4 + 42\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^5\right]$$

$$s''' = 6\cdot\frac{C_3}{\beta^3} + 24\cdot\frac{C_4}{\beta^4}\cdot\theta + 60\cdot\frac{C_5}{\beta^5}\cdot\theta^2 + 120\cdot\frac{C_6}{\beta^6}\cdot\theta^3 + 210\cdot\frac{C_7}{\beta^7}\cdot\theta^4$$

$$= \frac{1}{\beta^3}\left[6\cdot C_3 + 24\cdot C_4\cdot\left(\frac{\theta}{\beta}\right) + 60\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^2 + 120\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^3 + 210\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^4\right]$$

4a: Design this cam using Polynomial function for all the rises and falls.

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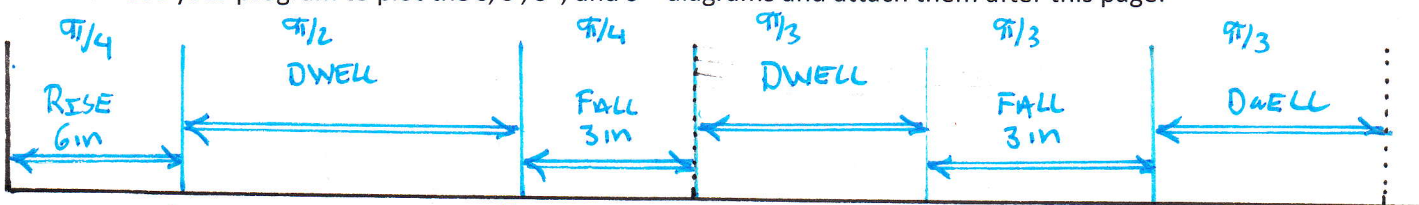


θ[DEG]	0	45	135	180	240	300	360
θ[RAD]	0	π/4	3π/4	π	4π/3	5π/3	2π
t [s]	0	0.625	1.875	2.5	3.333	4.167	5
S[in]	0	6	6	3	3	0	0
S'[in/rad]	0	0	0	0	0	0	0
S''[in/rad²]	0	0	0	0	0	0	0
S'''[in/rad³]	0	–	–	–	–	–	–

REGION 1: $0 \leq \theta \leq 45,\ 0 \leq \theta_1 \leq \beta_1 = 45° \rightarrow \pi/4$

$C_0 = C_1 = C_2 = 0$ FROM THE BC $S(0)=0,\ S'(0)=0,\ S''(0)=0$

$S(45°) = 6in = C_3 + C_4 + C_5$

$S'(45°) = 0 = 3 \cdot C_3 + 4 \cdot C_4 + 5 \cdot C_5$

$S''(45°) = 0 = 6 \cdot C_3 + 12 C_4 + 20 \cdot C_5$

$$\begin{bmatrix} 1 & 1 & 1 \\ 3 & 4 & 5 \\ 6 & 12 & 20 \end{bmatrix} \begin{Bmatrix} C_3 \\ C_4 \\ C_5 \end{Bmatrix} = \begin{Bmatrix} 6 \\ 0 \\ 0 \end{Bmatrix}$$

$$\Rightarrow \begin{Bmatrix} C_3 \\ C_4 \\ C_5 \end{Bmatrix} = \begin{Bmatrix} 60 \\ -90 \\ 36 \end{Bmatrix}$$

REGION 2: $45° \leq \theta \leq 135°,\ 0 \leq \theta_2 \leq \beta_2 = 90° = \pi/2$

$S = 6in,\ S' = 0\ in/rad,\ S'' = 0\ in/rad^2,\ S''' = 0\ in/rad^3$

REGION 3: $135° \leq \theta \leq 180°,\ 0 \leq \theta_3 \leq \beta_3 = 45° = \pi/2$

$S(0) = 6in = C_0$

$S'(0) = 0 = C_1$

$S''(0) = 0 = C_2$

$S(45°) = 3in = 6in + C_3 + C_4 + C_5 \Rightarrow -3in = C_3 + C_4 + C_5$

$S'(45°) = 0\ in/rad = 3 \cdot C_3 + 4 C_4 + 5 C_5$

$S''(45°) = 0\ in/rad^2 = 6 C_3 + 12 C_4 + 20 C_5$

$$\begin{bmatrix} 1 & 1 & 1 \\ 3 & 4 & 5 \\ 6 & 12 & 20 \end{bmatrix} \begin{Bmatrix} C_3 \\ C_4 \\ C_5 \end{Bmatrix} = \begin{Bmatrix} -3 \\ 0 \\ 0 \end{Bmatrix}$$

$$\Rightarrow \begin{Bmatrix} C_3 \\ C_4 \\ C_5 \end{Bmatrix} = \begin{Bmatrix} -30 \\ 45 \\ -18 \end{Bmatrix}$$

REGION 4: $180° \leq \theta \leq 240°,\ 0 \leq \theta_4 \leq \beta_4 = 60° = \pi/3$

$S = 3in,\ S' = 0\ in/rad,\ S'' = 0\ in/rad^2,\ S''' = 0\ in/rad^3$

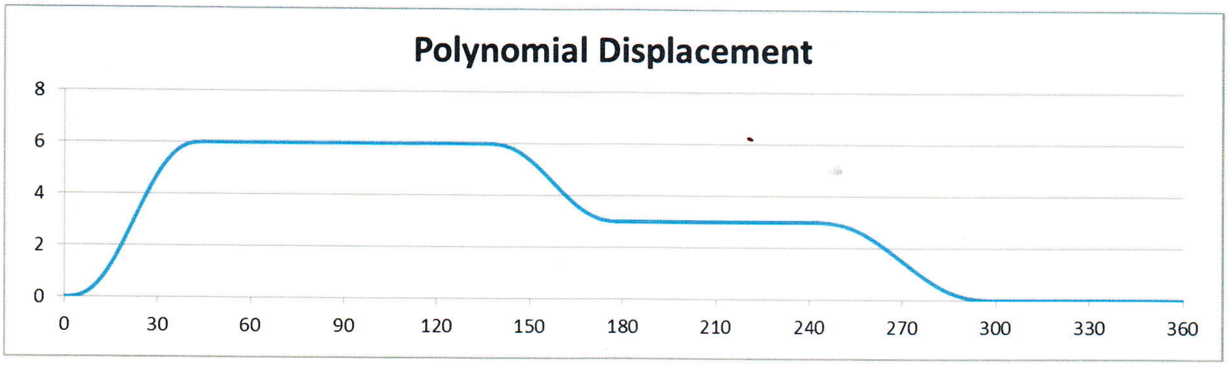
REGION 5: $240° \leq \theta \leq 300°,\ 0 \leq \theta_5 \leq \beta_5 = 60° = \pi/3$

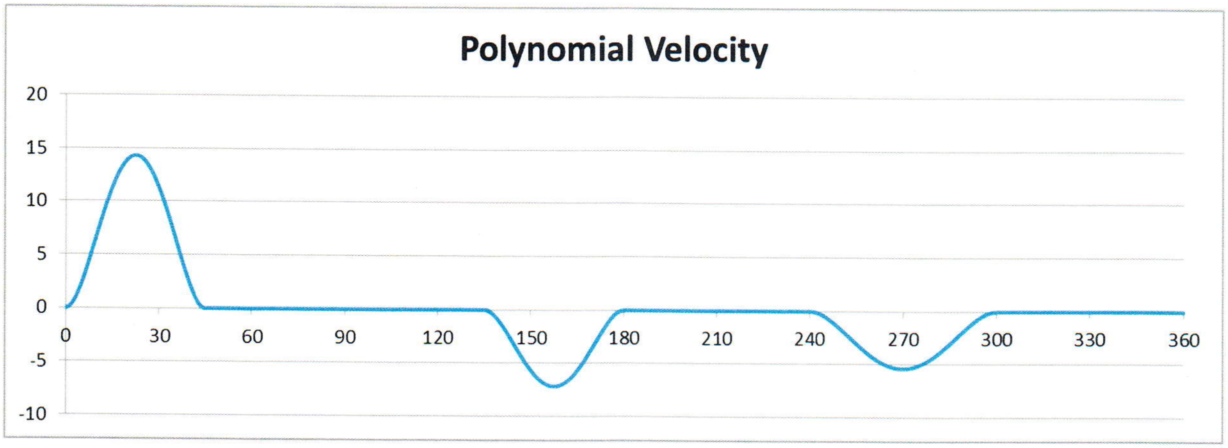
$S(0) = 3in = C_0,\quad S'(0) = 0 = C_1,\quad S''(0) = 0 = C_2$

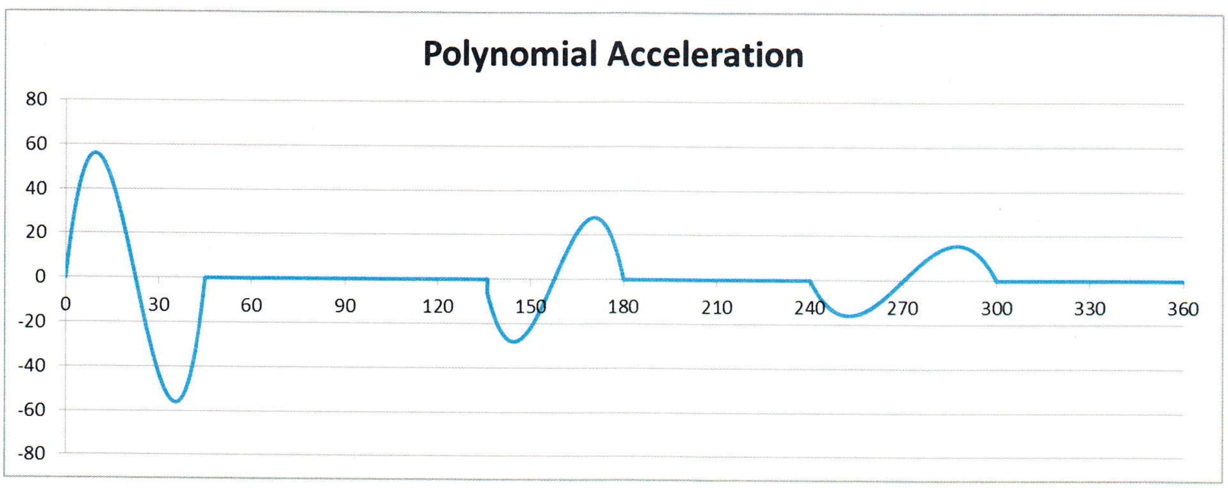
$C_3 = -30,\ C_4 = 45,\ C_5 = -18$

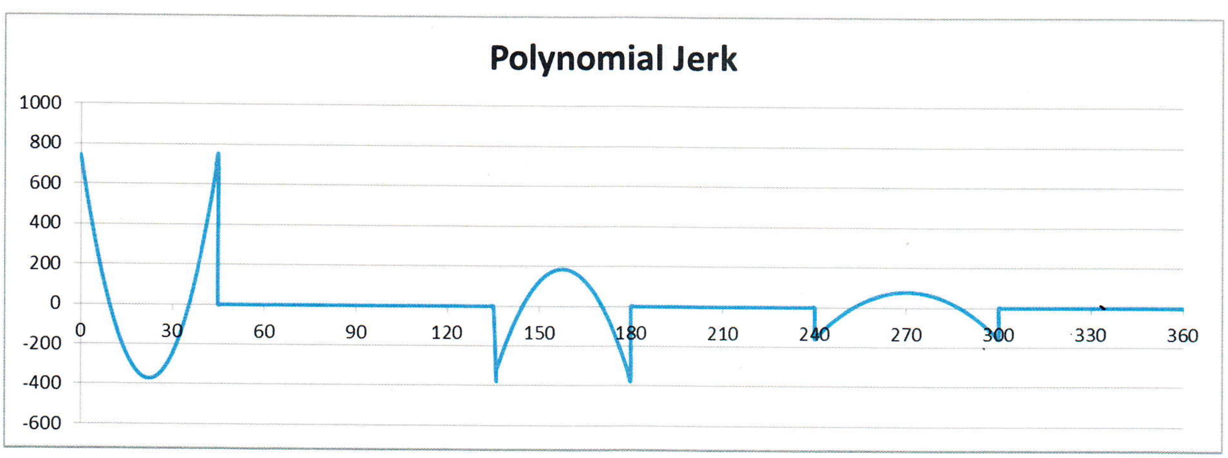
REGION 6: $240° \leq \theta \leq 360°,\ 0 \leq \theta_6 \leq \beta_5 = 60° = \pi/3$

$S = 0in,\ S' = 0\ in/rad,\ S'' = 0\ in/rad^2,\ S''' = 0\ in/rad^3$


Polynomial Displacement
8
6
4
2
0
0 30 60 90 120 150 180 210 240 270 300 330 360


Polynomial Velocity
20
15
10
5
0
-5
-10
0 30 60 90 120 150 180 210 240 270 300 330 360


Polynomial Acceleration
80
60
40
20
0
-20
-40
-60
-80
0 30 60 90 120 150 180 210 240 270 300 330 360


Polynomial Jerk
1000
800
600
400
200
0
-200
-400
-600
0 30 60 90 120 150 180 210 240 270 300 330 360

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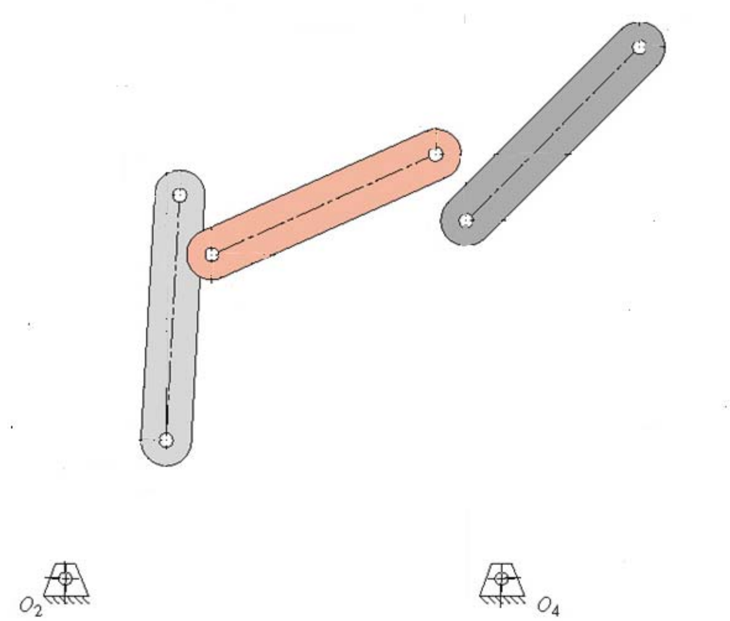
Signature: ____

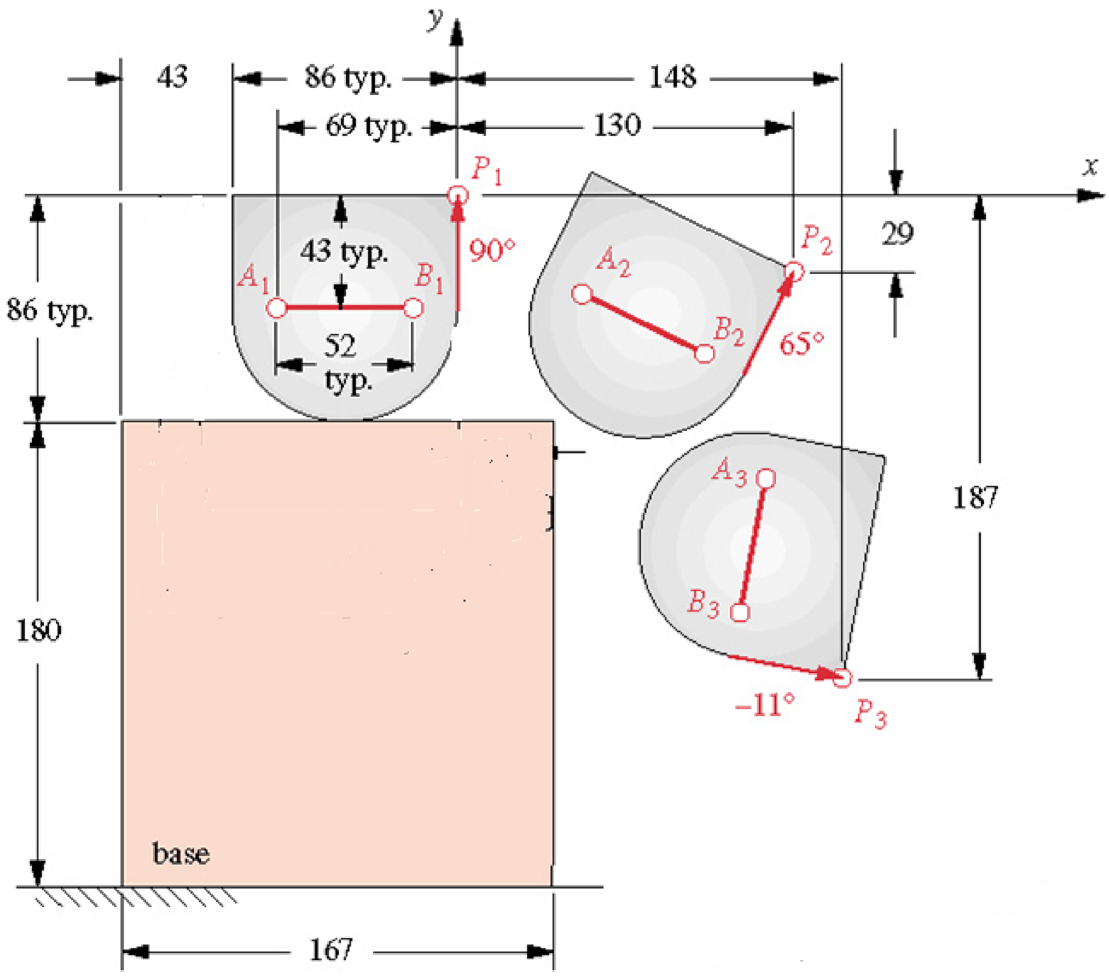
Print Name: ____

Exam Date: ____

PROBLEM 1: A mechanism needs to travel starting at the left position, moving through the middle positon, and ending at the right position as shown below below. Design the mechanism such that it attaches to the ground pivots shown.



PROBLEM 2: Using your three position algorithm, synthesize a mechanism that will take the bucket through the three positions shown. Make sure to use to pivots A and B. The ground pivots must be on the base. All dimensions are in millimeters.



PROBLEM 3: Design a cam to move a follower from 0 to 4 inches in 60°, dwell for 90°, fall 4 inches in 60°, and dwell for the remainder of the cycle. The total cycle time must take 4 seconds. Use CYCLOIDAL FUNCTIONS to accomplish the task.

Rise

$$s = y = h \cdot \left[\frac{\theta}{\beta} - \frac{1}{2\pi} \sin\left(2\pi \cdot \tfrac{\theta}{\beta}\right) \right]$$

$$y' = \frac{h}{\beta} \cdot \left[1 - \cos\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

$$y'' = \frac{2\pi \cdot h}{\beta^2} \cdot \sin\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

$$y''' = \frac{4 \cdot \pi^2 \cdot h}{\beta^3} \cdot \cos\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

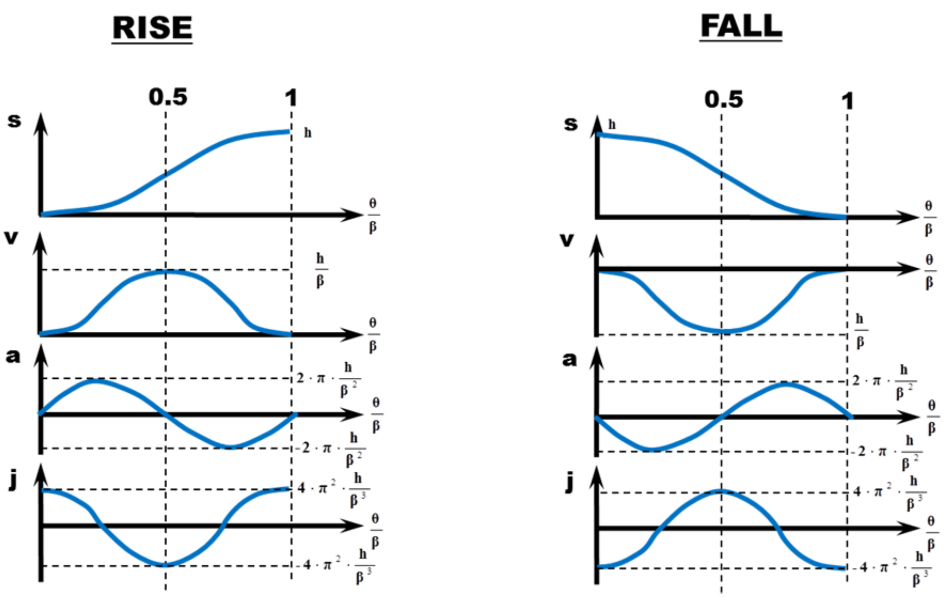
Fall

$$s = y = h - h \cdot \left[\frac{\theta}{\beta} - \frac{1}{2\pi} \sin\left(2\pi \cdot \tfrac{\theta}{\beta}\right) \right]$$

$$y' = -\frac{h}{\beta} \cdot \left[1 - \cos\left(2\pi \cdot \frac{\theta}{\beta}\right) \right]$$

$$y'' = -\frac{2\pi \cdot h}{\beta^2} \cdot \sin\left(2\pi \cdot \frac{\theta}{\beta}\right)$$

$$y''' = -\frac{4 \cdot \pi^2 \cdot h}{\beta^3} \cdot \cos\left(2\pi \cdot \frac{\theta}{\beta}\right)$$



3a: Design this cam using the CYCLOIDAL function for all the rises and falls.

3b: Use your program to plot the s, s', s'', and s''' diagrams and attach them after the last page of this problem.

PROBLEM 4: Design a cam to move a follower from 0 to 6 inches in 45°, dwell for 90°, fall 3 inches in 45°, dwell for 60°, fall 3 more inches in 60°, and dwell the remainder of the cycle. The total cycle time must take 5 seconds. Use POLYNOMIAL FUNCTIONS to accomplish the task.

$$s = C_0 + C_1\cdot\left(\frac{\theta}{\beta}\right) + C_2\cdot\left(\frac{\theta}{\beta}\right)^2 + C_3\cdot\left(\frac{\theta}{\beta}\right)^3 + C_4\cdot\left(\frac{\theta}{\beta}\right)^4 + C_5\cdot\left(\frac{\theta}{\beta}\right)^5 + C_6\cdot\left(\frac{\theta}{\beta}\right)^6 + C_7\cdot\left(\frac{\theta}{\beta}\right)^7$$
$$= C_0 + \frac{C_1}{\beta}\cdot\theta + \frac{C_2}{\beta^2}\cdot\theta^2 + \frac{C_3}{\beta^3}\cdot\theta^3 + \frac{C_4}{\beta^4}\cdot\theta^4 + \frac{C_5}{\beta^5}\cdot\theta^5 + \frac{C_6}{\beta^6}\cdot\theta^6 + \frac{C_7}{\beta^7}\cdot\theta^7$$

$$s' = \frac{C_1}{\beta} + 2\cdot\frac{C_2}{\beta^2}\cdot\theta + 3\cdot\frac{C_3}{\beta^3}\cdot\theta^2 + 4\cdot\frac{C_4}{\beta^4}\cdot\theta^3 + 5\cdot\frac{C_5}{\beta^5}\cdot\theta^4 + 6\cdot\frac{C_6}{\beta^6}\cdot\theta^5 + 7\cdot\frac{C_7}{\beta^7}\cdot\theta^6$$
$$= \frac{1}{\beta}\left[C_1 + 2\cdot C_2\cdot\left(\frac{\theta}{\beta}\right) + 3\cdot C_3\cdot\left(\frac{\theta}{\beta}\right)^2 + 4\cdot C_4\cdot\left(\frac{\theta}{\beta}\right)^3 + 5\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^4 + 6\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^5 + 7\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^6\right]$$

$$s'' = 2\cdot\frac{C_2}{\beta^2} + 6\cdot\frac{C_3}{\beta^3}\cdot\theta + 12\cdot\frac{C_4}{\beta^4}\cdot\theta^2 + 20\cdot\frac{C_5}{\beta^5}\cdot\theta^3 + 30\cdot\frac{C_6}{\beta^6}\cdot\theta^4 + 42\cdot\frac{C_7}{\beta^7}\cdot\theta^5$$
$$= \frac{1}{\beta^2}\left[2\cdot C_2 + 6\cdot C_3\cdot\left(\frac{\theta}{\beta}\right) + 12\cdot C_4\cdot\left(\frac{\theta}{\beta}\right)^2 + 20\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^3 + 30\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^4 + 42\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^5\right]$$

$$s''' = 6\cdot\frac{C_3}{\beta^3} + 24\cdot\frac{C_4}{\beta^4}\cdot\theta + 60\cdot\frac{C_5}{\beta^5}\cdot\theta^2 + 120\cdot\frac{C_6}{\beta^6}\cdot\theta^3 + 210\cdot\frac{C_7}{\beta^7}\cdot\theta^4$$
$$= \frac{1}{\beta^3}\left[6\cdot C_3 + 24\cdot C_4\cdot\left(\frac{\theta}{\beta}\right) + 60\cdot C_5\cdot\left(\frac{\theta}{\beta}\right)^2 + 120\cdot C_6\cdot\left(\frac{\theta}{\beta}\right)^3 + 210\cdot C_7\cdot\left(\frac{\theta}{\beta}\right)^4\right]$$

4a: Design this cam using Polynomial function for all the rises and falls.

4b: Use your program to plot the s, s', s'', and s''' diagrams and attach them after this page.