Roller Coaster Loops

Today's coasters provide riders with weightless sensations and abnormally large G forces. Weightless sensations occur when the seat pushes on riders with a force that is less than their weight. Large G forces occur when the seat pushes with a force much greater than their weight. The number of Gs (**Gz**) is the ratio of this seat force to the rider's weight. The loop-the-loop provides much of this thrill. The earliest designs included circular loops as shown in **Figure 1**. **Table 1** depicts the estimated speed (**v**) and the Gz for a rider starting from a 60-meter high drop.

Figure 1

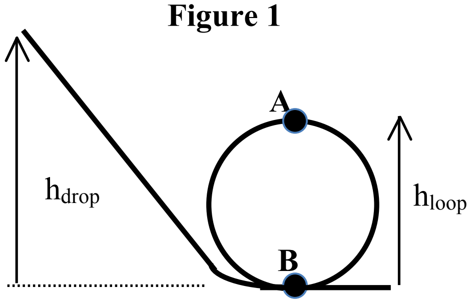

Table 1: Circular Loops

h_{loop} (m)	v_A * (m/s)	Gz at A	v_B * (m/s)	Gz at B
15	28.2	9.8	32.5	15.4
20	26.6	6.2	32.5	11.8
25	24.8	4.0	32.5	9.6
30	23.0	2.6	32.5	8.2
35	21.0	1.6	32.5	7.2
45	16.3	0.2	32.5	5.8
50	13.3	0.0	32.5	5.3

Because of the inherent dangers associated with circular loops and of the advent of tubular steel coasters, designers began to use non-circular loops in their designs. The teardrop-shaped loop is often called a **clothoid loop**. The shape is that of a cornu spiral, with a constantly changing radius of curvature as shown in **Figure 2**. **Table 2** shows the effect of the radii (**R**) at the top and bottom of a loop upon the rider experience.

Figure 2

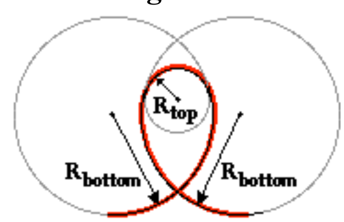

Table 2: Clothoid Loops

h_{loop} (m)	R_A (m)	v_A * (m/s)	Gz at A	R_B (m)	v_B * (m/s)	Gz at B
30	10	23.0	4.4	20	32.5	6.4
36	12	20.6	2.6	24	32.5	5.5
40	13	18.8	1.8	26	32.5	5.2
40	13	18.8	1.8	30	32.5	4.6
40	13	18.8	1.8	34	32.5	4.2
40	13	18.8	1.8	38	32.5	3.8
40	15	18.8	1.4	26	32.5	5.2
40	17	18.8	1.1	26	32.5	5.2
45	15	16.3	0.8	30	32.5	4.6
45	15	16.3	0.8	34	32.5	4.2
45	15	16.3	0.8	38	32.5	3.8
45	15	16.3	0.8	42	32.5	3.6
45	18	16.3	0.5	34	32.5	4.2
45	21	16.3	0.3	34	32.5	4.2

* Calculations based on a 10% energy loss due to air resistance, track vibration, etc.

Questions:

1. What effect does changing the height of a circular loop have upon the speed of the riders at position A?
   a. Increasing the height of the loop increases the speed at position A.
   b. Increasing the height of the loop decreases the speed at position A.
   c. Increasing the height of the loop has no effect upon the speed at position A.
   d. Increasing the height of the loop seems to affect the speed; the manner in which it does is not predictable.

2. What effect does changing the height of a circular loop have upon the speed of the riders at position B?
   a. Increasing the height of the loop increases the speed at position B.
   b. Increasing the height of the loop decreases the speed at position B.
   c. Increasing the height of the loop has no effect upon the speed at position B.
   d. Increasing the height of the loop seems to affect the speed; the manner in which it does is not predictable.

3. Use **Table 1** to predict the speed and Gz experienced by a rider at the top of a 40-m high circular loop if starting from a 60-meter high drop?
   a. Speed = 6.3 m/s (approximately) Gz = 0.2 (approximately)
   b. Speed = 18.5 m/s (approximately) Gz = 0.8 (approximately)
   c. Speed = 20.0 m/s (approximately) Gz = 1.4 (approximately)
   d. Speed = 23.0 m/s (approximately) Gz = 2.6 (approximately)

4. According to **Table 1**, at which of the following locations will a rider experience the least Gz?
   a. At the top of a 20-m high loop. b. At the top of a 35-m high loop.
   c. At the bottom of a 30-m high loop. d. At the bottom of a 45-m high loop.

5. According to **Table 2**, what effect does an increase in the radius of the top of a loop have upon the speed of the riders at the top of the loop?
   a. Increasing the radius of the top of the loop increases the speed at this location.
   b. Increasing the radius of the top of the loop decreases the speed at this location.
   c. Increasing the radius of the top of the loop has no effect upon the speed at this location.
   d. Increasing the radius of the top of the loop seems to affect the speed; the manner in which it does is not predictable.

6. According to **Table 2**, at which of the following locations on a clothoid-shaped loop will a rider experience the most Gz?
   a. At the top of a 30-m high loop having a radius of 10 m.
   b. At the top of a 40-m high loop having a radius of 15 m.
   c. At the bottom of a 36-m high loop having a radius of 24 m.
   d. At the bottom of a 40-m high loop having a radius of 26 m.

7. The number of Gz that can be considered safe depends upon a variety of factors – the age and health of the rider, the duration of those Gz and how abruptly they are experienced. Generally, the coaster industry seeks to keep the number of Gz at 5.0 or below. Given this concern, which one of the following clothoid loops would **not** be used in a 60-m high design?
a. h_{loop} = 40 m; R_A = 13 m; R_B = 30 m
b. h_{loop} = 40 m; R_A = 13 m; R_B = 38 m
c. h_{loop} = 40 m; R_A = 17 m; R_B = 26 m
d. h_{loop} = 45 m; R_A = 15 m; R_B = 34 m

8. A coaster engineer wishes to include a clothoid loop in a 60-m high design that provides the riders the following experience:

Top of Loop	Between 1.0 and 1.5 Gz
Bottom of Loop	Between 4.0 and 4.5 Gz

Use **Table 2** to determine which of the following loop parameters would be most suitable for such a coaster?
a. h_{loop} = 40 m; R_A = 15 m; R_B = 30 m
b. h_{loop} = 40 m; R_A = 17 m; R_B = 26 m
c. h_{loop} = 45 m; R_A = 15 m; R_B = 34 m
d. h_{loop} = 45 m; R_A = 15 m; R_B = 42 m

9. As the number of Gz at the top of an *inverted* (upside down) loop begins to approach zero, designers must regard the possibility of riders falling out of their seats as being the top safety hazard. If a design includes a clothoid loop with Gz less than 1.0 at the top, what change could be made to improve the safety at this location?
a. Switch to a circular loop.
b. Increase the height of the loop.
c. Increase the radius at the loop top.
d. Decrease the radius at the loop top.

10. A coaster engineer has included a clothoid loop in his coaster design. As currently designed, riders run the risk of falling out of their seats at the top of the loop. Which one of the following design changes would **NOT** fix this safety issue?
a. Decrease the height of the loop.
b. Increase the height of the first drop.
c. Decrease the radius of the top of the loop.
d. Increase the height of the loop and/or increase the radius of the top of the loop.

11. For the same loop heights, how are the values of the clothoid-shaped loops of **Table 2** different than the values for the circular loops of **Table 1**?
a. The speed at the top of the loops is less for clothoid-shaped loops.
b. The Gz at the top of the loops are greater for clothoid-shaped loops.
c. The Gz at both the top and the bottom of the loops are less for clothoid-shaped loops.
d. The speed at both the top and the bottom of the loops are less for clothoid-shaped loops.