

Trajectory of a Juggling Club

Figure 1 shows a picture of a wooden juggling club. The mass of a juggling club is not evenly distributed between about the length of the club. There is more wood present near the larger club head, thus shifting the **center of mass** towards the head of the club. When a club is juggled, it rotates about its center of mass as it travels through the air. The three boxes on the club indicate three positions on the club. The center box (not labeled) is the center of mass of the club. A video of a juggled club was taken and then analyzed to produce the graph shown in **Figure 2**. The motion of the club through the air began approximately 1.8 seconds into the video. As shown on the graph, the club was released from a height of 100-cm above the ground. The horizontal and the vertical position of the three marked points are shown as a function of time. The horizontal position is the X-position and the vertical position is the Y position. The zero position for the vertical motion is the ground.

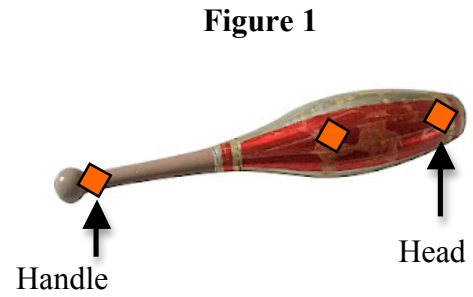
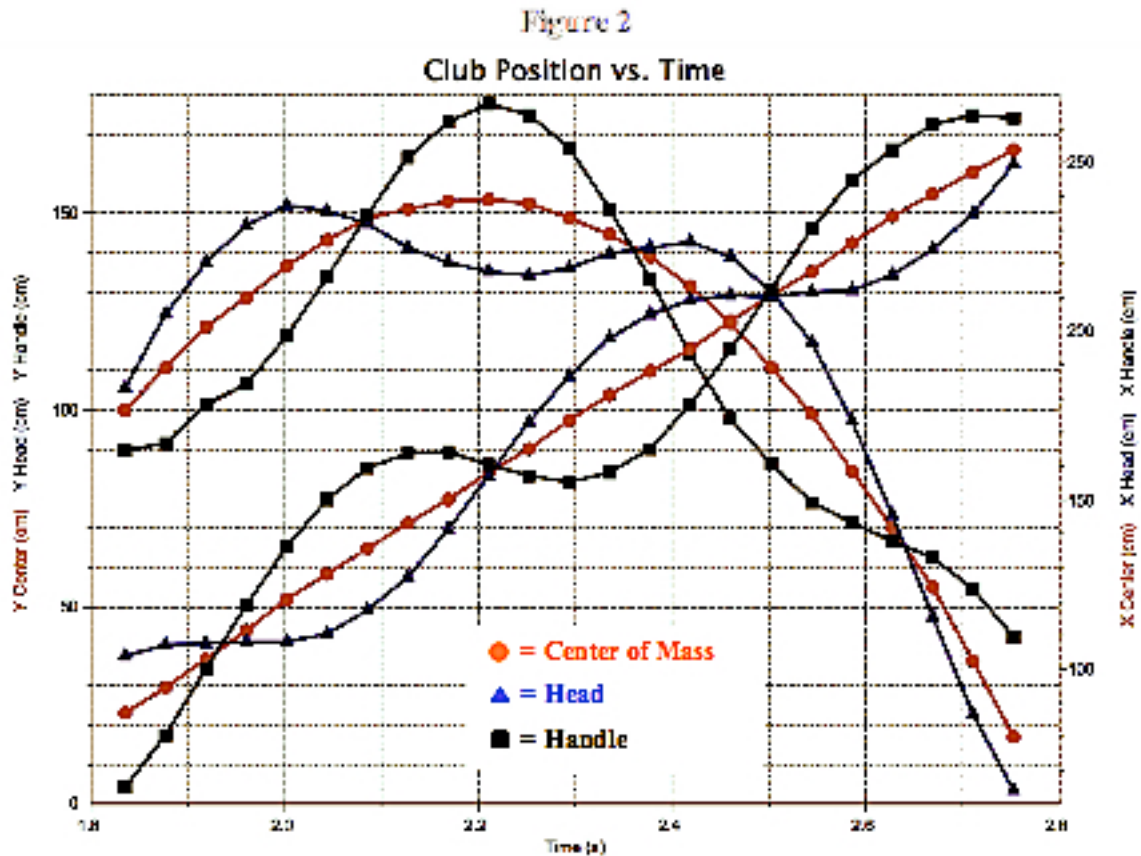
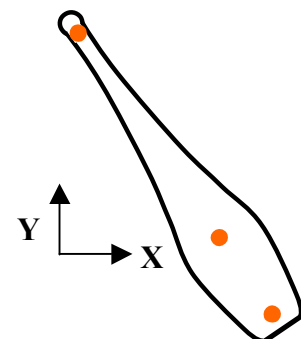
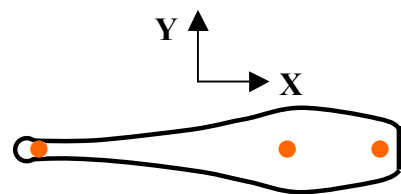


Figure 1

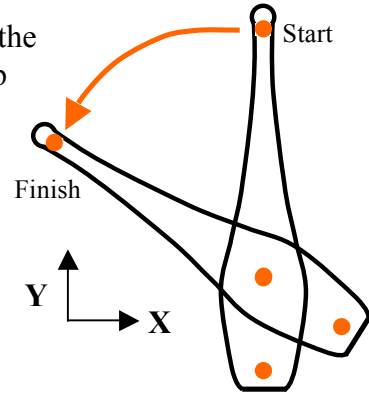


Questions:

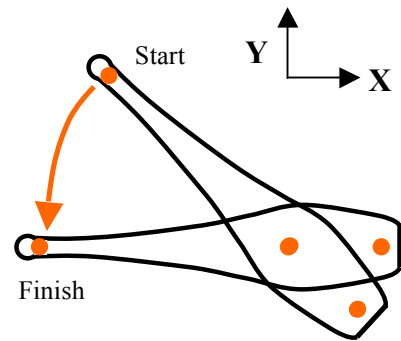
1. What is the vertical position of the head of the club at 2.0 seconds?
 - a. 41 cm
 - b. 109 cm
 - c. 152 cm
 - d. 238 cm
2. What is the height of the handle of the club when it (the handle) is at a horizontal position of 95 cm?
 - a. 30 cm
 - b. 98 cm
 - c. 153 cm
 - d. 165 cm
3. What is the height of the center of mass of the club when it (the center of mass) is at a horizontal position of 165 cm?
 - a. 90 cm
 - b. 148 cm
 - c. 152 cm
 - d. 252 cm
4. Which part of the club - handle or head - is furthest (horizontally) from the starting point and by how much at a time of 2.1 seconds?
 - a. The handle is furthest by 10 cm.
 - b. The handle is furthest by 29 cm.
 - c. The handle is furthest by 34 cm.
 - d. The head is furthest by 40 cm.
5. During which time period is the handle of the club moving *backwards* towards the starting position?
 - a. The handle is moving backwards between 2.17 seconds and 2.29 seconds.
 - b. The handle is moving backwards between 2.21 seconds and 2.75 seconds.
 - c. The handle is moving backwards between 2.63 seconds and 2.75 seconds.
 - d. The handle never moves backwards; it is always moving forwards.
6. At which of the following times is the club oriented vertically (perpendicular) to the ground?
 - a. At 1.93 seconds
 - b. At 2.00 seconds
 - c. At 2.08 seconds
 - d. At 2.30 seconds
7. At which of the following times is the club oriented as shown at the right?
 - a. At 1.93 seconds
 - b. At 2.08 seconds
 - c. At 2.21 seconds
 - d. At 2.36 seconds
8. At which of the following times is the club oriented as shown at the right?
 - a. At 2.00 seconds
 - b. At 2.17 seconds
 - c. At 2.25 seconds
 - d. At 2.46 seconds



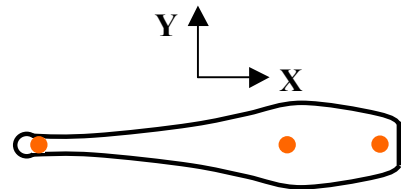
9. The diagram at the right shows two different orientations for the club. Between which two *Start* and *Finish* times does the club rotate between these two orientations?
- Start = 2.09 seconds; Finish = 2.17 seconds
 - Start = 2.22 seconds; Finish = 2.29 seconds
 - Start = 2.29 seconds; Finish = 2.36 seconds
 - Start = 2.50 seconds; Finish = 2.56 seconds



10. The diagram at the right shows two different orientations for the club. Between which two *Start* and *Finish* times does the club rotate between these two orientations?
- Start = 1.92 seconds; Finish = 2.00 seconds
 - Start = 2.09 seconds; Finish = 2.17 seconds
 - Start = 2.22 seconds; Finish = 2.29 seconds
 - Start = 2.29 seconds; Finish = 2.36 seconds



11. If the club does not hit the ground, then at what time after 2.8 seconds would the club have the orientation shown at the right?
- At approximately 2.93 seconds
 - At approximately 3.07 seconds
 - At approximately 3.21 seconds
 - At approximately 3.36 seconds



12. If the club does not hit the ground, then at what time after 2.8 seconds would the club have the orientation shown at the right?
- At approximately 2.93 seconds
 - At approximately 3.07 seconds
 - At approximately 3.21 seconds
 - At approximately 3.36 seconds

