Linear Impulse and Momentum

Problems:
1. Derive the principal of impulse and momentum from an initial cause and effect relationship to show an object’s final momentum.

2. Imagine a 100 N person walking. He generates an average net vertical reaction force during right foot contact with the ground of 100 N. If the TBCM vertical velocity at right foot contact is -0.2 m/s and the contact duration is 0.25 s, what is the TBCM vertical velocity at right toe off?

3. What is the take-off velocity of a 68.0 kg long jumper if his initial velocity is 8.50 m/s and his take-off step produces a net force of 2700 N for 0.200 s? Use the equation from #1.

4. A USC runner with a body weight of 490.5 N runs across a force plate, making contact with the plate for 0.25 s. During contact, her velocity increases from 2.5 m/s to 4.0 m/s. What was the net horizontal force she exerted while in contact with the force plate?

5. If the net vertical impulse of a 580 N person is 1800 Ns over 0.500 s, what was the vertical force produced? If her initial vertical velocity was –0.200 m/s, what was her vertical take-off velocity?

6. The plot seen here is a plot of the horizontal force generated by a long-jumper at take-off. Given that the long-jumper has a mass of 68.0 kg, and his approach velocity was 8.30 m/s, calculate the following:

   a. Horizontal velocity at take-off
   b. Resultant take-off velocity given that the vertical velocity at take-off was 3.10 m/s
   c. Height of TBCM at the apex if the position at take-off was 1.20 m
   d. Total horizontal displacement

7. During the last step of a high jump, a 50.0 kg jumper contacts the ground with a net vertical force of 2500 N and a vertical velocity of –3.0 m/s over 0.17 s. What is his take-off velocity?

8. A 400 kg car is speeding down the street with the velocity of 70.0 km/h. Suddenly, it crashes into a brick wall and stops. What was the impulse generated by the car?

9. Identify the true statement below.
   a. If the net impulse is known, so is the velocity of the total body center of mass.
   b. Angular velocity is the slope of the angular position time graph.
   c. Net force is equal to the moment of inertia times alpha.
   d. When standing on a bathroom scale, you are measuring your body weight.
   e. Impulse is equal to the change in momentum.
10. Which of the following statements must be true to increase horizontal velocity during running?
   a. The net horizontal impulse is positive in the direction you are running.
   b. The net horizontal impulse is negative in the direction you are running.
   c. The horizontal velocity is positive and no net horizontal force is applied.
   d. a & c are true.
   e. none of the above

11. When a person with a body weight of 1000 N performed a standing long jump, the net horizontal impulse applied to the body from time 1 to time 2 was determined to be 50.0 Ns. If the horizontal velocity of the total body center of mass (TBCM) was 0.0 m/s at time 1, determine the horizontal velocity at take-off (time 2).

12. Determine the horizontal force applied to a 1.0 kg ball from time 1 to time 2, given that at time 1, the velocity is –10.0 m/s and 0.05 s later the horizontal velocity is 50.0 m/s. Ignore air resistance and assume the force is constant.

13. Given the following vertical ground reaction force curve that was collected during a jump performed by a 600 N person, determine the net vertical impulse during contact.

14. In terms of ground reaction force and acceleration, what does it mean when we say that a person experiences a period of unweighting?
   a. Ground reaction force is less than body weight and acceleration is positive
   b. Ground reaction force is greater than body weight and acceleration is positive
   c. Ground reaction force is less than body weight and acceleration is negative
   d. Ground reaction force is greater than body weight and acceleration is negative
   e. Unweighting has nothing to do with ground reaction force or acceleration

15. True or False. When you stand on a bathroom scale you are measuring your body weight.

16. An 800 N person performs a vertical jump. The net vertical and horizontal impulses applied to the body from time 1 to time 2 were determined to be 300 Ns and 50.0 Ns, respectively. If both the vertical and horizontal velocities of the TBCM were 0.0 m/s at time 1, determine the resultant velocity at take-off.

17. After warm-up jog, a 100 kg runner starts to speed up. His horizontal velocity at foot strike and toe off are 5.0 m/s and 7.0 m/s, respectively. What is his linear impulse?

18. From the principle of impulse and momentum, how can you alter the impulse?
19. During the stance phase of running, the sum of the forces in the horizontal direction is 8.0 N. Given that the
stance phase time is 0.50 s and the subject’s mass is 80 kg, what is the change in velocity generated during this
stance phase?

20. A 50 kg gymnast exerts horizontal and vertical forces of 700 N and 1200 N, respectively, on a vaulting horse.
Assuming the forces are constant over a 0.30 s contact period, calculate the following
   a. Net horizontal impulse she generates
   b. Net vertical impulses she generates
   c. Change in horizontal velocity
   d. Change in vertical velocity

21. A gymnast with body mass of 60 kg has a vertical velocity of 3.0 m/s at the time of contact with the vaulting
horse. What net vertical impulse would the gymnast need to generate in order to depart the horse with a vertical
velocity of 4.5 m/s? If the contact duration is 0.30 s, what is the magnitude of the net vertical force applied to
the gymnast?

22. A 1.0 kg volleyball was hit and given a velocity of 60.0 m/s. What is the impulse necessary to stop the ball?

Use the following scenario for problems 25-30: A soccer ball has a mass of 1.00 kg. At time 1, the horizontal
velocity is –10 m/s, the vertical velocity is –2.0 m/s, and the angular velocity about the ball’s center of mass is 15
rad/s. When the ball is kicked at time 2, the foot contacts the ball on the side. The center of mass horizontal velocity
becomes 50 m/s, the vertical velocity becomes 8.0 m/s, and its angular velocity about the center of mass becomes –
30 rad/s. From time 1 to time 2, the ball experiences an average vertical reaction force from the ground of 5.0
newtons, applied directly below its center of mass. Assume air resistance is negligible.

23. Which of the following free body diagrams is the complete FBD of the ball during contact with the foot?
   a.      b.         c.   d.          e.

   ![Free Body Diagrams]

24. What is the horizontal momentum of the ball at time 1?

25. What is the change in vertical momentum of the ball from time 1 to time 2?

26. Determine the average horizontal force applied to the ball from time 1 to time 2, given that time 1 is 0.10 s and
time 2 is 0.15 s.

27. Determine the average vertical reaction force applied to the ball by the foot from time 1 to time 2.
28. The following graph is the vertical reaction force curve applied to the feet during a vertical jump. From 1 to 3, the person is standing stationary, then he squats down and jumps up, travels in the air, and finally lands back on the force plate remaining in a squatting position.

![Force-Time Curve of a Vertical Jump](image)

a. What is the magnitude of the subject’s body weight?
b. Identify, by numbers on the graph, the interval(s) when the vertical acceleration of the TBCM is zero.
c. Which number on the graph represents a period of unweighting?
d. At which number on the force curve does the subject leave the ground?
e. What is the net vertical impulse applied (from 3 to 7)? It may be helpful to draw a FBD.
f. If the net horizontal impulse applied to the body during the interval 7 to 8 was 10.0 Ns, how did the horizontal velocity change over this time period?

29. If we could measure how high an athlete will jump by looking at his vertical ground reaction force curve, what is the best recommendation we could give to an athlete who wants to jump higher?
   a. Maximize negative vertical impulse by counter-moving very quick.
   b. Maximize positive vertical impulse by pushing harder on the ground.
   c. Keep net impulse close to zero.
   d. Maximize positive net horizontal impulse.
   e. All of the above are comparable recommendations.

30. A 1000 N person performs a vertical jump. The net vertical and net horizontal impulse applied to the body from time 1 to time 2 were 250 Ns and 50 Ns, respectively. If both the vertical and horizontal velocities of the total body center of mass were 0.0 m/s at time 1, determine the resultant velocity at take-off.
31. During the Olympic long jump trial, the vertical ground reaction force of an athlete’s take-off leg was measured as shown below. At foot strike, the horizontal velocity of the take-off leg was 8.00 m/s and the vertical velocity of the take-off leg was -2.30 m/s. Given that he weighed 850 N, how far and how high did he jump? How could he improve his horizontal distance? Discuss the kinetic factors that influence performance.

![Graph showing vertical force over time](image)

**Answers:**
2. 2.25 m/s  
3. 16.4 m/s  
4. 300 N  
5. 3600 N, 30.3 m/s  
6. Net Impulse=63.75 Ns  
   a. 9.24 m/s  
   b. 9.75 m/s  
   c. 1.69 m  
   d. 8.41 m  
7. 5.5 m/s  
8. 7760 Ns  
9. b  
10. a  
11. 0.49 m/s  
12. 1200 N  
13. 300 Ns  
14. c  
15. False  
16. 3.73 m/s  
17. 200 Ns  
18. 0.05 m/s  
20. a. 210 Ns  
21. a. 700N  
   b. 1,2,3  
   c. 4  
   d. 7  
   e. 0.4 Ns  
   f. Increased  
22. 60Ns  
23. d  
24. –10 kg*m/s  
25. 10 kg*m/s  
26. 1200 N  
27. 200 N  
28. a. 213 Ns  
   b. 213 Ns  
   c. 4.2 m/s  
   d. 4.3 m/s  
29. 2.5 m/s  
30. 210 Ns  
31. Approximate net vertical impulse = 350 Ns  
   (V_{x1}=V_{x2} = 8.00 m/s, V_{y1} = 1.74 m/s)  
   Max height = 0.15 m, Distance = 2.88 m
**Bonus Problems:**

1. Determine the net vertical impulse needed to produce a change in total body center of mass vertical velocity of 3.00 m/s. Assume the individual weighs 300 N.
   a. 30.6 Ns
   b. **91.7 Ns**
   c. 122 Ns
   d. 275 Ns
   e. 900 Ns

2. From the graph below, determine the net angular impulse applied about the total body center of mass from time 1 to time 2.

   a. **500 Nms**
   b. 1500 Nms
   c. 2000 Nms
   d. 2500 Nms
   e. 3000 Nms
3. A 500 N volleyball player is performing a jump to block a ball. During the jump, her feet are in contact with the ground for 0.75 s. If her average vertical reaction force during the jump is 1000 N and her TBCM vertical velocity at touchdown is -0.50 m/s, determine her TBCM vertical velocity at jump take-off.
   a. 7.4 m/s  
   b. 7.8 m/s  
   c. 6.9 m/s  
   d. 14.2 m/s

4. Given that the tennis player is moving from right to left, hypothesize the direction of the ground reaction forces acting on the foot of the support leg.
5. If a 70.0 kg tennis player was traveling with a horizontal velocity of \(-5.0 \text{ m/s}\) to the ball and \(0.0 \text{ m/s}\) when he hit the ball, what was the horizontal braking impulse necessary to stop him at ball contact?

- a. \(-350 \text{ Ns}\)
- b. \(350 \text{ Ns}\)
- c. \(3433.5 \text{ Ns}\)
- d. \(-3433.5 \text{ Ns}\)
- e. \(-70 \text{ Ns}\)

6. Choose the most correct vertical ground reaction force-time graph for the movement from A to B.

a. ![Diagram A]

b. ![Diagram B]

c. ![Diagram C]

d. ![Diagram D]

e. ![Diagram E]