Biomechanics Sample Problems

Forces

1) A 90-kg ice hockey player collides head-on with an 80-kg ice hockey player. If the first person exerts a force of 450 N on the second player, how much force does the second player exert on the first? *-450 N*

2) How much force must be applied by a kicker to give a stationary 2.5-kg ball an acceleration of 40m/s/s? *100 N*

3) A 65-kg runner had a maximal vertical ground reaction force of 1700 N while running at moderate pace. What was the runner's weight in Newtons? *637 N* What is the maximal vertical ground reaction force when expressed in multiples of body weight (1 body weight is the weight of the runner). *2.67 times greater than body weight*

4) A high jumper with a body weight of 712 N exerts a force of 3000 N against the ground during takeoff. How much force does the ground on the high jumper exert? *3000 N in the opposite direction*

5) A track athlete running at fast pace had an instantaneous resultant force of 2800 N acting through the heel during heel strike. If the angle of the resultant force was 120 degrees with respect to the horizontal, what were the horizontal and vertical forces acting on the heel? Estimate his body mass if you know that in general vertical ground reaction force found in running are about 4.3 times the value of body weight. *-1400 N horizontal; 2425 N vertical; 57.5 kg*

6) The coefficient of friction between a basketball shoe and a court is 0.56, and the normal reaction force acting on the shoe is 350 N. How much horizontal force is required to make the shoe slide? *>196 N*

7) A 70-kg skier is in a tuck position and moving down a 20-degree hill. Air resistance applies a resultant force of 15 N against the movement of the skier. The coefficient of friction between the skis and the snow is 0.09. What is the resultant downhill force acting on the skier? *161 N downhill*

8) (Use g=-10) If a 70 kg person was sitting on a swing (centered evenly in the middle between the two ropes), what was the force being supported by each vertical rope (in Newtons)? *350 N each* If the same person was sitting in the middle of a hammock, and each rope had an angle of 30 degrees with respect to the horizontal, how much force was each rope supporting? (Note: Force in the rope is not the same in the two situations.) *700 N each*

9) An 85 kg cyclist (person + bike) was traveling at a constant speed level road. Upon starting up a hill with a 15-degree inclination, the cyclist stopped pedaling and coasted. What was the total downhill force acting on the cyclist considering the coefficient of friction between the tires and the road is 0.1? *136 N downhill*

10) The coefficient of static friction between a sled and the snow is 0.19, with a coefficient of dynamic friction of 0.16. A 25-kg girl sits on her sled facing down a 10-degree hill. What is the minimum push her friend needs to exert to start moving down the hill? After getting a push, does she continue to slide down the hill? Explain. *>45 N push downhill to start moving; yes, she continues to slide after a push; $F_{downhill}$ = 43 N; F_{static} friction uphill = 47 N; $F_{dynamic}$ friction uphill = 39 N*

11) Two people are playing tug-of-war. Due to their choice of footwear, their coefficient of static friction is different. Participant 1 has a mass of 60 kg, a coefficient of static friction of 2.0, and can pull with a maximum force of 1000 N. Participant 2 has a mass of 80 kg and a coefficient of static friction of 1.2, and can pull with a maximum force of 1200 N. Who wins? *participant 1 wins*

12) A football player pushed a 60 kg blocking sled with a constant horizontal force of 400 N. The coefficient of kinetic friction between the sled and ground is 0.5. How much horizontal force opposes the forward motion of the sled? 294 N What is the sled's horizontal acceleration? (assume that the playing surface is level). 1.77 m/s^2

Linear Kinematics
1) A 75 kg jumper lands stiff-legged on the floor and changes his velocity from –4.5 m/s to zero in 0.15 seconds. Compute the average resultant force working on the jumper. 2250 N If he increased the impact time to 0.2 s, what happens to the resultant force working on the jumper? 1688 N

2) If an athlete jumped 2 feet high and left the ground at an angle of 20 degrees with respect to the horizontal, how fast was the athlete going in the forward (positive horizontal) and upward (positive vertical) directions immediately after takeoff? Vertical velocity = 3.46 m/s Horizontal velocity = 9.51 If the height of takeoff was the same as the height of landing, how fast was the athlete going in the horizontal and vertical directions right before landing? Vertical velocity = -3.46 m/s Horizontal velocity = 9.51

3) An Olympic diver drops from the 10 meter platform with an initial vertical velocity of 0.0 m/s. What was the vertical velocity of the diver immediately before he/she hits the water? 14 m/s How long did it take the diver to reach the water? 1.43 s

4) A long jumper leaves the ground at an angle of 25 degrees with respect to the horizontal with a resultant velocity of 30 ft/s. What was the horizontal velocity of the jumper at takeoff in m/s? Horizontal velocity = 8.29 What was the vertical velocity at takeoff in m/s? Vertical velocity = 3.86 m/s How high did the CM rise above the point of takeoff? 0.76 m

5) Two balls were thrown upward and were caught at the same height from which they were released. Ball A was thrown upward with a vertical velocity of 10 m/s. Ball B was thrown upward with a vertical velocity which was twice that of ball A. How far did each ball rise above the point of release? Ball A: 5.1 m Ball B: 20.4 m
How long did each ball stay in the air (total time)? Ball A: 2.0 s Ball B: 4.1 s

6) If a shot is put an angle of 41 degrees relative to the horizontal with a velocity of 36 ft/s in the direction of the put, what will be the upward (vertical) velocity at the instant of release? 7.2 m/s What will be the forward (horizontal) velocity? 8.3 m/s How high (above the point of release) will the shot go? 2.64 m What is the time it takes the shot to reach its maximum height? 0.73 s

7) If the shot in problem 6 is released from a height of 6 ft and later lands on the ground (height = 0.0 ft), what was the total time of flight? 1.69 s How far did the shot travel horizontally? 14.0 m

8) What is the average speed of a breaststroke swimmer who completes 100m in a time of 1:15? 1.3 m/s

9) What is the average velocity of a breaststroke swimmer who completes 100m in a time of 1:15? 0 m/s since they start and finish in the same location

10) A ball is thrown vertically upward with a velocity of 15 m s-1. If the acceleration due to gravity is 9.8 m/s^2, what is the velocity of the ball 2 seconds after being thrown? -4.6 m/s Is the ball still going up or is it coming down? Down

10) An orienteer runs north at 5 m/s for 120 seconds, and then west at 4 m/s for 180 seconds. What is the resultant displacement with respect to the starting position? Provide an angle with respect to the north direction. 937 m at 50 deg

11) A skier averaged 15 m/s during a constant downhill slope of 630m. How long did it take her to ski the 630 m to the base of the hill? 42 s

12) The world record for the 24-hour run is about 160 miles. What is this distance in meters? 257,488m What is 24 hours in seconds? 86,400s What would be a runner's average speed in going 160 miles in a day in m/s and min/mi? 2.98 m/s or 9:00/mi

13) Bobsleds accelerate from rest to high speeds in a few seconds. If one sled's speed increased from 0 to 32 m/s in 8 seconds, what was its average acceleration during that time period? 4 m/s^2 How far did the sled travel down the track in the 8 seconds? 128 m

Projectile Motion

1) A soccer ball is kicked with an initial horizontal speed of 5 m/s and an initial vertical speed of 3 m/s. Assuming projection and landing heights are the same, identify the following quantities (ignoring air resistance):
    a. The ball's horizontal speed 0.5 seconds into its flight: 5 m/s
    b. The balls horizontal speed midway through its flight: 5 m/s
    c. The balls horizontal speed immediately before contact with the ground: 5 m/s
    d. The ball's vertical speed at the apex of flight: 0 m/s
    e. The ball's vertical speed midway through its flight: 0 m/s
    f. The ball's vertical speed immediately before contact with the ground: -3 m/s

g. The ball's velocity throughout the filght: -9.8 m/s²

2) A rugby player attempts a kick after scoring a try. The ball was kicked at an angle of 60 degrees with an initial resultant velocity of 40 miles/hour (ignoring air resistance).
   a. What was the initial resultant velocity in meters/second? 17.9 m/s
   b. What was the initial horizontal velocity in m/s? 9.0 m/s
   c. What was the initial vertical velocity in m/s? 15.5 m/s
   d. If the player was 40 meters away from the goal, and the height of the horizontal bar was 3 meters, did the player score? Assume that the trajectory of the ball was on target! No

3) A soccer ball is kicked from the playing field at a 45° angle. If the ball is in the air for 3 seconds, what is the maximum height achieved (ignoring air resistance)? 11.0 m

4) A mountain biker encounters a deep gorge. He has "heard" that if he jumps off the log on the edge of his side of the gorge he can expect 50° for his trajectory. He has also "heard" that the other side of the gorge is 1 meters higher that the side he is on. He knows that he can ride to a maximum speed of 20 mi/hr on the trail approaching the gorge and off of log. Assuming what the rider "heard" is accurate, how wide can the gorge be for him to not drop down the gorge? 7.1 m

Momentum
1) Two ice skaters start out motionless in the center of the ice rink. They then push each other apart. The man (mass = 80 kg) moves to the right with a speed of 2.5 m/s. The woman moves to the left at some unknown speed.
   a) If her mass is 58 kg, calculate that speed. (assume frictionless ice) 3.45 m/s
   b) What has happened to the total momentum of the system (woman + man) during the push-off? It was maintained since the resultant external force was zero when considering both people.

2) Lineman A has a mass of 100 kg and is traveling with a velocity of 4 m/s when he collides head-on with Lineman B, who has a mass of 90 kg and is traveling at 4.5 m/s. If both players remain on their feet, what will happen? (Answer: B will push A backward with a velocity of 0.026 m/s) Hint: Use the total mass to complete the problem.

Angular Kinematics
1) A golfer accelerates the club from the top of the backswing until impact with the ball with an average angular acceleration of 30 rad/s² for a period of 0.5 s. The radius of rotation is 1.1 m. Compute the angular velocity of the club at impact, the linear velocity of the club head at impact, and the radial acceleration of the club head at impact. 16.5 m/s

2) A champion hammer thrower rotates at a rate of 3.2 rev/s just prior to releasing the hammer.
   a) If the hammer is located 1.6 m away from the axis of rotation, what is the centripetal acceleration experienced by the athlete? 646 m/s²

b) How much tension (i.e. force) is needed to produce this radial acceleration if the mass of the hammer is 7.26 kg? 4696 N

3) A speed skater increases his speed from 10 m/s to 12.5 m/s over a period of 3 seconds while coming out of a curve of 20 m radius. What are the magnitudes of his tangential, centripetal, and resultant accelerations as he leaves the curve? (Answer: at = 0.83 m/s^2; ac = 7.81 m/s^2; a = 7.85 m/s^2)

4) A kicker's extended leg is swung for 0.4 seconds in a counter-clockwise direction while accelerating at 200 deg/s^2. What is the angular velocity of the leg at the instant of contact with the ball? (Answer: 80 deg/s or 1.4 rad/s)

5) A 1.2 m golf club is swung in a planar motion by a right-handed golfer with an arm length of 0.76 m. If the initial velocity of the golf ball is 35 m/s, what was the angular velocity of the left shoulder at ball contact? Assume that the left arm and golf club form a straight line and that the initial ball velocity is the same as the linear velocity of the club head at impact. (Answer: 17.86 rad/s)

Angular Kinetics
1) A 65 kg gymnast begins to prepare for his dismount from the high bar by increasing his angular velocity by a factor of 3. By what factor does the centripetal force change? (you may assume that r does not change) It increases by a factor of 9

2) A pitched ball with a mass of 1 kg reaches a catcher's glove traveling at a velocity of 28 m/s.
      a. How much momentum does the ball have?
      b. How much impulse is required to stop the ball?
      c. If the ball is in contact with the catcher's glove for 0.5 seconds during the catch, how much average force is applied by the glove?
(Answer: a. 28 kg m/s; b. 28 Ns; c. 56 N)

3) A 108-cm, 0.73 kg golf club is swung for 0.5 seconds with a constant acceleration of 10 rad/s^2. What is the linear momentum of the club head when it impacts the ball? (Answer: 3.9 kg m/s)

4) A volleyball player's 3.7-kg arm moves at an average angular velocity of 15 rad/s during the execution of a spike. If the average moment of inertia of the extending arm is 0.45 kg m^2, what is the average radius of gyration for the arm during the spike? (Answer: 0.35 m)

5) The patellar tendon attaches to the tibia at a 20 deg angle, 3-cm from the axis of rotation at the knee. If the tension in the tendon is 400 N, what is the resulting angular acceleration of the 4.2 kg lower leg and foot given a radius of gyration of 30 cm for the lower leg/foot with respect to the axis of rotation at the knee? (Answer: 15.6 rad/s^2)

6) A 60 kg diver is positioned so that his radius of gyration is 0.5 m as he leaves the board in a layout position with an angular velocity of 4 rad/s. What is the diver's angular velocity when he assumes a tuck position, altering his radius of gyration to 0.25 m? (Answer: ω = 16 rad/s)

8. The knee extensors insert on the tibia at an angle of 30 degrees (from the longitudinal axis of the tibia), at a distance of 3 cm from the axis of rotation at the knee. How much force must the knee extensors exert to produce an angular acceleration at the knee of 1 rad/s^2, given a mass of the lower leg and foot of 4.5 kg, and a radius of gyration of 23 cm? (Answer: F = 10.8 N)

Torque Problems
1) What is the torque on a bolt if you are pulling with a force of 200 N directed perpendicular to a wrench of length 25 cm? How does the torque change for a wrench of twice the length? 50 Nm 100Nm

2) In cycling, the torque generated about the crank axis depends on the magnitude of the force applied to the pedal and also the angle between the crank arm and the force vector. In the diagram below, an 800 N vertical force applied to the pedal will create a counter-clockwise torque of 140 Nm when the crank is at 90 degrees (where greatest torque is generated). How much torque will the same force generate when the crank is at 75 degrees and at 105 degrees? What torque will that same vertical force generate when the crank is at 180 degrees? (Answers: at 75 and 105 degrees, torque = 135.2 Nm , at 180 degrees, torque = 0)

3) What is the torque about the shoulder if the arm is held in an abducted position at 60 degrees from the body in the frontal plane while holding a 10 kg dumbbell? Assume that the mass of the arm is 6 kg, its center of mass is located 38 cm from the shoulder joint center, and the arm's total length is 80 cm. (Answers: torque of dumbbell = -69.3 Nm; torque of arm weight = -19.7 Nm; Torque at the shoulder = 89 Nm)

4) A 35 N hand and forearm are held at a 45 ° angle to the vertically oriented humerus. The center of gravity of the forearm and hand is located at a distance of 15 cm from the joint center at the elbow, and the elbow flexor muscles attach at a distance of 3 cm from the joint center (assume that the muscles attach at an angle of 45 ° to the axis of the forearm).
a. How much force must be exerted by the forearm muscles to maintain this position? (Answer: 175 N)
b. How much force must the forearm flexors exert if a 50 N weight is held in the hand at a distance along the arm of 25 cm? (Answer: 591.7 N)

5) A hand exerts a force of 90 N on a scale at 32 cm from the joint center at the elbow. The triceps attach to the ulna at a 90° angle, and at a distance of 3 cm from the joint center. The weight of the forearm and the hand is 40 N with the forearm/hand center of gravity located 17 cm from the elbow joint center. Considering these conditions, how much force is being exerted by the triceps? Remember that you are interested in the forces acting on the forearm system. (Answer: 733.3 N)

6) A therapist applies a lateral force of 80 N to the forearm at a distance of 25 cm from the elbow joint center. The biceps attaches to the radius at a 90° angle and at a distance of 3 cm from the elbow. How much force is required of the biceps to stabilize the arm in position? <mark>(Answer: 666.7 N)</mark>