

# PHYS12 CH459:

## Test Prep

Mr. Gullo

November 2024

# Table of Contents

1 Circus Performer Problem

2 Aircraft Towing Problem

3 Car Acceleration Problem

# Problem 1: Circus Performance

## Problem Statement

During a circus act:

- One performer hangs upside down from trapeze
- Holds another performer by the legs
- Upward force is three times the lower performer's weight
- Calculate the stretch in the upper legs (femurs)

CH9.5 4,5,9 Review/Screenshot 2024-11-12 10022

# Problem 1: Given Information

- Mass of performer = 60.0 kg
- Each femur:
  - Length ( $L_0$ ) = 35.0 cm = 0.350 m
  - Radius = 1.80 cm = 0.0180 m
- Young's modulus ( $Y$ ) =  $1.6 \times 10^{10}$  N/m<sup>2</sup>
- Force = 3 times weight

# Problem 1: Solution Approach

Key equation for elastic deformation:

$$\Delta L = \frac{1}{Y} \frac{F}{A} L_0$$

where:

- $\Delta L$  = change in length
- $Y$  = Young's modulus
- $F$  = applied force
- $A$  = cross-sectional area
- $L_0$  = original length

# Problem 1: Calculations

- 1 Calculate total force:

$$F_{\text{tot}} = 3mg = 3(60.0 \text{ kg})(9.80 \text{ m/s}^2) = 1764 \text{ N}$$

- 2 Force per leg:

$$F_{\text{leg}} = F_{\text{tot}}/2 = 882 \text{ N}$$

- 3 Cross-sectional area:

$$A = \pi r^2 = \pi(0.0180 \text{ m})^2 = 1.018 \times 10^{-3} \text{ m}^2$$

# Problem 1: Final Result

Substituting into the equation:

$$\Delta L = \frac{1}{1.6 \times 10^{10} \text{ N/m}^2} \frac{882 \text{ N}}{1.018 \times 10^{-3} \text{ m}^2} (0.350 \text{ m})$$

$$\Delta L = 1.90 \times 10^{-5} \text{ m}$$

Or in centimeters:

$$\Delta L = 1.90 \times 10^{-3} \text{ cm}$$

# Table of Contents

1 Circus Performer Problem

2 Aircraft Towing Problem

3 Car Acceleration Problem



# Problem 2: Aircraft Towing

## Problem Statement

A tractor pushes an airplane:

- Tractor mass = 1800 kg
- Force on pavement =  $1.75 \times 10^4$  N backward
- Total resistance = 2400 N
- Acceleration =  $0.150 \text{ m/s}^2$

Find: (a) airplane mass, (b) force on airplane

CH9.5 4,5,9 Review/Screenshot



## Problem 2: Solution Part (a)

Using Newton's Second Law:

$$\text{net } F = Ma = (m_a + m_t)a = F - f$$

$$m_a = \frac{F - f}{a} - m_t$$

$$m_a = \frac{1.75 \times 10^4 \text{ N} - 2400 \text{ N}}{0.150 \text{ m/s}^2} - 1800 \text{ kg}$$

$$m_a = 9.89 \times 10^4 \text{ kg}$$

## Problem 2: Solution Part (b)

Force on airplane:

$$\text{net } F = F' - f' = m_a a$$

$$F' = m_a a + f'$$

$$F' = (9.89 \times 10^4 \text{ kg})(0.150 \text{ m/s}^2) + 2200 \text{ N}$$

$$F' = 1.70 \times 10^4 \text{ N}$$

# Table of Contents

1 Circus Performer Problem

2 Aircraft Towing Problem

3 Car Acceleration Problem

# Problem 3: Car Acceleration

## Problem Statement

A car accelerates forward:

- Wheels exert 2100 N backward on road
- Friction force = 250 N
- Acceleration =  $1.80 \text{ m/s}^2$

Find the mass of car plus occupants

## Problem 3: Solution

Using Newton's Second Law:

$$\text{net } F = F - f = ma$$

$$m = \frac{F - f}{a}$$

$$m = \frac{2100 \text{ N} - 250 \text{ N}}{1.80 \text{ m/s}^2}$$

$$m = 1.03 \times 10^3 \text{ kg}$$

CH9.5 4,5,9 Review/Screenshot 2024-11-12 09295

# Key Takeaways

- Elastic deformation depends on material properties and geometry
- Newton's laws apply to complex systems like aircraft-tractor combinations
- Free-body diagrams help organize force analysis
- Always check units and magnitudes for reasonable results



# Problem: Forces on Head at Drafting Board

## Problem Statement

A person working at a drafting board holds her head at an angle:

- Three major forces act on the head:
  - Weight ( $w$ ) = 50.0 N
  - Muscle force ( $F_M$ ) = 60.0 N at  $33^\circ$
  - Vertebrae force ( $F_V$ ) at unknown angle  $\theta$
- All forces act through center of mass
- Head is stationary (in equilibrium)

Find direction ( $\theta$ ) and magnitude of vertebrae force ( $F_V$ ).

CH9.5 4,5,9 Review/Screenshot 2024-11

# Solution Approach

- Since head is stationary, sum of forces = 0
- Break forces into x and y components:

$$\hat{x} : F_M \cos 33 = F_V \cos \theta$$

$$\hat{y} : w + F_M \sin 33 = F_V \sin \theta$$

- Use these equations to find  $\theta$  and  $F_V$

CH9.5 4,5,9 Review/Screenshot 2024-11-12 10343

# Solution: Finding the Angle

- Divide y-equation by x-equation to find  $\theta$ :

$$\tan \theta = \frac{w + F_M \sin 33}{F_M \cos 33}$$

- Substitute known values:

$$\tan \theta = \frac{50.0 \text{ N} + (60.0 \text{ N}) \sin 33}{(60.0 \text{ N}) \cos 33} = 1.643$$

- Solve for  $\theta$ :

$$\theta = \tan^{-1}(1.643) = 58.7 \approx 59$$

# Solution: Finding the Force Magnitude

- Use x-component equation:

$$F_V = \frac{F_M \cos 33}{\cos 58.7}$$

- Substitute values:

$$F_V = \frac{(60.0 \text{ N}) \cos 33}{\cos 58.7} = 97 \text{ N}$$

- Therefore:
  - Direction:  $\theta = 59$  from horizontal
  - Magnitude:  $F_V = 97 \text{ N}$

# Physical Interpretation

- The vertebrae must supply a significant force (97 N) to maintain head position
- Force is nearly 2 times the weight of the head
- Angle is determined by:
  - Head position ( $33^\circ$  muscle angle)
  - Need to balance both vertical and horizontal components
  - Requirement that force passes through center of mass
- Demonstrates why poor posture can lead to muscle strain

# Problem: Leg Exercise Device

## Problem Statement

An exercise device for the upper leg muscle:

- Mass of 10.0 kg attached via pulleys
- System maintained at constant speed
- Lever arm distances:
  - $r_{\perp} = 35.0$  cm (perpendicular distance to tension force)
  - $r'_{\perp} = 2.00$  cm (perpendicular distance to muscle force)

Calculate the force exerted by the upper leg muscle.

Key physics concepts:

- Constant speed implies:
  - Acceleration  $a = 0$
  - Net force  $= 0$
  - Net torque  $\tau = 0$
- Torque relationship:
  - $\tau = Fr_{\perp}$  (force  $\times$  perpendicular distance)
  - Sum of torques  $= 0$  for equilibrium

# Solution Steps

- 1 Calculate tension force from weight:

$$T = w = (10.0 \text{ kg})(9.80 \text{ m/s}^2) = 98.0 \text{ N}$$

- 2 Use torque equilibrium about pivot:

$$F_m r'_{\perp} - T r_{\perp} = 0$$

- 3 Solve for muscle force:

$$F_m = T \frac{r_{\perp}}{r'_{\perp}}$$



# Final Calculation

Substituting values:

$$\begin{aligned}F_m &= 98.0 \text{ N} \times \frac{35.0 \text{ cm}}{2.00 \text{ cm}} \\&= 98.0 \text{ N} \times 17.5 \\&= 1715 \text{ N} \\&= 1.72 \times 10^3 \text{ N}\end{aligned}$$

# Physical Interpretation

- The muscle must exert a force of 1715 N
- This large force results from mechanical disadvantage:
  - Muscle attachment point (2.00 cm) much closer to pivot
  - Than weight attachment point (35.0 cm)
  - Creates a force multiplier of 17.5
- Demonstrates why leg muscles need to be very strong
- Shows importance of lever arms in biomechanics