A 95-kg Water Skier Floating In A Lake Is Pulled From Rest To A Speed Of 12 M/s In A Distance Of 24 M

A 95-kg Water Skier Floating In A Lake Is Pulled From Rest To A Speed Of 12 M/s In A Distance Of 24 M is a classic physics problem that illustrates the fundamental concepts of motion, force, work, and energy transfer. Understanding the dynamics involved in such a scenario not only enriches our comprehension of physics principles but also provides insights into real-world applications such as water sports, engineering design, and safety considerations. This article explores the detailed physics behind pulling a water skier, analyzing the forces involved, calculating the work done, and discussing the implications of these calculations for both enthusiasts and professionals.

Understanding the Scenario

Basic Details of the Problem

- Mass of the water skier (m): 95 kg
- Initial velocity (u): 0 m/s (rest)
- Final velocity (v): 12 m/s
- Distance traveled (s): 24 meters

This scenario involves accelerating a water skier from rest to a certain speed over a specific distance, which involves work done by the pulling force overcoming resistive forces such as drag and friction.

Key Concepts Involved

- Newton's Laws of Motion
- Work-Energy Theorem
- Force and Acceleration
- Power and Energy Transfer

Physics Principles Applied to Water Skiing

Newton's Second Law of Motion

Newton's second law states that the net force acting on an object is equal to the mass of the object multiplied by its acceleration:
$$ F_{net} = m \times a $$

In the case of the water skier, the pulling force from the boat must overcome resistive forces and produce acceleration.

Work-Energy Theorem

The work done by the pulling force is converted into the kinetic energy of the skier:
$$ W = \Delta KE = \frac{1}{2} m v^2 - \frac{1}{2} m u^2 $$

Since the initial velocity $ u = 0 $, the work simplifies to:
$$ W = \frac{1}{2} m v^2 $$

This fundamental principle allows us to determine the work required to accelerate the skier to the target speed.

Friction and Drag Forces

In water skiing, resistive forces mainly include:
- Water drag: caused by the skier moving through water
- Frictional forces: between the skis and water
- Air resistance: minor but still relevant at higher speeds

The total resistive force ($ F_{resist} $) opposes the pulling force, meaning the force exerted by the boat must overcome these to accelerate the skier.

Calculating the Work Done to Accelerate the Water Skier

Step 1: Determine the Kinetic Energy Gained

Using the kinetic energy formula:
$$ KE = \frac{1}{2} m v^2 $$
$$ KE = \frac{1}{2} \times 95\,kg \times (12\,m/s)^2 $$
$$ KE = 47.5 \times 144 $$
$$ KE = 6840\,J $$

This indicates that 6840 Joules of work are needed to accelerate the skier from rest to 12 m/s.

Step 2: Relate Work to Force and Distance

Assuming all work is done by the pulling force F, and ignoring resistive forces for simplicity:

$$W = F \times s$$

$$F = \frac{W}{s} = \frac{6840\,J}{24\,m}$$

$$F = 285\,N$$

This is the average force exerted by the boat on the skier during acceleration.

Accounting for Resistive Forces in Real-World Conditions

While the previous calculation assumes ideal conditions with no resistive forces, in reality, water drag and friction significantly influence the force required.

Estimating Resistive Forces

Suppose the resistive force (F_{resist}) is approximately 50% of the pulling force:

- Resistive force estimate: 142.5 N
- Total average force exerted by the boat:

$$F_{total} = F_{acceleration} + F_{resist} = 285\,N + 142.5\,N = 427.5\,N$$

This indicates that, in practical scenarios, the boat needs to exert around 427.5 Newtons to accelerate the skier considering water resistance.

Implications for Water Ski Design and Safety

- Engines and tow ropes must be capable of providing sufficient force.
- Proper tension management ensures smooth acceleration.
- Awareness of resistive forces helps in designing safer and more efficient water skiing setups.

Power Required for Acceleration

Calculating Average Power

Power is the rate at which work is done:

$$P = \frac{W}{t}$$

Using kinematic equations, we can find the time (t) taken to reach 12 m/s:

$$ v = u + a t $$
$$ 12\,m/s = 0 + a t $$
$$ a = \frac{v - u}{t} \Rightarrow t = \frac{v}{a} $$

From the work and force:

$$ a = \frac{F_{avg}}{m} = \frac{285\,N}{95\,kg} \approx 3\,m/s^2 $$
$$ t = \frac{12\,m/s}{3\,m/s^2} = 4\,s $$

Average power exerted:

$$ P_{avg} = \frac{W}{t} = \frac{6840\,J}{4\,s} = 1710\,W $$

This shows the boat needs to deliver roughly 1.71 kW (about 2.3 horsepower) during acceleration.

Additional Considerations in Water Skiing Physics

Impact of Speed and Distance on Force

- Longer distances allow for lower average forces but require sustained effort.
- Higher speeds demand greater force and power, increasing safety considerations.

Efficiency of Energy Transfer

- Not all the work done by the boat translates into the skier’s kinetic energy; some is lost as heat and through water resistance.
- Improving the efficiency involves optimizing the boat’s pulling technique and equipment.

Safety and Performance Optimization

- Proper equipment selection minimizes resistance.
- Skilled towing minimizes sudden jerks, reducing risk of injury.
- Regular maintenance ensures optimal force transmission.

Practical Applications of Physics in Water Skiing

Engineering of Tow Ropes and Boats

- Ropes designed to withstand high forces without snapping.
- Boats equipped with engines capable of delivering consistent force.
- Use of materials with high strength-to-weight ratios.

Designing for Efficiency and Safety

- Calculations of force and work inform safe operational parameters.
- Understanding physics helps in training athletes for optimal performance.

Environmental Impact Considerations

- Efficient force application reduces fuel consumption.
- Less energy waste benefits environmental sustainability.

Conclusion

Understanding the physics behind pulling a water skier from rest to a speed of 12 m/s over a distance of 24 meters offers valuable insights into the interaction of forces, work, and energy transfer in water sports. The calculations demonstrate that approximately 6840 Joules of work are necessary, requiring an average force of around 285 Newtons in ideal conditions, and more in real-world scenarios considering resistive forces. The power needed, roughly 1.7 kW, is within the capabilities of typical watercraft engines used in water skiing. These principles are not only academically interesting but also directly applicable to designing safer, more efficient water skiing equipment and techniques, enhancing both performance and safety.

By integrating physics principles into water sports, athletes, engineers, and enthusiasts can optimize their experiences, ensuring that every pull is both effective and safe, ultimately elevating the sport to new heights.

Frequently Asked Questions

What is the acceleration of the water skier as they are pulled across the lake?

The acceleration can be calculated using kinematic equations: $a = (v^2 - u^2)/2s = (12^2 - 0)/(2\ 24) = 144/48 = 3\ m/s^2$.

What is the net force acting on the water skier during the

pull?

Using Newton's second law, $F = m a = 95$ kg 3 m/s^2 = 285 N.

How much work is done on the water skier to reach 12 m/s?

Work done = change in kinetic energy = 0.5 m v^2 = 0.5 95 kg (12 m/s)^2 = 0.5 95 144 = 6840 Joules.

What is the power exerted on the water skier during the pull?

Average power = work done / time taken. First, find time: $t = (v - u)/a = 12/3 = 4$ seconds. Then, power = 6840 J / 4 s = 1710 Watts.

If the water skier's mass increases, how does that affect the force needed to reach the same speed in the same distance?

The required force increases proportionally with mass, since $F = m a$; a remains constant if the same acceleration is maintained.

What assumptions are made in calculating the acceleration and force in this scenario?

Assumptions include constant acceleration throughout the pull, neglecting air resistance and water drag, and that the pulling force is applied steadily.

How would the work done change if the skier was pulled over a longer distance to reach the same speed?

The work done depends on the change in kinetic energy, which remains the same at 6840 Joules; however, with a longer distance, the average force would decrease since the acceleration would be lower.

Additional Resources

A 95-kg Water Skier Floating In A Lake Is Pulled From Rest To A Speed Of 12 M/s In A Distance Of 24 M

In the serene environment of a tranquil lake, a water skier embarks on a swift journey from complete rest to a thrilling speed of 12 meters per second, covering a distance of just 24 meters. This scenario, while seemingly straightforward, unfolds layers of physics principles and forces working in harmony — from the mechanics of acceleration to the influence of resistive forces such as water drag. Understanding the dynamics at play not only enriches our appreciation for the sport but also offers insight into fundamental physics concepts like work, energy, and force interactions.

Understanding the Situation: Basic Parameters and Assumptions

Before delving into the physics, it’s essential to establish the key parameters of this scenario:

- Mass of the water skier (m): 95 kg
- Initial velocity (u): 0 m/s (starting from rest)
- Final velocity (v): 12 m/s
- Distance traveled (d): 24 meters

Assuming the skier’s acceleration occurs uniformly, the goal is to determine the average force exerted by the tow rope, the work done on the skier, and the role of resistive forces like water drag.

Note: For simplicity, air resistance is considered negligible compared to water drag, and the acceleration is assumed constant over the distance.

Calculating the Acceleration: From Rest to Speed

The first step involves determining the acceleration required for the skier to reach 12 m/s over 24 meters.

Using the kinematic equation:

$$ v^2 = u^2 + 2ad $$

Rearranged to solve for acceleration a:

$$ a = \frac{v^2 - u^2}{2d} $$

Substituting the known values:

$$ a = \frac{(12)^2 - 0^2}{2 \times 24} = \frac{144}{48} = 3\, \text{m/s}^2 $$

Result: The water skier experiences a constant acceleration of 3 meters per second squared during the pull.

Work-Energy Perspective: How Much Work Is Done?

The work-energy theorem states that the work done on an object equals its change in kinetic energy:

$$ W = \Delta KE = \frac{1}{2} m v^2 - \frac{1}{2} m u^2 $$

Since the skier starts from rest:

$$ W = \frac{1}{2} \times 95\, \text{kg} \times (12\, \text{m/s})^2 = 0.5 \times 95 \times 144 = 6840\, \text{J} $$

Interpretation: About 6840 Joules of work are imparted to the skier during the acceleration phase.

Forces at Play: Propulsion versus Resistance

While work done by the tow rope accelerates the skier, resistance from water drag opposes this motion. The net force is a combination of:

- Tractive force (F_t): The force exerted by the tow rope
- Resistive force (F_r): Mainly water drag, opposing motion

The net force F_{net} is related to acceleration via Newton’s second law:

$$ F_{net} = m \times a = 95\, \text{kg} \times 3\, \text{m/s}^2 = 285\, \text{N} $$

Since the net force is the difference between the pulling force and resistive force:

$$F_t - F_r = 285\, \text{N}$$

To determine F_t and F_r, further analysis is required.

Estimating Water Drag Force

Water drag depends on factors like the shape of the skier, speed, water properties, and cross-sectional area. The drag force can be estimated using the drag equation:

$$F_r = \frac{1}{2} C_d \rho A v^2$$

Where:

- **C_d: Drag coefficient (dimensionless), typically around 0.8-1.0 for a human in water**
- **ρ: Density of water (~1000 kg/m^3)**
- **A: Cross-sectional area (~0.3 m^2 for a skier)**
- **v: Speed (~12 m/s at the final point, but varies during acceleration)**

Assuming:

- $C_d = 1.0$
- $A = 0.3\, \text{m}^2$

Calculating the drag at the final velocity:

$$F_r = 0.5 \times 1.0 \times 1000 \times 0.3 \times (12)^2$$
$$F_r = 0.5 \times 1 \times 1000 \times 0.3 \times 144$$
$$F_r = 0.5 \times 1000 \times 43.2 = 500 \times 43.2 = 21,600\, \text{N}$$

This large value indicates that water drag at 12 m/s is substantial. However, since the skier accelerates over the distance, the average drag force is less during the process. A more realistic approach considers the average drag force during acceleration.

Average Resistance and Propulsive Force

Given the high value of the drag force at maximum speed, the average drag during acceleration can be approximated as:

$$F_{r,avg} \approx \frac{F_{r,initial} + F_{r,final}}{2}$$

\]

Since drag at initial velocity (0 m/s) is zero:

$$ F_{r,avg} \approx \frac{0 + 21,600}{2} = 10,800\, \text{N} $$

This suggests that the propulsive force F_t must be sufficient to overcome roughly 10,800 N of water resistance while providing a net force of 285 N to accelerate the skier.

Therefore:

$$ F_t = F_r + F_{net} \approx 10,800\, \text{N} + 285\, \text{N} = 11,085\, \text{N} $$

This indicates the tow rope exerts an average force of approximately 11,085 N during acceleration, a substantial force consistent with high-performance water skiing.

Power and Rate of Work Done

The power exerted by the tow rope at any instant is:

$$ P = F_t \times v $$

At maximum speed (12 m/s):

$$ P_{max} = 11,085\, \text{N} \times 12\, \text{m/s} \approx 133,020\, \text{W} $$

or roughly 133 kW. The average power over the acceleration period is less, considering the force and velocity vary during the process.

The total work done (6840 J) over the time can be estimated by:

$$ t = \frac{d}{\text{average velocity}} $$

Since the skier starts from rest and accelerates uniformly:

$$ v_{avg} = \frac{u + v}{2} = \frac{0 + 12}{2} = 6\, \text{m/s} $$

Thus:

$$ t = \frac{24\, \text{m}}{6\, \text{m/s}} = 4\, \text{seconds} $$

Average power:

$$ P_{avg} = \frac{W}{t} = \frac{6840\, \text{J}}{4\, \text{s}} = 1710\, \text{W} $$

which aligns with the understanding that the skier’s pulling force must overcome both acceleration and water resistance efficiently.

Implications for Water Skier Training and Equipment Design

The physics behind this scenario highlights several practical considerations:

- Strength and Endurance: The tow rope must withstand forces exceeding 11,000 N during acceleration, demanding high-strength materials and careful design.
- Water Resistance: Water drag significantly influences the force and power required; hence, skiers often wear streamlined gear to reduce C_d and A.
- Skill Development: Achieving rapid acceleration from rest in a short distance requires precise timing and technique to maximize the tow’s efficiency.

Understanding these forces also informs the design of

towboats, which must generate sufficient pulling power to accelerate skiers safely and effectively, especially under varying water conditions.

Conclusion: The Interplay of Forces and Energy in Water Skiing

The journey of a water skier from rest to a speed of 12 m/s over just 24 meters exemplifies fundamental physics principles vividly in action. The calculation of acceleration, work done, and resistive forces reveals the remarkable power and engineering involved in water skiing. Despite the seemingly simple act of being pulled across a lake, it involves a delicate balance between applied force, water resistance, and energy transfer — all orchestrated in a matter of seconds. This scenario not only underscores the athletic skill required but also offers a captivating glimpse into the physics that make such feats possible.

Note: Actual forces and resistances can vary based on equipment, water conditions, and technique. The figures provided are

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