A 1.50 103-kg Car Starts From Rest And Accelerates Uniformly To 17.3 M/s In 11.9 S. Assume That Air Resistance

A 1.50 103-kg Car Starts From Rest And Accelerates Uniformly To 17.3 M/s In 11.9 S. Assume That Air Resistance plays a significant role in the vehicle's motion, influencing the net force acting upon it and subsequently its acceleration. Understanding the dynamics of such a scenario involves applying fundamental principles of physics, specifically Newton's laws of motion, to analyze the forces at play, calculate the acceleration, and estimate the power required for the car's acceleration. This comprehensive examination not only elucidates the mechanics behind the car's movement but also highlights the effects of air resistance and how it factors into real-world vehicular physics.

Understanding the Basic Parameters of the Car's Motion

Before diving into calculations, it's essential to recognize the key parameters given:

- Mass of the car, $m = 1.50 \times 10^3$ kg
- Initial velocity, $u = 0$ m/s (starts from rest)
- Final velocity, $v = 17.3$ m/s
- Time taken to reach final velocity, $t = 11.9$ s

These parameters serve as the foundation for calculating acceleration, forces, and power requirements.

Calculating the Car's Acceleration

Uniform Acceleration Concept

Since the car accelerates uniformly, its acceleration a can be determined using the basic kinematic equation:

$$
v = u + at
$$

Rearranging for a:

$$
a = \frac{v - u}{t}
$$

Substituting the known values:

$$
a = \frac{17.3\, \text{m/s} - 0}{11.9\, \text{s}} \approx 1.45\, \text{m/s}^2
$$

This acceleration indicates that the car's speed increases steadily at approximately 1.45 meters per second squared over the 11.9 seconds.

Analyzing Forces Acting on the Car

Newton’s Second Law and Net Force

According to Newton's Second Law, the net force F_{net} acting on the car is:

$$
F_{\text{net}} = m \times a
$$

Calculating:

$$
F_{\text{net}} = 1.50 \times 10^3\, \text{kg} \times 1.45\, \text{m/s}^2 \approx 2175\, \text{N}
$$

This net force is responsible for the car's acceleration.

Role of Air Resistance

In real-world scenarios, air resistance opposes the motion of the vehicle. If we assume air resistance force F_{air} acts in the opposite direction to the driving force, then the total driving force F_{drive} supplied by the engine must overcome both the inertia (mass and acceleration) and air resistance.

Expressed as:

$$
F_{\text{drive}} = F_{\text{net}} + F_{\text{air}}
$$

Without specific data on air resistance, we can explore how it affects the overall force and power needed for the acceleration.

Estimating the Effect of Air Resistance

Modeling Air Resistance

Air resistance (drag force) generally depends on the velocity of the vehicle and can be modeled as:

$$
F_{\text{air}} = \frac{1}{2} C_d \rho A v^2
$$

Where:
- C_d is the drag coefficient (depends on vehicle shape),
- ρ is the air density (~1.225 kg/m^3 at sea level),
- A is the frontal area of the vehicle,
- v is the velocity.

Suppose typical values for a car:
- $C_d \approx 0.30$,
- $A \approx 2.2\, \text{m}^2$.

Calculating:

$$
F_{\text{air}} = \frac{1}{2} \times 0.30 \times 1.225\, \text{kg/m}^3 \times 2.2\, \text{m}^2 \times (17.3)^2
$$

$$
F_{\text{air}} \approx 0.15 \times 1.225 \times 2.2 \times 299.29
$$

$$
F_{\text{air}} \approx 0.15 \times 1.225 \times 2.2 \times 299.29 \approx 152.2\, \text{N}
$$

Thus, at the final speed, air resistance opposes motion with approximately 152 N.

Average Air Resistance During Acceleration

Since speed increases from 0 to 17.3 m/s linearly over time, the average velocity during acceleration is:

$$
v_{\text{avg}} = \frac{u + v}{2} = \frac{0 + 17.3}{2} = 8.65\, \text{m/s}
$$

Correspondingly, the average air resistance:

$$
F_{\text{air, avg}} \approx \frac{1}{2} C_d \rho A v_{\text{avg}}^2
$$

$$
F_{\text{air, avg}} \approx 0.15 \times 1.225 \times 2.2 \times (8.65)^2
$$

$$
F_{\text{air, avg}} \approx 0.15 \times 1.225 \times 2.2 \times 74.83 \approx 36.8\, \text{N}
$$

This suggests that, on average, about 37 N of force opposes the car's motion due to air resistance during acceleration.

Calculating the Total Driving Force Needed

Given the net force required for acceleration (~2175 N) and the average opposing air resistance (~37 N), the total driving force from the engine must be:

$$
F_{\text{drive}} \approx F_{\text{net}} + F_{\text{air, avg}} \approx 2175\, \text{N} + 37\, \text{N} = 2212\, \text{N}
$$

This total force accounts for overcoming inertia and air resistance during the acceleration phase.

Power Required for the Acceleration

Instantaneous Power

Power at any moment is given by:

$$
P = F \times v
$$

At the final velocity:

$$
P_{\text{final}} = F_{\text{drive}} \times v = 2212\, \text{N} \times 17.3\, \text{m/s} \approx 38,312\, \text{W} \approx 38.3\, \text{kW}
$$

Similarly, the initial power is zero (since velocity is zero), and it increases linearly as speed increases.

Average Power During Acceleration

To estimate the average power, note that the force varies as the car accelerates. The average power:

$$
P_{\text{avg}} = \frac{1}{t} \int_0^t F(t) \times v(t) dt
$$

Since force and velocity are proportional during uniform acceleration:

$$
P_{\text{avg}} \approx \frac{1}{2} \times P_{\text{final}} \approx 19.15\, \text{kW}
$$

This indicates that, on average, the engine must produce roughly 19.15 kW of power during the acceleration period.

Summary of Key Calculations

- Acceleration: approximately 1.45 m/s^2
- Net force required for acceleration: about 2175 N
- Average air resistance during acceleration: roughly 37 N
- Total driving force: approximately 2212 N
- Power at final speed: around 38.3 kW
- Average power during acceleration: roughly 19.15 kW

Implications for Vehicle Design and Performance

Understanding these forces and power requirements is crucial for automotive engineers designing engines and drivetrains capable of delivering sufficient torque and power to meet acceleration targets. The influence of air resistance becomes increasingly significant at higher speeds, which is why aerodynamics are a critical component in modern vehicle design. Moreover, this analysis underscores the importance of optimizing factors like the drag coefficient and frontal area to reduce energy consumption and improve performance.

Conclusion

The motion of a car starting from rest and accelerating uniformly to 17.3 m/s over 11.9 seconds involves a complex interplay of forces. Calculating the acceleration using kinematic equations provides the foundation for understanding the required net force. Factoring in air resistance, modeled through drag equations, reveals that the engine must exert a force slightly above the force needed for acceleration alone to account for

Frequently Asked Questions

What is the acceleration of the car during its 11.9-second period?

The acceleration can be calculated using the formula $a = (v - u) / t$. Here, $u = 0$ m/s, $v = 17.3$ m/s, $t = 11.9$ s, so $a = (17.3 - 0) / 11.9 \approx 1.45$ m/s^2.

What is the initial and final kinetic energy of the car?

Initial kinetic energy is zero since the car starts from rest: $KE_{initial} = 0.5\ 1.50 \times 10^3$ kg $0^2 = 0$ J. Final kinetic energy is $KE_{final} = 0.5\ 1.50 \times 10^3$ kg $(17.3$ m/s$)^2 \approx 2.24 \times 10^5$ J.

How much work is done on the car during its acceleration?

Assuming negligible air resistance, the work done equals the change in kinetic energy: approximately 2.24×10^5 Joules.

What role does air resistance play in this scenario?

Air resistance opposes the motion of the car, reducing the net acceleration and the overall work done. If considered, it would mean the actual engine work exceeds the change in kinetic energy to account for drag.

What is the average power output of the car's engine during acceleration?

Average power is the work done divided by the time: $P = 2.24 \times 10^5$ J / 11.9 s $\approx 1.88 \times 10^4$ Watts or 18.8 kW.

If air resistance was neglected, how would that affect the calculation of work and power?

Neglecting air resistance simplifies calculations, assuming all work goes into increasing kinetic energy. Including air resistance would mean additional work is required to overcome drag, increasing total work and power estimates.

Additional Resources

Comprehensive Analysis of Uniform Acceleration in a Car Starting from Rest

Introduction

Understanding the motion of a vehicle undergoing uniform acceleration is fundamental in classical mechanics, offering insights into kinematic behavior, forces involved, and energy transformations. In this detailed review, we examine a specific scenario: a car with a mass of 1.50×10^3 kg starting from rest and reaching a speed of 17.3 m/s in 11.9 seconds. We will analyze the various aspects of this motion, including kinematic equations, forces involved, energy considerations, and the implications of air resistance.

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1. Fundamental Kinematic Parameters

1.1 Initial Conditions and Known Data

- Mass of the car (m): 1.50×10^3 kg
- Initial velocity (u): 0 m/s (starts from rest)
- Final velocity (v): 17.3 m/s
- Time taken (t): 11.9 seconds

1.2 Calculating Acceleration

Since the car accelerates uniformly, the acceleration a can be derived using the basic kinematic equation:

$$
v = u + at
$$

Rearranged to find a:

$$
a = \frac{v - u}{t}
$$

Substituting the known values:

$$
a = \frac{17.3\, \text{m/s} - 0\, \text{m/s}}{11.9\, \text{s}} \approx 1.45\, \text{m/s}^2
$$

This suggests the car experiences a steady acceleration of approximately 1.45 m/s^2.

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2. Kinematic Analysis

2.1 Displacement During Acceleration

Using the displacement formula for uniformly accelerated motion:

$$
s = ut + \frac{1}{2} a t^2
$$

Given that $u = 0$:

$$
s = \frac{1}{2} a t^2
$$

Substituting the known values:

$$
s = \frac{1}{2} \times 1.45\, \text{m/s}^2 \times (11.9\, \text{s})^2
$$
$$
s \approx 0.725 \times 141.61 \approx 102.8\, \text{m}
$$

The car travels approximately 102.8 meters during its acceleration phase.

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3. Forces Acting on the Car

Understanding the forces involved requires analyzing both driving forces and resistive forces such as air resistance and rolling resistance.

3.1 Driving Force

The primary force propelling the car forward must overcome resistive forces to sustain acceleration. The net force F_{net} is related to acceleration via Newton's second law:

$$
F_{net} = m a
$$

Calculating:

$$
F_{net} = 1.50 \times 10^3\, \text{kg} \times 1.45\, \text{m/s}^2 \approx 2175\, \text{N}
$$

This is the net force required to produce the observed acceleration, which must be supplied by the engine through the drive system.

3.2 Resistive Forces: Air Resistance and Rolling Resistance

- Air Resistance (Drag): Opposes the motion and increases with speed, often modeled as:

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

where:

- ρ: air density (~1.225 kg/m^3 at sea level)
- C_d: drag coefficient (depends on vehicle shape)
- A: frontal area
- v: velocity

- Rolling Resistance: Also opposes motion, proportional to normal force:

$$
F_{rolling} = C_{rr} \times N
$$

where:

- C_{rr}: coefficient of rolling resistance
- N: normal force (approximately mg on level ground)

Given the problem statement mentions "Assume that air resistance," but does not specify its magnitude, we consider its effect qualitatively and quantitatively as necessary.

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4. Power and Energy Considerations

4.1 Work Done by the Engine

The work done on the car is equal to the change in kinetic energy:

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

Calculating:

$$
W = \frac{1}{2} \times 1500\, \text{kg} \times (17.3\, \text{m/s})^2
$$
$$
W = 750 \times 299.29 \approx 224,467\, \text{J}
$$

The engine must supply approximately 224.5 kJ of work to reach the final speed, ignoring resistive forces.

4.2 Power Output

Average power P_avg over the acceleration:

$$
P_{avg} = \frac{W}{t} \approx \frac{224,467\, \text{J}}{11.9\, \text{s}} \approx 18,860\, \text{W} \approx 18.86\, \text{kW}
$$

This is the average power delivered to the car during acceleration. Real engines often operate at higher instantaneous power outputs, especially considering resistive losses.

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5. Effects of Air Resistance

Given the mention of air resistance, it is essential to analyze its impact on the car's acceleration and energy efficiency.

5.1 Estimating Air Resistance at Final Speed

Assuming typical values:

- $\rho = 1.225\, \text{kg/m}^3$
- Frontal area $A \approx 2.2\, \text{m}^2$ (average for a sedan)
- Drag coefficient $C_d \approx 0.30$

Calculating:

$$
F_{air} = \frac{1}{2} \times 1.225 \times 0.30 \times 2.2 \times (17.3)^2
$$
$$
F_{air} = 0.6125 \times 0.30 \times 2.2 \times 299.29
$$
$$
F_{air} \approx 0.6125 \times 0.66 \times 299.29 \approx 0.404 \times 299.29 \approx 121\, \text{N}
$$

At the final velocity, air resistance opposes motion with roughly 121 N.

5.2 Implications During Acceleration

- Since the net force required for acceleration is 2175 N, and air resistance is about 121 N at top speed, the resistive force at lower speeds will be less. But during acceleration, air resistance is less at lower velocities, increasing with v^2.

- To compute the total work against air resistance during acceleration, integrate the force over the displacement or consider average values.

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6. Role of Rolling Resistance

Rolling resistance generally contributes a smaller force compared to air resistance at higher speeds but is still significant:

$$
F_{rolling} = C_{rr} \times m g
$$

Assuming $C_{rr} \approx 0.015$:

$$
F_{rolling} = 0.015 \times 1500 \times 9.81 \approx 0.015 \times 14715 \approx 220.7\, \text{N}
$$

This force opposes motion constantly, adding to air resistance.

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7. Total Resistive Forces and Power Requirements

Summing resistive forces at high speed:

$$
F_{resistive} \approx F_{air} + F_{rolling} \approx 121\, \text{N} + 221\, \text{N} \approx 342\, \text{N}
$$

The engine's required force during acceleration must be:

$$
F_{engine} = F_{net} + F_{resistive}
$$
$$
F_{engine} \approx 2175\, \text{N} + 342\, \text{N} \approx 2517\, \text{N}
$$

Corresponding instantaneous power at the final velocity:

$$
P = F_{engine} \times v \approx 2517\, \text{N} \times 17.3\, \text{m/s} \approx 43,560\, \text{W} \approx 43.56\, \text{kW}
$$

This indicates that while average power over the entire acceleration is about 18.86 kW, the instantaneous power at top speed is significantly higher, which matches typical engine performance profiles.

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8. Real-World Implications and Additional Factors

8.1 Engine Efficiency

- Engines are not 100% efficient; typical efficiencies are around 25-30%.
- The actual energy input from fuel would be higher than the calculated work, considering losses.

8.2 Transmission and Mechanical Losses

- Additional energy losses occur in the drivetrain, transmission, and tires.
- These factors increase the total energy consumption and power demand.

8.3 Impact of Additional Resistances

- Tire

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