An 90.0 Kg Spacewalking Astronaut Pushes Off A 620 Kg Satellite, Exerting A 120 N Force For The 0.590

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Introduction

In the vast expanse of space, interactions between objects are governed by the fundamental principles of physics, particularly Newton's laws of motion. One intriguing scenario involves a spacewalking astronaut pushing off a satellite. This interaction not only demonstrates the conservation of momentum but also highlights how forces and masses influence motion in microgravity environments. In this article, we will analyze a specific case where a 90.0 kg astronaut applies a 120 N force over a duration of 0.590 seconds to push off a 620 kg satellite. Through detailed calculations and explanations, we aim to understand the resulting velocities, momenta, and the physical implications of such an action in space.

Understanding the Scenario

Key Details of the Situation

- Astronaut mass (m_1): 90.0 kg
- Satellite mass (m_2): 620 kg
- Force exerted (F): 120 N
- Duration of force application (Δt): 0.590 s

The astronaut applies this force in a specific direction to push against the satellite, causing both to move in opposite directions due to Newton's third law. The core principles involved include Newton's second law ($F = ma$), conservation of momentum, and the relationship between force, mass, and acceleration.

Calculating the Impulse and Resulting Velocities

Impulse Delivered to the Satellite

Impulse (J) is the product of force and the time over which it acts:

- $J = F \times \Delta t$

Substituting the values:

- $J = 120\ N \times 0.590\ s = 70.8\ N \cdot s$

This impulse imparts a change in momentum to the satellite, which is equal to the impulse itself:

- $\Delta p_2 = J = 70.8\ N \cdot s$

Calculating the Satellite's Velocity After Push-Off

The change in momentum for the satellite relates to its velocity change (Δv_2):

- $\Delta v_2 = \Delta p_2 / m_2 = 70.8\ kg \cdot m/s / 620\ kg \approx 0.1143\ m/s$

Since the force is applied over a finite time, the satellite gains a velocity of approximately 0.1143 m/s in the direction opposite to the astronaut's push.

Conservation of Momentum and Astronaut's Velocity

By Newton's third law, the astronaut experiences an equal and opposite change in momentum:

- $\Delta p_1 = -J = -70.8\ N \cdot s$

The astronaut's resulting velocity change (Δv_1) is:

- $\Delta v_1 = \Delta p_1 / m_1 = -70.8\ kg \cdot m/s / 90.0\ kg \approx -0.7867\ m/s$

The negative sign indicates the astronaut moves in the opposite direction to the satellite's push.

Final Velocities of the Astronaut and Satellite

Assumptions

We assume the initial velocities of both the astronaut and satellite are zero (they are initially at rest relative to each other). Under this assumption, their final velocities after the push are:

- v_1_final = $\Delta v_1 \approx -0.7867$ m/s
- v_2_final = $\Delta v_2 \approx 0.1143$ m/s

Implications of the Velocities

The astronaut moves backward at approximately 0.787 m/s, while the satellite gains a much smaller velocity of about 0.114 m/s in the opposite direction. These velocities are significant in the microgravity environment of space, where even small forces can lead to noticeable motion over time.

Energy Considerations

Work Done by the Force

The work done by the astronaut on the satellite is equal to the force times the displacement during the push. To estimate the work, we need to determine the displacements of both objects during the force application.

Estimating Displacements

Using the relation for constant acceleration ($a = F/m$), we find the accelerations:

- For the astronaut: $a_1 = F / m_1 = 120 \text{ N} / 90.0 \text{ kg} \approx 1.333 \text{ m/s}^2$
- For the satellite: $a_2 = -F / m_2 = -120 \text{ N} / 620 \text{ kg} \approx -0.1935 \text{ m/s}^2$

Displacement during the force application (assuming initial velocities are zero):

- $d = 0.5 \times a \times (\Delta t)^2$

Calculations:

- $d_1 = 0.5 \times 1.333 \text{ m/s}^2 \times (0.590 \text{ s})^2 \approx 0.5 \times 1.333 \times 0.3481 \approx 0.232 \text{ m}$
- $d_2 = 0.5 \times (-0.1935) \text{ m/s}^2 \times (0.590 \text{ s})^2 \approx -0.5 \times 0.1935 \times 0.3481 \approx -0.0337 \text{ m}$

Note: The negative displacement indicates movement in the opposite direction.

Calculating Work Done

The work done by the astronaut:

- $W_1 = F \times d_1 \approx 120$ N × 0.232 m ≈ 27.8 Joules

The work done on the satellite:

- $W_2 = F \times d_2 \approx 120$ N × (-0.0337 m) ≈ -4.04 Joules

The positive work done on the satellite reflects the energy transferred to its motion, consistent with the increase in kinetic energy.

Conservation of Momentum and Energy in Space

Principle of Conservation of Momentum

The total momentum of the system before and after the push remains constant:

- Initial total momentum: 0 (assuming both are initially at rest)
- Final total momentum: $m_1v_{1\_final} + m_2v_{2\_final} \approx$ 90.0 kg × (-0.7867 m/s) + 620 kg × 0.1143 m/s ≈ -70.8 + 70.8 = 0

This confirms the law of conservation of momentum applies perfectly in an isolated system like space, where external forces are negligible.

Energy Considerations

While kinetic energy increases for both objects, some energy is also dissipated or transformed during the process, especially considering factors like internal friction or other minor effects. Nonetheless, the total kinetic energy after the push is:

- $KE\_total = 0.5 \times m_1 \times v_{1\_final}^2 + 0.5 \times m_2 \times v_{2\_final}^2$

Calculations:

- $KE_1 = 0.5 \times 90.0$ kg × (0.7867 m/s)² ≈ 0.5 × 90.0 × 0.619 ≈ 27.86 Joules
- $KE_2 = 0.5 \times 620$ kg × (0.1143 m/s)² ≈ 0.5 × 620 × 0.01307 ≈ 4.04 Joules

Total kinetic energy gained: approximately 31.9 Joules, slightly more than the work done on the satellite, due to the energy imparted to the astronaut's motion.

Practical Implications and Applications

Spacewalk Dynamics and Safety

- Understanding these interactions helps in planning extravehicular activities (EVAs), ensuring astronauts can maneuver safely without unintended collisions or drift.
- Spacecraft and satellite servicing missions often involve similar pushing-off techniques, making these calculations essential for mission planning.

Designing Spacecraft and Satellites

- Designers must account for the reaction forces generated during maintenance or assembly

Frequently Asked Questions

What is the primary physics principle involved when the astronaut pushes off the satellite?

Newton's Third Law of Motion, which states that for every action, there is an equal and opposite reaction, is the primary principle involved.

How can we calculate the acceleration of the astronaut after pushing off the satellite?

Using Newton's Second Law, the astronaut's acceleration is $a = F / m = 120\ N / 90.0\ kg \approx 1.33\ m/s^2$.

What is the resulting velocity of the astronaut after exerting the force for 0.590 seconds?

The velocity can be calculated as $v = a t \approx 1.33 \text{ m/s}^2 \ 0.590 \text{ s} \approx 0.785 \text{ m/s}$.

How does the satellite's recoil velocity compare to the astronaut's velocity?

Using conservation of momentum, the satellite's recoil velocity is $v_{satellite} = (m_{astronaut} \ v_{astronaut}) / m_{satellite} \approx (90 \text{ kg} \ 0.785 \text{ m/s}) / 620 \text{ kg} \approx 0.114 \text{ m/s}$ in the opposite direction.

How much momentum does the astronaut gain from pushing off?

The momentum gained by the astronaut is $p = m v \approx 90.0 \text{ kg} \ 0.785 \text{ m/s} \approx 70.7 \text{ kg·m/s}$.

What is the significance of the force exerted over 0.590 seconds in this scenario?

The duration of force application determines the impulse imparted, which changes the astronaut’s momentum and velocity.

Could the astronaut's push cause any noticeable movement of the satellite?

Yes, the satellite would recoil in the opposite direction with a velocity of approximately 0.114 m/s due to conservation of momentum.

What assumptions are made in calculating the velocities and momenta in this scenario?

Assumptions include a perfectly inelastic and isolated system with no external forces like gravity or drag, and that the force is constant during the push.

How might this physics scenario be relevant to real

spacewalk operations?

Understanding recoil and momentum transfer is crucial for astronauts to maneuver safely and accurately while performing extravehicular activities in space.

Additional Resources

An 90.0 kg Spacewalking Astronaut Pushes Off A 620 kg Satellite, Exerting A 120 N Force For The 0.590 Seconds — this intriguing scenario offers a fascinating glimpse into the principles of physics that govern motion in space. When an astronaut pushes off a satellite in the vacuum of space, the interaction follows the fundamental laws of Newtonian mechanics. Analyzing this situation allows us to explore concepts like conservation of momentum, impulse, and the resulting velocities of both the astronaut and the satellite. In this guide, we'll break down the problem step-by-step, providing a comprehensive understanding of the physics involved, and illustrating how such interactions occur in real-world space missions.

Introduction: The Physics of Space Push-Offs

In the weightless environment of space, pushing off objects becomes a dance governed by Newton's third law: for every action, there is an equal and opposite reaction. When an astronaut exerts a force on a satellite, both the astronaut and satellite experience accelerations in opposite directions. Unlike on Earth, gravity doesn't significantly influence the immediate aftermath of the push; instead, the interaction is governed purely by the conservation of momentum and impulse.

This particular scenario involves an astronaut with a mass of 90.0 kg pushing against a satellite with a mass of 620 kg. The astronaut applies a force of 120 N for a duration of 0.590 seconds. Our goal is to understand the resulting velocities of both objects after the push, and to interpret what this means physically.

Fundamental Concepts and Principles

Newton's Laws in Space

- First Law (Inertia): An object at rest stays at rest unless acted upon by an external force. In space, external forces are minimal, so objects tend to maintain their velocity.

- Second Law (F = ma): The acceleration of an object depends on the force applied and its mass.

- Third Law (Action-Reaction): When one object exerts a force on another, the second exerts an equal and opposite force.

Conservation of Momentum

In the absence of external forces, the total momentum of a system remains constant. For the astronaut and satellite, initial momenta are zero (assuming both are initially stationary). After the push:

$$ p_{\text{initial}} = p_{\text{final}} $$

which simplifies to:

$$ 0 = m_{a} v_{a} + m_{s} v_{s} $$

where:

- m_{a} = astronaut mass = 90.0 kg
- m_{s} = satellite mass = 620 kg
- v_{a} = astronaut's velocity after push
- v_{s} = satellite's velocity after push

Impulse

Impulse is the product of force and the duration over which it is applied:

$$ J = F \times \Delta t $$

It relates directly to the change in momentum:

$$ J = \Delta p = m \Delta v $$

Step-by-Step Analysis

Step 1: Calculating the Impulse

Given:

- Force $F = 120\, \text{N}$
- Time duration $\Delta t = 0.590\, \text{s}$

The impulse exerted on the astronaut (and equally on the satellite, but in opposite direction) is:

$$ J = F \times \Delta t = 120\, \text{N} \times 0.590\, \text{s} = 70.8\, \text{Ns} $$

This impulse imparts a change in momentum to both the astronaut and the satellite.

Step 2: Determining the Velocities

Since the initial momenta are zero, the final momenta are:

$$ p_{a} = m_{a} v_{a} $$
$$ p_{s} = m_{s} v_{s} $$

And from Newton's third law:

$$ m_{a} v_{a} = - m_{s} v_{s} $$

The impulse relates to the change in momentum:

$$ J = m_{a} v_{a} = - m_{s} v_{s} $$

So:

$$ v_{a} = \frac{J}{m_{a}} = \frac{70.8\, \text{Ns}}{90.0\, \text{kg}} \approx 0.787\, \text{m/s} $$

$$ v_{s} = -\frac{J}{m_{s}} = -\frac{70.8\, \text{Ns}}{620\, \text{kg}} \approx -0.114\, \text{m/s} $$

The negative sign indicates the satellite's velocity is in the opposite direction to the astronaut's push.

Step 3: Interpreting the Results

- Astronaut’s velocity: approximately 0.787 m/s in the direction of the push.
- Satellite’s velocity: approximately 0.114 m/s in the opposite direction.

Despite the force applied, the astronaut gains a significantly higher velocity than the satellite due to the mass difference. The lighter astronaut accelerates more, but both bodies move in opposite directions, adhering to conservation of momentum.

Real-World Implications in Space Missions

Spacewalk Maneuvers and Safety

Understanding these physics principles is critical for astronauts performing extravehicular activities (EVAs). When pushing off objects or stations, they must be aware of how their mass and the force applied influence their motion, especially since they cannot rely on friction or gravity to stop themselves.

Use of Tethers and Reaction Control

To prevent unintended drifting, astronauts often use tethers or thrusters to control their movement after pushing off. Proper planning ensures they don't drift away from the spacecraft or station, which could be dangerous or mission-critical.

Satellite Servicing and Docking

In satellite repair or servicing missions, astronauts might push or pull components.

Calculating the resulting velocities ensures precise control, preventing damage or unintended movement.

Additional Factors to Consider

While the calculations above assume ideal conditions, real-world scenarios include:

- Microgravity environment: No significant external gravitational influence during the push.
- Reaction forces: The force exerted by the astronaut must be balanced; their suit and tether distribute forces.
- Rotational effects: Pushing off might induce torque, causing rotation, which requires further analysis.
- Equipment constraints: The astronaut's suit and tools can influence force application and movement.

Advanced Topics and Related Calculations

Kinetic Energy After Push

The kinetic energy imparted to each object can be computed as:

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

- Astronaut:

$$ KE_{a} = \frac{1}{2} \times 90.0\, \text{kg} \times (0.787\, \text{m/s})^2 \approx 27.9\, \text{J} $$

- Satellite:

$$ KE_{s} = \frac{1}{2} \times 620\, \text{kg} \times (0.114\, \text{m/s})^2 \approx 4.0\, \text{J} $$

This indicates most of the energy from the impulse goes into moving the astronaut, due to their lower mass.

Effect of Varying Force and Duration

Changing the force magnitude or the duration affects the velocities proportionally. For example, increasing force or duration results in higher velocities.

Concluding Remarks

The scenario of an astronaut pushing off a satellite encapsulates fundamental physics principles that are pivotal in space exploration. It highlights how conservation of momentum governs all interactions in space, where external forces are minimal. Understanding impulse and the resulting velocities not only ensures safe and effective maneuvering but also deepens our appreciation for the elegant laws of physics that operate beyond Earth's atmosphere.

By mastering these concepts, engineers and astronauts can design better tools, plan safer EVAs, and execute complex satellite servicing missions with precision and confidence. The simplicity of the equations belies the profound importance they hold in making human spaceflight possible.

Key Takeaways:

- The impulse delivered during a push determines the velocities of both objects.
- The astronaut's velocity is significantly higher due to their much lower mass.
- Conservation of momentum is fundamental in analyzing space interactions.
- Real-world applications require considering additional factors like rotational motion and equipment constraints.

Understanding these principles ensures that spacewalks and satellite operations are conducted safely, efficiently, and with scientific precision.

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