A 968-kg Satellite Orbits The Earth At A Constant Altitude Of 108-km.How Much Energy Must Be Added To

A 968-kg Satellite Orbits The Earth At A Constant Altitude Of 108-km. How Much Energy Must Be Added To maintain its orbit, overcome gravitational forces, and ensure operational stability involves understanding complex physics principles. This comprehensive article explores the various aspects of satellite energy requirements, including the fundamental physics of orbital mechanics, the calculation of energy needed for orbital insertion, and the continuous energy considerations for maintaining a stable orbit at an altitude of 108 km. Whether you're an aerospace engineer, student, or space enthusiast, understanding these concepts is crucial for grasping how satellites operate and how energy plays a pivotal role in space missions.

Understanding Satellite Orbits: Basic Concepts

What Is Orbital Altitude?

Orbital altitude refers to the height of a satellite above the Earth's surface. In this case, the satellite orbits at a constant altitude of 108 km, which is considered very low Earth orbit (LEO). For comparison, the International Space Station orbits at approximately 420 km, making 108 km notably lower, within the atmosphere's upper layers.

Why Is Orbital Altitude Important?

- Determines the gravitational forces acting on the satellite.
- Affects atmospheric drag and orbit decay.
- Influences the energy needed for orbit insertion and maintenance.

Orbital Mechanics Fundamentals

- Satellites are kept in orbit primarily due to the balance between gravitational pull and their tangential velocity.
- To stay at a fixed altitude, the satellite must maintain a specific velocity, known as orbital velocity.

Physics of Satellite Orbits

Gravitational Potential Energy

The gravitational potential energy (U) of a satellite in orbit depends on its mass and its distance from the Earth's center:

$$
U = - \frac{G \cdot M_{Earth} \cdot m}{r}
$$

where:
- G is the gravitational constant ($6.674 \times 10^{-11} \, \mathrm{Nm^2/kg^2}$)
- M_{Earth} is Earth's mass ($5.972 \times 10^{24} \, \mathrm{kg}$)
- m is the satellite's mass (968 kg)
- r is the distance from Earth's center to the satellite

Kinetic Energy in Orbit

The kinetic energy (K) for a satellite moving at orbital velocity v:

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

Orbital Velocity at 108 km Altitude

To achieve a stable orbit at 108 km altitude, the satellite must reach a specific velocity:

$$
v = \sqrt{\frac{G M_{Earth}}{r}}
$$

where $r = R_{Earth} + h$, with:
- $R_{Earth} \approx 6371 \, \mathrm{km}$
- $h = 108 \, \mathrm{km}$

Calculating this velocity provides insight into the energy required to reach and maintain this orbit.

Calculating the Energy Required for Orbital Insertion

Step 1: Determine the Distance from Earth's Center

$$
r = 6371 \, \mathrm{km} + 108 \, \mathrm{km} = 6479 \, \mathrm{km} = 6.479 \times 10^6 \, \mathrm{m}
$$

\]

Step 2: Calculate Orbital Velocity

\[
v = \sqrt{\frac{6.674 \times 10^{-11} \times 5.972 \times 10^{24}}{6.479 \times 10^6}} \approx 7.36 \, \mathrm{km/s}
\]

Step 3: Find the Kinetic Energy

\[
K = \frac{1}{2} \times 968 \, \mathrm{kg} \times (7360 \, \mathrm{m/s})^2 \approx 2.63 \times 10^{10} \, \mathrm{J}
\]

Step 4: Calculate Change in Gravitational Potential Energy

Initial energy at Earth's surface:

\[
U_{initial} = - \frac{6.674 \times 10^{-11} \times 5.972 \times 10^{24} \times 968}{6.371 \times 10^6} \approx -6.07 \times 10^{9} \, \mathrm{J}
\]

Energy at orbital altitude:

\[
U_{final} = - \frac{6.674 \times 10^{-11} \times 5.972 \times 10^{24} \times 968}{6.479 \times 10^{6}} \approx -5.98 \times 10^{9} \, \mathrm{J}
\]

Change in potential energy:

\[
\Delta U = U_{final} - U_{initial} \approx 9.0 \times 10^{7} \, \mathrm{J}
\]

Step 5: Total Energy Needed for Orbital Insertion

Adding kinetic energy and the increase in potential energy:

\[
E_{total} \approx 2.63 \times 10^{10} \, \mathrm{J} + 9.0 \times 10^{7} \, \mathrm{J} \approx 2.63 \times 10^{10} \, \mathrm{J}
\]

Since gravitational potential energy becomes less negative (energy increases), the primary energy input is for reaching the orbital velocity.

Continuous Energy Considerations for Low Earth Orbit at 108 km

Atmospheric Drag and Orbit Decay

- At 108 km, the satellite experiences significant atmospheric drag.
- This drag causes gradual orbital decay, requiring periodic energy boosts to maintain altitude.
- Propulsion systems or onboard thrusters are used to compensate for this energy loss.

Energy for Orbit Maintenance

- To counteract atmospheric drag, the satellite needs to perform periodic maneuvers.
- The energy required depends on the extent of drag, satellite cross-sectional area, and propulsion efficiency.

Impact of Altitude on Energy Requirements

- Lower altitudes mean higher atmospheric density, thus more drag and higher energy expenditure.
- Maintaining an orbit at 108 km demands continuous energy input, unlike higher orbits where atmospheric influence is negligible.

Practical Aspects of Supplying Energy to Satellites

Methods of Energy Supply

- Onboard Propellant: Provides the necessary energy for orbital adjustments.
- Solar Panels: Convert sunlight into electrical energy to power thrusters and onboard systems.
- Battery Storage: Stores energy for use during orbital maneuvers or periods of low sunlight.

Energy Efficiency in Satellite Operations

- Efficient propulsion systems reduce fuel consumption.
- Optimizing orbital maneuvers minimizes energy expenditure.
- Using solar power extends operational lifespan and reduces mission costs.

Conclusion: How Much Energy Must Be Added?

Calculations reveal that to insert a 968-kg satellite into a stable orbit at 108 km altitude, approximately 26.3 gigajoules (GJ) of energy are required primarily to reach the necessary orbital velocity. This energy accounts for overcoming Earth's gravitational pull and achieving the tangential speed needed to stay in orbit. Additionally, due to atmospheric drag at this low altitude, continuous energy input is necessary to maintain the orbit over time.

While the initial energy input is substantial, ongoing energy management plays a vital role in satellite operations, especially at such low altitudes where atmospheric effects are pronounced. Modern satellite systems leverage solar energy, efficient thrusters, and precise orbital control to sustain their missions effectively.

SEO Keywords and Phrases

- Satellite orbital energy calculation
- Energy required for satellite orbit insertion
- Low Earth orbit at 108 km altitude
- Gravitational potential energy of satellites
- Atmospheric drag in satellite operations
- Maintaining satellite orbit energy needs
- Spacecraft propulsion and energy management
- How much energy to launch a satellite
- Satellite orbit maintenance energy
- Space mission energy requirements

This detailed analysis provides a comprehensive understanding of the energy dynamics involved in satellite orbits at low altitudes, emphasizing the importance of physics, engineering, and continuous energy management in space missions.

Frequently Asked Questions

How do you calculate the total energy required to raise a satellite to a 108 km orbit at 968 kg?

You need to compute the change in the satellite's gravitational potential energy and its kinetic energy at the orbit compared to the Earth's surface, then sum these values to find the total energy required.

What is the approximate energy needed to place a 968-kg satellite into a 108 km orbit around Earth?

Approximately 5.2×10^9 joules of energy must be added, considering both overcoming gravity and providing orbital velocity.

Why is it necessary to add energy to a satellite to reach orbit at 108 km altitude?

Because the satellite must overcome Earth's gravitational pull (potential energy) and gain sufficient velocity (kinetic energy) to stay in a stable orbit, requiring energy input.

How does the altitude of 108 km affect the energy needed to orbit the Earth compared to lower altitudes?

Higher altitudes like 108 km require more energy since the satellite must climb higher against gravity and reach a higher orbital velocity, increasing both potential and kinetic energy requirements.

What assumptions are typically made when calculating the energy needed to orbit a satellite like the 968-kg one at 108 km altitude?

Assumptions often include treating Earth as a perfect sphere, neglecting atmospheric drag at high altitude, and assuming the satellite is initially at rest on Earth's surface, with a simplified model of Earth's gravity.

Additional Resources

A 968-kg Satellite Orbits The Earth At A Constant Altitude Of 108 km. How Much Energy Must Be Added To It?

In the realm of space physics and satellite engineering, understanding the energy dynamics involved in maintaining or altering a satellite's orbit is fundamental. When a satellite orbits close to Earth's surface, at an altitude of just 108 km, several intriguing questions arise regarding the energy required to sustain or change its orbital parameters. This article delves into the detailed physics underpinning such a scenario, analyzing how much energy must be added to a 968-kg satellite to keep it in a stable orbit at this low altitude, and exploring the broader implications of that energy input.

Understanding the Basics of Satellite Orbits

The Nature of Orbital Motion

A satellite in orbit around Earth is essentially in continuous free fall, moving forward fast enough that the curvature of the Earth "falls away" beneath it, resulting in a stable orbit. The balance between gravitational pull and the satellite's tangential velocity ensures that it neither crashes into Earth nor escapes into space.

Orbital Altitude and Its Significance

The altitude of 108 km places the satellite within the exosphere, which is generally considered the outermost layer of Earth's atmosphere. This is an extremely low orbit, often called a suborbital trajectory because the atmosphere's density at this altitude is significant enough to cause rapid atmospheric drag, making sustained orbital motion challenging without continuous energy input.

Why Is Orbit at 108 km Unusual?
Most satellite orbits are at much higher altitudes—LEO (low Earth orbit) satellites typically operate between 160 km and 2,000 km. At 108 km, atmospheric drag becomes a dominant factor, requiring significant energy to maintain the orbit. This altitude is closer to the Kármán line (100 km), which is often used to define the boundary between Earth's atmosphere and space.

The Physics of Orbital Energy

Gravitational Potential Energy (GPE)

The gravitational potential energy of a satellite in orbit is given by:

$$
U = - \frac{G M_e m}{r}
$$

\]

where:
- G is the gravitational constant ($6.674 \times 10^{-11} \, \text{Nm}^2/\text{kg}^2$),
- M_e is Earth's mass ($5.972 \times 10^{24} \, \text{kg}$),
- m is the satellite's mass (968 kg),
- r is the distance from Earth's center to the satellite.

Since Earth's radius R_e is approximately 6371 km, the orbital radius r at 108 km altitude is:

$$
r = R_e + h = 6371\, \text{km} + 108\, \text{km} = 6479\, \text{km} = 6.479 \times 10^{6} \, \text{m}
$$

Kinetic Energy (KE)

The kinetic energy of the satellite is:

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

where v is the orbital velocity.

Orbital Velocity at a Given Altitude

The orbital velocity necessary for a circular orbit at radius r is derived from the balance of gravitational and centripetal forces:

$$
v = \sqrt{\frac{G M_e}{r}}
$$

Calculating this velocity provides insight into how fast the satellite must travel to stay in orbit at 108 km.

Calculating the Orbital Velocity at 108 km Altitude

Using the known values:

$$
v = \sqrt{\frac{6.674 \times 10^{-11} \times 5.972 \times 10^{24}}{6.479 \times 10^{6}}}
$$

Calculating step-by-step:

1. Numerator:

$$
6.674 \times 10^{-11} \times 5.972 \times 10^{24} \approx 3.986 \times 10^{14}
$$

2. Divide by r:

$$
\frac{3.986 \times 10^{14}}{6.479 \times 10^{6}} \approx 6.15 \times 10^{7}
$$

3. Take the square root:

$$
v \approx \sqrt{6.15 \times 10^{7}} \approx 7,845\, \text{m/s}
$$

Result: The satellite needs approximately 7.85 km/s of tangential velocity to maintain a circular orbit at 108 km altitude.

Energy Analysis: How Much Energy Must Be Added?

Initial Energy State of the Satellite

The total mechanical energy E of a satellite in orbit is:

$$
E = K + U
$$

which simplifies for a circular orbit to:

$$
E = - \frac{G M_e m}{2 r}
$$

This relation stems from the virial theorem, indicating that the total energy is half the gravitational potential energy but opposite in sign.

Calculating the initial total energy:

$$
E_{initial} = - \frac{6.674 \times 10^{-11} \times 5.972 \times 10^{24} \times 968}{2 \times 6.479 \times 10^{6}}
$$

Numerator:

$$
6.674 \times 10^{-11} \times 5.972 \times 10^{24} \times 968 \approx 3.86 \times 10^{17}
$$

Denominator:

$$
2 \times 6.479 \times 10^{6} = 1.2958 \times 10^{7}
$$

Therefore:

$$
E_{initial} \approx - \frac{3.86 \times 10^{17}}{1.2958 \times 10^{7}} \approx -2.98 \times 10^{10} \, \text{J}
$$

This negative value indicates a bound orbit, with the magnitude representing the energy required to escape Earth's gravity from that orbit.

Energy Required to Increase Orbital Altitude or Maintain Orbit

To raise the satellite's orbit or counteract atmospheric drag, additional energy must be supplied. The key question is: How much energy must be added to increase or sustain the orbit at 108 km?

- For maintaining orbit: Because atmospheric drag causes orbital decay at this low altitude, continuous energy input (via thrusters or other propulsion methods) is necessary to compensate for energy lost due to drag.

- For changing orbit: To increase altitude from 108 km to a higher orbit, the satellite must gain kinetic energy (speed) and potential energy. The amount of energy needed depends on the change in orbital parameters.

Calculating the Energy to Achieve the Orbital Velocity

The kinetic energy at the orbital velocity:

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

Using $v = 7,845\, \text{m/s}$:

$$

$$K = 0.5 \times 968 \times (7,845)^2 \approx 0.5 \times 968 \times 61.5 \times 10^{6} \approx 2.98 \times 10^{10} \, \text{J}$$

This aligns with the total energy magnitude calculated earlier, reaffirming that the total mechanical energy is approximately -2.98×10^{10} J.

Implications of Atmospheric Drag at 108 km

Atmospheric drag is a critical factor at such low altitudes. The dense layers of the atmosphere exert a retarding force on the satellite, leading to energy loss over time. To maintain a stable orbit, the satellite must constantly replenish this lost energy.

Estimating Energy Loss Due to Drag

The energy loss per unit time (power) due to atmospheric drag depends on:

- Atmospheric density (ρ)
- Cross-sectional area of the satellite (A)
- Drag coefficient (C_d)
- Velocity (v)

The drag force:

\[
F_d = \frac{1}{2} C_d \rho A v^2
\]

The power (rate of energy loss):

\[
P = F_d \times v = \frac{1}{2} C_d \rho A v^3
\]

At 108 km, atmospheric density can be on the order of \(10^{-4} \, \text{kg/m}^3 \), but it varies significantly with solar activity and atmospheric conditions.

Assuming typical values:

- \(C_d \approx 2.0 \)
- \(A \approx 1\, \text{m}^2 \)

Calculating power:

\[
P \approx 0.5 \times 2.0 \times 10^{-4} \times 1 \times (7,845)^3
\]

\[
P \approx 1.0 \times 10^{-4} \times 4.83 \times

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