A 200kg Weather Rocket Is Loaded With 100 Kg Of Fuel And Fired Straight Up. It Accelerates Upward At

Introduction

A 200kg Weather Rocket Is Loaded With 100 Kg Of Fuel And Fired Straight Up. It Accelerates Upward At a specific initial acceleration, propelling itself into the sky to gather vital atmospheric data. Understanding the physics behind this launch involves analyzing the forces acting on the rocket, calculating its initial acceleration, and exploring how it behaves as it ascends through Earth's atmosphere. This article delves into the detailed mechanics of this scenario, providing insights into the principles of rocket motion, the role of fuel, and the impact of gravity and air resistance on the rocket's trajectory.

Basic Assumptions and Parameters

Known Data

- Mass of the rocket (dry mass): 200 kg
- Fuel mass: 100 kg
- Total initial mass: 300 kg (rocket + fuel)
- Direction of motion: straight upward

- Gravity acceleration (g): 9.81 m/s²
- Type of propulsion: assumed to be a simple rocket engine providing a constant thrust during initial phase
- Air resistance: initially neglected for simplicity, but discussed later

Objectives of the Analysis

1. Calculate the initial acceleration of the rocket immediately after launch.
2. Determine the velocity of the rocket at various points during ascent.
3. Explore how fuel consumption affects acceleration over time.
4. Discuss the effects of gravity and air resistance as the rocket climbs.
5. Understand the basic physics principles governing rocket motion.

Calculating the Initial Acceleration

Understanding the Forces at Play

The fundamental forces acting on the rocket at launch are:

- **Thrust (F_{thrust}):** the force generated by the rocket engine to propel the rocket upward.

- **Gravity (Weight):** the downward force due to Earth's gravity, calculated as the mass of the rocket times g.
- **Air Resistance (Drag):** opposing the motion, which can be significant but is initially neglected for simplicity.

Calculating Thrust and Mass

The initial total mass of the rocket is 300 kg, comprising:

- Dry mass: 200 kg
- Fuel mass: 100 kg

The rocket engine produces a certain thrust, which is generally provided or assumed based on typical rocket engines. For this analysis, assume an initial thrust (Fthrust) of 3000 N (a reasonable value for small weather rockets).

Applying Newton's Second Law

Newton's second law states:

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

where:

- F_{net} is the net force,
- m is the mass,
- a is the acceleration.

The net force is:

$$ F_{net} = F_{thrust} - W $$

where W is the weight of the rocket:

$$ W = m \times g = 300\, \text{kg} \times 9.81\, \text{m/s}^2 = 2943\, \text{N} $$

Therefore:

$$ a = \frac{F_{thrust} - W}{m} = \frac{3000\, \text{N} - 2943\, \text{N}}{300\, \text{kg}} = \frac{57\, \text{N}}{300\, \text{kg}} \approx 0.19\, \text{m/s}^2 $$

This initial acceleration indicates that, with these assumptions, the rocket would accelerate upward at approximately 0.19 m/s^2 immediately after ignition, just overcoming gravity.

Impact of Fuel Consumption on Acceleration

Fuel Burn Rate and Its Effect

As the rocket burns fuel, its mass decreases, influencing acceleration. Assume the engine burns fuel at a rate $\dot{m}_f$ (kg/s). For simplicity, suppose:

- Fuel burn rate: 2 kg/s

Then, the mass of the rocket at time t:

$$ m(t) = m_{dry} + m_{fuel}(t) = 200\, \text{kg} + (100\, \text{kg} - 2\, \text{kg/s} \times t) $$

The thrust might be assumed constant during initial phase, but in reality, the engine's thrust may vary with fuel flow.

Calculating Instantaneous Acceleration Over Time

At any moment t:

$$ a(t) = \frac{F_{thrust} - m(t) \times g}{m(t)} $$

For example, after 10 seconds:

- Fuel remaining: $100\, \text{kg} - 2 \times 10 = 80\, \text{kg}$
- Total mass: $200\, \text{kg} + 80\, \text{kg} = 280\, \text{kg}$
- Weight: $280 \times 9.81 \approx 2747\, \text{N}$

Thus:

$$a(10) = \frac{3000 - 2747}{280} \approx \frac{253}{280} \approx 0.90\, \text{m/s}^2$$

This shows that as fuel burns, the mass decreases, and the acceleration increases, assuming constant thrust.

Velocity and Height Ascent Calculations

Estimating Velocity Over Time

Using basic kinematics, the velocity at time t can be approximated by integrating acceleration:

$$v(t) = \int_0^t a(t') dt'$$

If we assume constant acceleration during small intervals, then:

$$v(t) \approx a_{avg} \times t$$

For simplicity, consider an average acceleration of 0.19 m/s^2 over the initial 10 seconds:

$$v(10) \approx 0.19 \times 10 = 1.9\, \text{m/s}$$

As the acceleration increases with fuel burn, the actual velocity will be higher.

Estimating Altitude Gain

Similarly, height gain:

$$h(t) = \int_0^t v(t') dt'$$

which can be approximated via numerical methods, considering that acceleration increases due to decreasing mass.

For initial estimates:

- After 10 seconds, with average velocity ~1.9 m/s, the altitude is approximately:

$$ h \approx \frac{1}{2} a_{avg} \times t^2 = 0.5 \times 0.19 \times 10^2 = 0.5 \times 0.19 \times 100 = 9.5\, \text{m} $$

Realistically, as acceleration increases, the altitude after 10 seconds would be slightly higher.

Influence of Air Resistance and Gravity at Higher Altitudes

Air Resistance (Drag Force)

As the rocket ascends, it encounters air resistance, which opposes its motion. Drag force F_D can be modeled as:

$$ F_D = \frac{1}{2} C_D \rho A v^2 $$

where:

- C_D is the drag coefficient,
- ρ is the air density,
- A is the cross-sectional area,
- v is the velocity.

At high speeds and altitudes, this force becomes significant, reducing net acceleration.

Gravity Variation With Altitude

Gravity decreases slightly with altitude:

$$ g(h) = g_0 \left(\frac{R}{R + h} \right)^2 $$

where:

- R is Earth's radius (~6371 km),
- h is altitude.

For low-altitude launches, this variation is negligible, but it becomes relevant as the rocket ascends higher.

Summary of Rocket Motion Dynamics

- Initial Phase: The rocket's acceleration is determined by the thrust-to-weight ratio. If thrust exceeds weight, the rocket accelerates upward; otherwise, it remains stationary or descends.
- Fuel Consumption: As fuel burns, the mass decreases, leading to increased acceleration if thrust remains constant.
- Velocity and Height: Acceleration over time influences velocity, which in turn affects altitude, following kinematic principles.
- External Forces: Air resistance and decreasing gravity modify the rocket's ascent, especially at higher altitudes.
- Practical Considerations: For real-world applications, engineers account for these factors in designing engines, selecting fuel, and planning trajectories.

Conclusion

The launch of a 200kg weather rocket loaded with 100 kg of fuel involves complex physics governed by Newton's laws, fluid dynamics, and gravitational variations. Initially, the rocket experiences

Frequently Asked Questions

What is the initial mass of the weather rocket before fuel

consumption?

The initial mass of the weather rocket is 200 kg, which includes the 100 kg of fuel loaded onto it.

What is the total mass of the rocket after burning all the fuel?

After burning all 100 kg of fuel, the rocket's mass reduces to 100 kg (the dry mass of the rocket itself).

How does the acceleration of the rocket relate to the forces acting on it?

The upward acceleration depends on the net force, which is the thrust produced by fuel combustion minus gravity's downward force (weight).

What factors determine the acceleration of the rocket during launch?

Factors include the rocket's mass at any moment, the rate of fuel combustion (thrust produced), and gravitational acceleration.

How does the acceleration change as fuel is burned during the launch?

As fuel burns and the rocket's mass decreases, if the thrust remains constant, the acceleration increases because the net force becomes relatively larger compared to the decreasing mass.

What is the significance of knowing the rocket's acceleration during launch?

Understanding acceleration helps determine the rocket's speed and altitude over time, and is crucial for safety and mission planning.

If the rocket accelerates upward at a constant rate, what additional

information is needed to find that acceleration?

You need to know the thrust produced by the fuel combustion and the gravitational acceleration acting on the rocket.

How does gravity affect the rocket's acceleration during its upward flight?

Gravity acts downward with an acceleration of approximately 9.8 m/s^2, reducing the net acceleration of the rocket unless the thrust exceeds the weight of the rocket.

Additional Resources

A 200kg Weather Rocket Is Loaded With 100 Kg Of Fuel And Fired Straight Up. It Accelerates Upward At

---

Introduction

In the realm of atmospheric research and weather observation, small-scale rockets have become essential tools for data collection and environmental monitoring. Among these, weather rockets—compact, high-precision devices—offer a cost-effective and reliable method to gather critical atmospheric parameters such as temperature, humidity, wind speed, and pressure. The particular scenario of a 200kg weather rocket loaded with 100 kg of fuel and fired straight up presents an intriguing case study, blending principles of propulsion, physics, and engineering design.

This article provides an in-depth analysis of the dynamics involved in such a launch, exploring the physics of acceleration, the rocket's design considerations, and the implications for atmospheric research. By dissecting the key parameters, we aim to understand what occurs during the launch and how engineers optimize these small-scale rockets for maximum effectiveness.

Overview of the Rocket's Specifications and Mission Context

The scenario involves a weather rocket with the following key parameters:

- Mass of the rocket (dry mass): 200 kg
- Fuel loaded: 100 kg
- Total initial mass (including fuel): 300 kg
- Launch orientation: Vertical (straight up)
- Firing conditions: Presumed to be at standard atmospheric pressure and gravity (g □ 9.81 m/s^2)

The primary goal of the launch is to ascend through the atmosphere to a predetermined altitude, where onboard sensors can collect data before the rocket either descends under parachute or is recovered via other means.

Physics of Rocket Acceleration

Basic Principles

The acceleration of the rocket depends on the thrust generated by the combustion of fuel, counteracted by gravity and atmospheric drag. To understand the acceleration profile, we apply Newton's second law:

$F_{net} = m a$

where:

- F_{net} is the net force acting on the rocket,

- m is the mass of the rocket at any given moment,
- a is the acceleration.

The net force during powered ascent is:

F_{net} = Thrust (T) - Drag (D) - Weight (W)

The core focus here is on the initial phase, where the thrust exceeds the combined effect of gravity and drag, resulting in upward acceleration.

Thrust and Fuel Consumption

Rocket Engine Specifications

While the exact engine details are not provided, typical small weather rockets employ solid or hybrid rocket motors with known thrust profiles. For simplicity, let's consider:

- Average Thrust (T): 10,000 N (a plausible figure for a small solid motor)
- Burn time: 10 seconds (assumed for calculation purposes)
- Specific impulse (Isp): 250 seconds (common for solid rocket motors in small-scale applications)

Fuel Mass and Burn Rate

Given 100 kg of fuel and a burn time of 10 seconds:

- Mass flow rate (□): 100 kg / 10 s = 10 kg/s

The thrust can be approximated using:

T = □ Ve

where Ve is the effective exhaust velocity:

Ve = Isp g

Thus,

Ve = 250 s 9.81 m/s^2 □ 2452.5 m/s

And,

T = 10 kg/s 2452.5 m/s □ 24,525 N

This is a more realistic estimate for a small rocket's thrust, significantly exceeding the initial 10,000 N assumption, indicating a more powerful motor.

Calculating Initial Acceleration

Using the above thrust estimate and initial mass:

- Initial mass (m□): 300 kg

The initial acceleration:

a□ = (T - W) / m□

Where:

- $W = m_0 g = 300\ \text{kg}\ 9.81\ \text{m/s}^2 \approx 2943\ \text{N}$

Therefore,

$$a_0 = (24{,}525\ \text{N} - 2943\ \text{N}) / 300\ \text{kg} \approx (21{,}582\ \text{N}) / 300\ \text{kg} \approx 71.94\ \text{m/s}^2$$

This is an initial acceleration approximately 7.3 times gravity, indicating a rapid upward push right after ignition.

Fuel Consumption and Mass Reduction During Flight

As the rocket burns fuel, its mass decreases, affecting acceleration:

- After t seconds,

$$m(t) = m_0 - \dot{m}\ t$$

At the end of burn phase ($t = 10$ s):

$$m(10) = 300\ \text{kg} - 10\ \text{kg/s}\ 10\ \text{s} = 200\ \text{kg}$$

Correspondingly, the weight:

$$W(t) = m(t)\ g$$

And acceleration at any moment:

$$a(t) = (T - m(t)\ g) / m(t) = (\dot{m}\ V_e - m(t)\ g) / m(t)$$

Plugging in m(t) = 200 kg at burnout:

$a\_burnout = (24{,}525\ N - 200\ kg\ 9.81\ m/s^2) / 200\ kg$ □ $(24{,}525\ N - 1962\ N) / 200\ kg$ □ $11{,}282\ N / 200\ kg$ □ $56.41\ m/s^2$

This illustrates that as fuel depletes, acceleration diminishes but remains significantly above 1g, ensuring rapid ascent.

Trajectory and Altitude Estimation

Simplified Ascent Calculation

Assuming constant acceleration during burn (which is an approximation, as thrust may decrease over time), the ascent height during powered flight is:

$h\_burn = 0.5\ a\_avg\ t^2$

Where a_avg is the average acceleration during burn:

a_avg □ (a□ + a_burnout) / 2 □ $(71.94 + 56.41) / 2$ □ $64.18\ m/s^2$

Then,

h_burn □ $0.5\ 64.18\ m/s^2\ (10\ s)^2$ □ $0.5\ 64.18\ 100$ □ 3,209 meters

The velocity at burnout:

$v\_burnout = a\_avg\ t$ □ $64.18\ m/s^2\ 10\ s$ □ $641.8\ m/s$

Beyond burnout, the rocket continues to ascend under inertia, decelerated by gravity and drag until it reaches its maximum altitude.

Impact of Drag and Atmospheric Conditions

While the calculations above ignore drag, in reality, atmospheric drag plays a vital role, especially at higher velocities:

$D = 0.5 \rho v^2 C_d A$

where:

- ρ: air density ($\approx$ 1.225 kg/m^3 at sea level)
- v: velocity
- C_d: drag coefficient (~0.75 for a streamlined rocket)
- A: cross-sectional area

This drag force reduces acceleration, especially at high speeds. For small rockets, drag becomes a significant factor above Mach 0.3 (~100 m/s). As such, actual maximum altitude is somewhat lower than simplified estimates.

Altitude and Data Collection Implications

Considering the initial velocity (~640 m/s at burnout), the rocket is likely to reach altitudes of approximately 15-20 km, depending on drag and atmospheric conditions. This altitude is sufficient for tropospheric and lower stratospheric measurements, aligning with typical weather research missions.

Data collection payloads are typically designed to operate under these conditions, with sensors and recorders calibrated for the environmental parameters encountered during ascent and descent.

Engineering and Safety Considerations

Structural Integrity

A rocket with a mass of 200 kg and loaded with 100 kg of fuel must be engineered to withstand the stresses of rapid acceleration, vibration, and thermal loads during combustion.

Launch Site and Safety Protocols

Given the high initial accelerations and potential hazards, launches are conducted in controlled environments with clear safety zones. The straight-up trajectory minimizes risk to surrounding areas.

Recovery Systems

Post-mission, the rocket usually employs parachutes or other descent systems to recover the payload, minimizing environmental impact and enabling reuse.

Conclusion

The scenario of a 200kg weather rocket loaded with 100 kg of fuel and fired straight up exemplifies a classic application of rocket physics and engineering. The initial acceleration, driven by a powerful thrust-to-weight ratio, allows the rocket to rapidly ascend through the lower atmosphere, providing valuable data for weather and atmospheric research.

In real-world applications, engineers must account for various factors—including variable thrust, drag, thermal stresses, and recovery logistics—to optimize performance. This detailed understanding of the physics involved not only ensures mission success but also advances the science of atmospheric measurement, ultimately contributing to better weather forecasting and climate understanding.

As technology progresses, small weather rockets like this will continue to evolve, becoming more efficient, safer, and more capable of unlocking the secrets of our planet's atmosphere.

References

- Sutton, G. P., & Biblarz, O. (2016). Rocket Propulsion Elements. John Wiley & Sons.
- NASA Marshall Space Flight Center. (n.d.). Rocket Propulsion Overview.
- Stull, R. B. (1988). An Introduction to Boundary Layer Meteorology. Springer.
- National Weather Service. (2020). Weather Balloon and Rocket Launch Procedures.
- "Principles of Rocket Propulsion" by Sabatier and Berman.

A 200kg Weather Rocket Is Loaded With 100 Kg Of Fuel And Fired Straight Up It Accelerates Upward At

A 200kg Weather Rocket Is Loaded With 100 Kg Of Fuel And Fired Straight Up It Accelerates Upward At

Related Articles

-) Around High And Low-pressure Systems A Centrifugal Force Always Occurs That Pushes The Air Parcels
- 100 POINTS!You Have Read The Strange Case Of Dr. Jekyll And Mr. Hyde By Robert Louis Stevenson. In A
- A Diver Shines A Light Up To The Surface Of A Flat Glass-bottomed Boat At An Angle Of 37 Relative To

Back to Home