Takeoff speed of an airplane

FizziQ activity · High school · 25 min

Scan to open in FizziQ

Record an airliner's acceleration during takeoff with the smartphone accelerometer, then integrate the data in FizziQ to find the takeoff speed. High school.

Learning objectives

- Record the horizontal acceleration during an aircraft takeoff using the smartphone accelerometer
- Integrate the acceleration data over time to calculate the aircraft's velocity at any moment
- Determine the takeoff speed and compare it with published values for the aircraft type
- Understand the relationship between acceleration, velocity, and displacement in kinematics
- Identify the different phases of the takeoff roll from the acceleration profile

Instruments and sensors

Linear acceleration (X-axis) · Accelerometer

Materials

- Smartphone with the FizziQ application
- A plane flight (commercial or private)
- An armrest or stable, flat surface to secure the smartphone with its X-axis aligned with the direction of travel
- FizziQ experiment notebook to record, graph and analyze the acceleration data
- Note: the protocol remains adaptable to any comparable acceleration-measurement tool.

Protocol

1. Before the flight, open FizziQ and select the Linear Acceleration X sensor (horizontal axis along the direction of travel).
2. Secure the smartphone on the armrest or tray table so the X-axis is aligned with the aircraft's direction of travel. Use a case or wedge to prevent sliding.
3. Before taxiing, start a test recording to verify the sensor reads approximately 0 m/s² when the aircraft is stationary.
4. When the aircraft lines up on the runway and begins the takeoff roll, start recording.
5. Record continuously until the aircraft is clearly airborne (you feel the nose lift and the ground vibrations stop). This typically takes 25-40 seconds.
6. Stop recording shortly after liftoff.
7. After the flight, examine the acceleration versus time graph. Identify the start of the roll (acceleration rises sharply from zero).
8. Identify the liftoff moment (acceleration drops as the aircraft becomes airborne and the rolling friction disappears).
9. To calculate the speed, perform a numerical integration: for each time interval Δt, calculate v += a × Δt. Start with $v_0 = 0$ at the beginning of the roll.
10. Plot the velocity versus time graph from your integrated data.
11. Read the takeoff speed from the graph at the moment of liftoff. Convert from m/s to km/h (×3.6) and to knots (×1.944).
12. Compare your result with typical takeoff speeds: 240-280 km/h (130-150 knots) for a medium-haul airliner like an A320 or B737.

Expected results

The acceleration graph should show a sharp increase at the start of the takeoff roll, reaching 2-4 m/s^2 within the first few seconds as the engines reach full thrust. The acceleration then gradually decreases as aerodynamic drag increases with speed, typically falling to 1-2 m/s^2 by the time of liftoff. The integrated velocity should show an approximately linear increase (for roughly constant acceleration) reaching 65-80 m/s (235-290 km/h) at liftoff. The total takeoff roll duration is typically 25-40 seconds for a medium-haul airliner. Measurement precision depends on the phone's alignment with the direction of travel; a misalignment of 5° introduces about a 0.4% error, which is negligible.

Questions

- Why is the acceleration not constant during the takeoff roll? What forces change?
- How does the takeoff speed depend on the aircraft's weight and the wind conditions?
- What is the relationship between acceleration, velocity, and displacement? How are they connected mathematically?
- Why do pilots calculate V1 (decision speed) and VR (rotation speed) before every takeoff?
- How would the acceleration profile differ for a fighter jet compared to a commercial airliner?
- What sources of error might affect the integration of acceleration data to obtain velocity?

Going further

- Compare takeoff accelerations for different aircraft types (short-haul vs. long-haul)
- Record the landing deceleration and compare the braking profile with the takeoff acceleration
- Calculate the runway distance used by double-integrating the acceleration ($d = \iint a\, dt^2$)
- Investigate the effect of wind by comparing takeoffs in different directions from the same airport
- Record the acceleration during the climb phase and compare with the takeoff roll