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THE EFFECTS OF ENVIRONMENTAL CONDITIONS ON TAKEOFF DISTANCE AND CLIMB PERFORMANCE OF THE BOEING 737 MAX 8

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Abstract

Takeoff and initial climb are critical phases of flight in which aircraft performance is strongly influenced by atmospheric, runway, and operational conditions. This study examines the effects of air temperature, atmospheric pressure, airport elevation, humidity, wind, runway condition, and aircraft weight on the takeoff distance and climb performance of the Boeing 737 MAX 8. The study employed a narrative literature-review method by analyzing peer-reviewed journal articles, aviation handbooks, and official technical publications related to aircraft performance. The findings indicate that high air temperature and high pressure altitude reduce air density, resulting in lower aerodynamic lift, reduced engine-performance margins, longer takeoff distances, and lower climb rates or climb gradients. Airport elevation intensifies these effects because atmospheric pressure generally decreases with increasing altitude. Headwinds normally improve takeoff performance by reducing the groundspeed required to achieve the necessary airspeed, while tailwinds produce the opposite effect. Humidity has a smaller influence than temperature and pressure but may contribute to reduced performance under hot-and-high conditions. Aircraft weight and runway condition further determine whether available runway length and obstacle-clearance requirements can be satisfied. The study concludes that these factors should not be assessed independently because their combined effects can create substantial operational limitations. Accurate weather observations, aircraft-specific performance calculations, appropriate runway selection, and careful aircraft-loading management are therefore essential for maintaining safe and efficient Boeing 737 MAX 8 operations.
Keywords : Boeing 737 MAX 8, takeoff distance, climb performance, density altitude, environmental conditions, aircraft performance

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INTRODUCTION

Operational efficiency and flight safety are fundamental priorities in commercial aviation. Among all phases of flight, takeoff and initial climb are particularly critical because the aircraft must accelerate to the required takeoff speed, become airborne within the available runway length, clear surrounding obstacles, and maintain the minimum required climb performance. The successful completion of these processes depends on aircraft configuration, aircraft weight, engine performance, runway characteristics, and atmospheric conditions.

Environmental variables such as air temperature, atmospheric pressure, airport elevation, humidity, wind speed, and wind direction can significantly affect aircraft performance. These variables primarily affect performance through changes in air density. When air density decreases, an aircraft must reach a higher true airspeed to generate the lift required for takeoff. Reduced air density can also decrease engine-performance margins, resulting in slower acceleration, longer takeoff distance, and lower climb performance (Federal Aviation Administration [FAA], 2023).

Temperature is one of the most important environmental variables influencing aircraft takeoff performance. As air temperature increases at constant atmospheric pressure, air density decreases. Consequently, the wings generate less lift at a given airspeed, and the aircraft may require a longer distance to become airborne. Rising temperature can also reduce the maximum permissible takeoff weight, particularly at airports with short runways, high elevations, or extreme temperature conditions (Coffel & Horton, 2015; Coffel et al., 2017).

Airport elevation and atmospheric pressure produce similar effects. Airports located at higher elevations generally have lower atmospheric pressure than airports located near sea level. The combination of high elevation and high temperature produces high density-altitude conditions, commonly known as "hot-and-high" conditions. Under these circumstances, the aircraft may experience reduced aerodynamic and engine performance, resulting in a longer takeoff distance and reduced climb capability (FAA, 2023; Zhou et al., 2018).

The aircraft examined in this study is the Boeing 737 MAX 8. In official Boeing technical documentation, this aircraft is designated as the Boeing 737-8. However, the term Boeing 737 MAX 8 is widely used in airline operations, manufacturer communications, and public discussions. Therefore, this article consistently uses the term **Boeing 737 MAX 8**, while recognizing that Boeing's airport-planning documentation uses the technical model designation **737-8** (Boeing Commercial Airplanes, 2025).

The Boeing 737 MAX 8 is part of the Boeing 737 MAX family and is equipped with LEAP-1B engines, advanced-technology winglets, and aerodynamic improvements intended to enhance operational and fuel efficiency. Boeing's airport-planning documentation provides separate takeoff runway-length charts for different pressure altitudes, aircraft weights, engine configurations, and temperature conditions. The existence of these separate charts demonstrates that takeoff performance cannot be determined using a single general correction factor (Boeing Commercial Airplanes, 2025).

Previous studies have examined the effects of temperature and climate change on the takeoff performance of commercial aircraft. Coffel et al. (2017) found that increasing temperatures may lead to more frequent aircraft-weight restrictions, particularly at airports with short runways and high temperatures. Zhou et al. (2018) similarly showed that higher temperature and pressure altitude can increase takeoff distance and reduce climb rate.

More recent research has also demonstrated that takeoff distance does not necessarily increase linearly with temperature. The performance penalty may become progressively larger at higher temperatures, depending on aircraft weight, airport characteristics, and atmospheric conditions (Wang et al., 2023). Yalçınkaya Çağlıyan and Demirhan (2024) also reported that increases in temperature and pressure altitude were associated with longer takeoff distances and lower climb rates at selected airports.

However, most publicly available quantitative studies have used the Boeing 737-800 rather than the Boeing 737 MAX 8. Although the basic aerodynamic relationships involving temperature, pressure, air density, and aircraft weight apply to both aircraft, numerical findings for the Boeing 737-800 cannot automatically be treated as exact performance values for the Boeing 737 MAX 8.
Accordingly, a research gap remains concerning the synthesis of environmental effects specifically in relation to Boeing 737 MAX 8 operational planning. Previous studies also frequently examine temperature, pressure altitude, or climate change separately, whereas actual flight operations involve interactions among atmospheric conditions, wind, runway condition, aircraft weight, and airport characteristics.

This literature review therefore aims to:

1. identify the principal environmental and operational variables affecting takeoff distance and climb performance;
2. explain how temperature, atmospheric pressure, airport elevation, humidity, wind, runway condition, and aircraft weight interact;
3. compare relevant findings from previous aircraft-performance studies; and

4. identify the implications of these findings for Boeing 737 MAX 8 operational planning and aviation safety.

RESEARCH METHODS

This study employed a structured narrative literature-review method to analyze the effects of environmental conditions on the takeoff distance and climb performance of the Boeing 737 MAX 8.

The literature search covered peer-reviewed journal articles, aviation handbooks, aircraft-manufacturer documents, and publications issued by aviation-related institutions. The sources were identified through Google Scholar, SpringerLink, ScienceDirect, aviation-journal platforms, the Federal Aviation Administration, and official Boeing publications.

The search combined terms related to Boeing 737 MAX 8 performance, aircraft takeoff distance, climb rate, temperature, pressure altitude, airport elevation, density altitude, wind, humidity, aircraft weight, runway condition, and climate change. Publications issued primarily between 2015 and 2025 were prioritized to represent contemporary aircraft-performance and environmental research. Official technical manuals and aviation handbooks were included regardless of publication type because of their operational relevance.

The inclusion criteria consisted of publications that:

1. examined aircraft takeoff distance, climb rate, climb gradient, or takeoff-weight limitations;
2. discussed atmospheric or runway variables affecting aircraft performance;
3. presented findings relevant to commercial jet aircraft or the Boeing 737 family; and
4. provided official technical or operational guidance concerning aircraft performance.

Studies focusing exclusively on the Boeing 737 MAX accidents, corporate reputation, engineering ethics, automation, financial effects, or passenger perceptions were excluded because they did not directly examine environmental effects on takeoff and climb performance.

The selected literature was analyzed thematically. The findings were classified into air temperature, atmospheric pressure, airport elevation, wind, humidity, aircraft weight, runway condition, and combined environmental effects.

The findings from different studies were subsequently compared and interpreted in relation to Boeing 737 MAX 8 operations.

No statistical meta-analysis was conducted because the reviewed publications used different aircraft models, airport locations, climate scenarios, performance assumptions, and analytical methods. Therefore, the numerical findings were interpreted as comparative evidence rather than universal performance values for the Boeing 737 MAX 8.

RESULTS AND DISCUSSION

1. Air Temperature

Air temperature has a substantial influence on takeoff distance and climb performance. At constant atmospheric pressure, increasing temperature causes air to expand and become less dense. The reduced density decreases the amount of lift generated by the aircraft wings at a given true airspeed. Consequently, the aircraft must achieve a higher true airspeed before sufficient lift is produced for takeoff (FAA, 2023). Higher temperature can also reduce engine-performance margins. A reduction in available thrust, combined with lower aerodynamic lift, causes the aircraft to accelerate more slowly and may increase the required takeoff distance. During the initial climb, the reduction in excess thrust may result in a lower climb rate or climb gradient.

Coffel and Horton (2015) demonstrated that high temperature can impose aircraft-weight restrictions, particularly at airports with short runways and limited opportunities for runway expansion. Their study showed that temperature, airport elevation, runway length, and aircraft weight interact in determining whether an aircraft can depart at its maximum allowable weight.

Coffel et al. (2017) further explained that, as temperature rises, aircraft may be required to reduce payload, fuel, or both to satisfy takeoff-performance requirements. Their model projected that aircraft operating at the daily maximum temperature would increasingly experience takeoff-weight restrictions under future warming conditions.

Zhou et al. (2018) reported that higher temperature and pressure altitude resulted in longer takeoff distances and lower climb rates. Their projections indicated that average summer takeoff distance could increase by approximately 0.95–6.5% from the historical period to the middle of the twenty-first century.

Summer climb rates were projected to decline by approximately 0.68–3.4% over the same comparison period.

However, Zhou et al. (2018) used a Boeing 737-800 as the example aircraft. These percentages should therefore not be treated as exact values for the Boeing 737 MAX 8. They nevertheless provide evidence of the general relationship between increasing temperature, longer takeoff distance, and reduced climb performance.

Wang et al. (2023) similarly found that warming conditions decreased maximum permissible takeoff weight and increased takeoff distance. Their findings also indicated that the relationship between temperature and takeoff distance was nonlinear, with greater performance penalties occurring at higher temperature levels.

Boeing's runway-length charts for the Boeing 737 MAX 8 provide different results for standard-day conditions and temperatures above the standard atmosphere. This confirms that changes in temperature must be included in aircraft-specific takeoff-performance calculations rather than estimated using a fixed percentage (Boeing Commercial Airplanes, 2025).

2. Atmospheric Pressure and Airport Elevation

Atmospheric pressure and airport elevation influence aircraft performance through their effects on air density. Atmospheric pressure normally decreases with increasing altitude. Therefore, an airport located at high elevation generally has lower air density than an airport located near sea level. Lower atmospheric pressure reduces the number of air molecules flowing around the aircraft wings and entering the engines. The aircraft consequently requires a higher true airspeed to produce the necessary aerodynamic lift. Reduced atmospheric density can also decrease engine thrust and excess power available during the initial climb (FAA, 2023).

Airport elevation should not be evaluated independently from temperature. When an airport has both high elevation and high temperature, its density altitude may be substantially higher than its physical elevation. These hot-and-high conditions can significantly increase takeoff distance and reduce climb capability.
Coffel and Horton (2015) found that airport elevation affects the temperature threshold at which aircraft-weight restrictions become necessary. Airports with high elevations or short runways generally experience more severe performance limitations than low-elevation airports with long runways.

The Boeing 737 MAX airport-planning manual presents takeoff runway-length requirements according to aircraft weight and pressure altitude. Separate performance charts are provided for standard-day conditions and several temperatures above standard conditions. These charts demonstrate that pressure altitude, temperature, engine configuration, and aircraft weight must be considered simultaneously (Boeing Commercial Airplanes, 2025).

Therefore, a statement that a particular increase in airport elevation always produces a fixed percentage increase in takeoff distance would be technically inappropriate. The actual effect depends on temperature, atmospheric pressure, aircraft weight, runway characteristics, engine configuration, flap setting, and obstacle requirements.

3. Wind Speed and Direction

Wind affects takeoff performance through the relationship between airspeed and groundspeed. The aircraft produces lift in response to airflow over its wings rather than its speed relative to the ground.

A headwind allows the aircraft to achieve the required airspeed at a lower groundspeed. As a result, the aircraft generally requires a shorter ground distance to become airborne. In contrast, a tailwind requires the aircraft to reach a higher groundspeed to obtain the same aerodynamic airspeed, generally increasing the required takeoff distance (FAA, 2023).

The effects of headwind and tailwind should not be represented using universal percentage corrections. The exact performance effect depends on the wind component, aircraft weight, runway surface condition, aircraft configuration, and manufacturer-approved calculation procedures.

Crosswind has a smaller direct effect on theoretical takeoff distance than headwind or tailwind. However, it affects directional control, aircraft handling, runway selection, and pilot workload. Each aircraft and operator also has applicable crosswind limitations or recommended maximum crosswind values.

Wind information must therefore be accurately measured and communicated to flight crews. Automated Weather Observing Systems can provide continuous measurements of wind direction, wind speed, air temperature, atmospheric pressure, and other weather variables needed for airport operations (Sutanto et al., 2022).

4. Air Humidity

Humidity affects air density because water vapour is less dense than the primary gases contained in dry air. As the water-vapour content increases, air density decreases slightly. Therefore, high humidity may produce a small reduction in aerodynamic and engine performance.

The influence of humidity is generally less significant than the influences of temperature and atmospheric pressure. Nevertheless, humidity becomes more operationally relevant when combined with high temperature and high airport elevation. Under these conditions, the combined density-altitude effect may further reduce takeoff and climb performance (FAA, 2023).

The effect of humidity cannot be accurately represented by claiming that it always reduces engine performance by a fixed percentage. The actual effect depends on atmospheric temperature, pressure, engine characteristics, and aircraft-performance calculation methods.

Consequently, humidity should be regarded as one component of the actual atmospheric condition rather than as an independent and constant performance penalty.

5. Aircraft Weight

Although aircraft weight is not an environmental variable, it strongly influences the extent to which environmental conditions affect takeoff and climb performance.

A heavier aircraft requires more lift to become airborne. It also requires more energy to accelerate to takeoff speed and greater thrust to maintain the required climb performance. Therefore, increasing takeoff weight generally increases the required takeoff distance and decreases the available climb gradient.

During high-temperature or high-density-altitude operations, the maximum permissible takeoff weight may be lower than the aircraft's structural maximum takeoff weight. The actual permissible weight may be limited by runway length, engine-out climb performance, obstacle clearance, brake-energy limitations, tyre-speed limitations, or runway condition (Boeing Commercial Airplanes, 2025).

Coffel et al. (2017) found that weight reduction may become a necessary operational response to increasing temperature. The reduction may involve decreasing passenger numbers, cargo, baggage, or fuel load. However, reducing fuel may also require an additional refuelling stop or route adjustment.

The relationship between aircraft weight and takeoff distance is nonlinear. Therefore, the claim that every one-percent increase in aircraft weight automatically results in a specific percentage increase in takeoff distance should not be used without verified aircraft-specific performance data.

6. Runway Surface Condition and Runway Characteristics

Runway condition influences aircraft acceleration and rejected-takeoff performance. A dry runway normally provides better tyre friction than a wet or contaminated runway. Water, snow, slush, ice, or other contaminants can reduce braking effectiveness and may increase rolling resistance.

Although contamination may not directly reduce aerodynamic lift, it can increase the distance required for acceleration and stopping. The operator must therefore apply the appropriate runway-condition adjustments when determining allowable takeoff weight and required runway length.

Runway slope also affects aircraft performance. An uphill runway generally reduces acceleration and increases takeoff distance. A downhill runway may improve acceleration but can adversely affect stopping performance during a rejected takeoff.

Available runway length, runway slope, runway surface condition, airport elevation, temperature, and wind must consequently be considered together. Boeing’s airport-planning documentation provides general runway-requirement information, but the document is intended for airport-planning purposes and does not replace operator-specific approved takeoff data (Boeing Commercial Airplanes, 2025).

7. Combined Effects of Environmental Conditions

Environmental conditions rarely affect aircraft performance independently. The most significant operational limitations usually result from combinations of high temperature, high airport elevation, low atmospheric pressure, high humidity, unfavourable wind, high aircraft weight, and limited runway length.

For example, an airport located at high elevation may experience high daytime temperatures. The combination produces high density altitude, reducing both aerodynamic lift and engine-performance margins. A tailwind or contaminated runway can further increase the takeoff distance required.

If the aircraft is operating close to its performance-limited weight, relatively small changes in temperature, wind, or runway condition may require a reduction in payload or fuel. Alternatively, the flight may have to use another runway, depart during a cooler period, or be delayed until conditions improve.

Yalçınkaya Çağlıyan and Demirhan (2024) projected increases of approximately 4–7% in takeoff distance and decreases of approximately 3–5% in climb rate between the selected near- and distant-future periods. However, their calculations were based on the Boeing 737-800. These findings are useful for understanding the direction and potential scale of environmental effects, but they should not be interpreted as exact Boeing 737 MAX 8 performance values.

Similarly, Wang et al. (2023) found that global warming could increase the number of days on which aircraft experience takeoff-weight restrictions. Their findings highlight the importance of incorporating future temperature conditions into airport planning and airline operational strategies.

8. Implications for Boeing 737 MAX 8 Operations

The results of this literature review demonstrate that safe Boeing 737 MAX 8 operations require accurate and current atmospheric information. Temperature, atmospheric pressure, wind direction, wind speed, humidity, and runway condition should be obtained from reliable airport observation and reporting systems.

The data must then be entered into approved aircraft-performance calculation systems. General academic findings and airport-planning charts cannot replace aircraft-specific operational calculations.

Pilots, flight dispatchers, and airline operations personnel should pay particular attention to:

- actual outside-air temperature;
- pressure altitude and density altitude;
- runway wind components;
- runway surface condition and slope;
- available takeoff and accelerate-stop distances;
- aircraft takeoff weight;
- engine-out climb requirements;
- departure obstacles; and
- operational limitations specified by the manufacturer and operator.

Scheduling departures during cooler morning or evening periods may provide additional performance margins at airports experiencing high daytime temperatures. Airlines may also need to adjust payload, fuel planning, runway selection, or departure time when operating from hot-and-high airports.

Accurate Automated Weather Observing System data can support these decisions by providing continuous measurements of relevant meteorological parameters. However, observation technology must be supported by equipment calibration, system maintenance, reliable data communication, and competent aviation personnel (Sutanto et al., 2022)

CONCLUSION

Environmental and operational conditions substantially influence the takeoff distance and climb performance of the Boeing 737 MAX 8. High temperature, high pressure altitude, and high airport elevation reduce air density, resulting in lower aerodynamic lift, reduced engine-performance margins, longer takeoff distances, and lower climb rates or climb gradients. Humidity has a smaller influence than temperature and pressure but may contribute to the overall density-altitude penalty under hot-and-high conditions. Headwinds generally improve takeoff performance, whereas tailwinds increase the required groundspeed and takeoff distance. Aircraft weight, runway slope, and runway surface condition further determine whether the aircraft can satisfy runway-length, stopping, and obstacle-clearance requirements.

These variables should not be assessed independently because their combined effects may create substantial operational restrictions. Therefore, safe and efficient Boeing 737 MAX 8 operations require accurate weather observations, aircraft-specific performance calculations, appropriate runway selection, and careful management of aircraft weight.

This study is limited by its reliance on secondary data and publicly available literature. Several quantitative findings were derived from studies of the Boeing 737-800 and therefore should not be interpreted as exact performance values for the Boeing 737 MAX 8. Future research should use actual Boeing 737 MAX 8 operational data collected under different environmental and airport conditions to produce more precise aircraft-specific findings.

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