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Comparative Analysis of Weather Impact on Aircraft Takeoff Performances in Nigeria

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Abstract

Takeoff performance remains one of the most important qualities in flying activities of an aircraft. Its impacts influence both military and civil aircraft, such that there are notable effects on passenger safety, fuel economy and adherence to operational schedules. Climatic changes and variability have significantly affected aircraft by increasing the takeoff distance required and decreasing maximum takeoff mass. These had greatly affected landing performance by influencing diversions and missed approaches in Nigeria. It is observed that weather conditions in Nigeria also contribute negatively to the safety of flights, where their operations do even lead to financial losses and incidences. These multicultural and diverse weather-climatic conditions, present across Nigeria's terrestrial regions exacerbate many scenarios. Periods like the wet season, the dry season and the harmattan season, present a whole spectrum of specific hurdles that must be addressed before aircraft takeoff operations. These are notable effects associated with meteorological patterns, associated with seasonal variations. Thus, knowing precisely how weather events may influence aircraft performance, is crucial in improving operational efficiency, flight safety and better aviation experience. This study investigates the impact of weather conditions on aircraft takeoff performance in Nigeria, with a focus on three major airports: Murtala Muhammed International Airport Lagos, Nnamdi Azikiwe International Airport Abuja, and Mallam Aminu Kano International Airport Kano. Utilizing meteorological data from 2020 to 2025 and

performance parameters of the Boeing 737-800, a Python-based simulation engine integrated with a Streamlit web interface was developed to analyze performance across various weather scenarios. The research, models how key weather variables like temperature, wind, precipitation, humidity, pressure, and visibility affect critical takeoff metrics of the aircraft. These include thrust, lift, acceleration, and required runway length. Thereafter, Statistical methods for descriptive analysis like correlation and time series analysis were employed to validate and interpret the results. The findings reveal that high temperatures and low air density significantly increase takeoff distance, while wet and low-friction runways heighten the risk of hydroplaning. It also shows that harmattan-induced poor visibility compounds operational risks. The research provides recommendations for airlines, airport authorities, and regulators to enhance safety and efficiency during adverse weather conditions. It also contributes a customized performance simulation tool and localized data-driven insights that can support airport runway operational planning in Nigeria civil aviation space.

Keywords: Airport-Runway, Harmattan, Takeoff-Performance, Adverse-Weather, Meteorology, Terrestrial

Introduction

The operating challenges brought on by Nigeria's different climatic conditions affect airline operators and air transportation in Nigeria. Although, rising temperatures may require weight restrictions on 10-30% of annual flights affecting both mid-sized and large scale aircraft, yet these require adaptations in aircraft designs, schedules and runway lengths [1].

Important Nigerian airports like Murtala Muhammed International Airport (MMIA) in Lagos, Nnamdi Azikiwe International Airport (NAIA) in Abuja and Mallam Aminu Kano International (MAKIA) Airport in Kano are strategically located in several climatic zones around the country, where there are dissimilar weather conditions. Each of these airports operates under its own unique set of climatic circumstances and weather patterns that distinguished the region in which they are situated. Lagos has properties of high humidity, heavy and frequent rainfall but rather steady hot temperatures that do not dropdown significantly for most of the year. It is located in coastal southwestern Nigeria, while Abuja's tropical climate, with clearly defined dry and rainy seasons is located in the middle belt of Nigeria. Lastly, being in the northern region, Kano experiences great and severe seasonal temperature swings incorporating the harsh North East Trade wind called harmattan. The harmattan season, which is mainly distinguished by dry and dusty air that greatly lowers visibility and produces low humidity in the surroundings, affects the area and some other places as well.

Hence, air density altitude rises from high ambient temperatures, sometimes seen during the dry season and more often as a direct result of global climate change. This lowers the total lift capability as well as the thrust of the aircraft engine.

On the other hand, occurrences of heavy precipitation in the wet season create very bad runway conditions, producing wet runway surfaces that greatly reduce friction between the aircraft wheels and the runway surface. This lowers friction, improving the likelihood of hydroplaning accidents. Usually, crosswinds and tailwinds, which are occasionally associated with storms, add another layer of complexity to the launch procedure, making it riskier and more

challenging. Perhaps, the harmattan winds prevalent in northern Nigeria cause a sharp reduction in visibility and also harmfully affect engine performance by the swallowing of dust particles as foreign object debris (FOD) into the engine system.

Notwithstanding the great technical advancements seen in the domains of weather forecasting and the creation of advanced aircraft systems, Nigeria's civil aviation sector still confronts major obstacles in lowering the operational consequences caused by bad weather, especially during the crucial phases of takeoff. Further aggravated by a number of problems from the geographical contrasts that define Nigeria's varied climate, the intrinsic constraints in the constructed infrastructure and the lack of local study aimed at gauging how particular weather patterns prevalent within Nigeria affect the performance of several aircraft types are challenges to be addressed. These are also other notable consequences affecting airport operations, for instance, the results of such weather concerns further worsens the operational capabilities of airlines or airline operators with attendant effect on the economy.

Given this concerns, the interest to undertake extensive investigations, examine and evaluate the several ways in which weather patterns influence takeoff performance of different aircraft and Nigerian aviation was essential. The focus was originally on three major airports—Lagos, Abuja and Kano but can extended to cover more airports. Therefore, using weather data from the airports from 2000 - 2025 and performing data analysis to provide useful operational findings, aerodynamic properties of different types of airlines were used to formulate aerodynamic models that were employed as system models for the project.

Apart from these, in other to compare contrast and validate study, repository data which evaluates weather data for a typical Boeing 737-800 performance under the weather parameters was studied. The results obtained were designed to significantly increase flight safety, encourage decision-making for aviation activity and guide required regulatory changes within Nigeria's aviation sector so as to advance general air travel efficiency and safety in the country.

LITERATURE REVIEW

Aircraft takeoff performance is an important phase of flight that is highly sensitive to surrounding environmental conditions, particularly weather. For many years inclement weather has been a significant factor in Nigeria's aviation history, contributing to several fatal accidents over the decades. According to the international air transport association (IATA), 71% of air accidents in Nigeria are attributed primarily to poor weather conditions, alongside contributing factors such as human errors, aging aircraft and deficiencies in safety management systems [2].

One notable example is the ADC Airlines Flight 053 crash on October 29, 2006**,** which occurred shortly after takeoff from Nnamdi Azikiwe International Airport, Abuja**.** The crash was attributed to the flight crew's decision to proceed with takeoff under severe wind shear and adverse weather conditions**,** highlighting the critical impact of weather on takeoff safety. The most significant factors affecting runway performance are takeoff clearance delay, air traffic congestion, and adverse weather conditions, which can be improved through proper procedures and training [3], Nigeria is characterized by an extensive array of climatic factors that are greatly influenced by its diverse geographical composition and distinctive seasonal trends. The impact of atmospheric conditions which are temperature, wind (headwind and tailwind), rain, fog, and harmattan-induced visibility constitute impairment on aircraft takeoff performance,

For instance, the coastal regions such as Lagos are most prone to high humidity levels, in addition to regular thunderstorms and intense rainfalls. These weather conditions are most prevalent during the rainy season, which stretches from April to October every year. Thus, their conjunction gives rise to the

occurrence of wet runway conditions, resulting in reduced braking efficacy and limited visibility for pilots. Each of these elements cumulatively, impacts the safety and precision of takeoff procedures, demonstrating the challenges faced by aviation in these conditions.

In Abuja, the tropical savannah climate of the middle belt initiates periods of elevated temperatures with moderate humidity and wind variability. The elevated temperatures increase density altitude, which reduces air density and in the process, weakens engine thrust and lift, equivalent to higher required takeoff distances. These performance problems are not only technical but also logistical, normally resulting in flights being delayed or rescheduled due to inadequate runway margins in hot weather.

In the northern region of Nigeria predominantly, in the Kano region, the dry and arid climate of the Sahel introduces yet another set of complex issues that must be surmounted. For a period usually from November to February each year, the area is blanketed by dust-filled winds during the harmattan season. These winds are no trivial matter; they significantly reduce visibility to unsafe levels and can cause severe degradation in engine performance due to particulate ingestion. Moreover, the low humidity that prevails during this particular time frame alters the density of the air, which affects the production of lift as well. This alteration in air density degrades the critical performance of takeoff even further, making operations even more difficult. Climate change will lead to longer takeoff distances and lower climb rates for aircraft in the coming century, with variations among different airports [4]. Takeoff performance is controlled by several interdependent factors, including air density, thrust, aerodynamic lift, rolling resistance, and runway surface conditions. These parameters are extremely sensitive to changes in weather conditions. Increased temperatures reduce air density, requiring extended takeoff rolls; unfavorable wind components like tailwind reduce the effectiveness of acceleration; heavy rain reduces runway friction; and reduced visibility in fog or harmattan that can lead to delays, pilot workload increase, and rejected takeoffs influencing not only the aircraft's performance envelope but also operational safety margins.

Despite the fact that the global aviation industry keeps progressing and improving, constantly, powered by phenomenal enhancements in sophisticated weather forecasting systems, the utilization of real-time analysis of data and the use of automated decision support tools in Nigerian airports and airlines are presented with persistent limitations. These undermine their ability to harness the sophisticated technologies in an optimal way due to non-availability of the equipment or trained manpower. The absence of localized modeling capacities, critical in making sure weather phenomena in the local environment are precisely assessed, in addition to the seeming failure to invest heavily in weather-monitoring equipment, has been a major predicament. This has ultimately made it extremely difficult to develop and implement predictive guidelines that are specifically tailored to provide for the specific operational needs of Nigerian airports.

Similarly, it is evident that there exists a vast knowledge gap in the proper literature and industry reports that is specifically addressing and reacting to the varied ways in which local weather conditions, i.e., harmattan dust, tropical storms, high humidity, or scorching heat, influence and impact on the takeoff performance of aircraft in Nigeria. The majority of existing studies predominantly concentrate on standard international conditions or rely on simulations that fail to accurately capture the unique operational conditions encountered at airports across the African continent.

Moreover, there is a serious lack of empirical information that effectively correlates the performance of different aircraft types and prevailing weather conditions in Nigeria particularly during the critical phases of takeoff. The majority of civil aircraft operators in the country still utilize generic or

manufacturer-provided takeoff charts that are not necessarily calibrated for non-standard runway conditions, variable crosswind components, or local weather idiosyncrasies.

As a result, pilots and flight planners are often forced to make critical decisions with partial or non-contextualized information, which increases exposure to operational inefficiencies and safety risks. An intensive and detailed analysis is required to explore in detail how various specific weather parameters influence the performance of aircraft during the most critical phase of takeoff. Factors such as temperature, humidity, precipitation, wind speed and visibility are the enablers that were used to carefully correlate these weather conditions with the most significant parameters of aircraft performance, such as the acceleration, the takeoff roll distance, engine thrust and lift during takeoff.

The goal is to produce implementable conclusions which can inform and enhance aviation operations in terms of weather effects. The findings that have emerged from provided significant support for the formulation and advancement of data-driven strategies that are not only relevant to local contexts but also specifically tailored to enhance flight safety. Furthermore, these strategies aim to reduce weather-related delays that can affect travel plans, while also working to optimize the performance protocols utilized within the Nigerian civil aviation sector.



Figure 1: Boeing 737-800 aircraft is seen taking off from the runway under adverse weather conditions Copilot 2025

As Nigeria's aviation sector increases in capacity and complexity, the research into how local weather conditions influence the performance of air vehicles is more vital now than ever. While international research has extensively explored weather impacts on takeoff and landing procedures, relatively fewer investigations focus on sub-Saharan Africa, and even less on airport-specific trends in Nigerian contexts. Besides, the integration of computational modeling, especially on platforms such as Python and its libraries for visualization of performance metrics, is an unfolding frontier in localized aviation research. In order to establish both empirical and theoretical foundation for the research through exploring the principles that govern takeoff performance and weather interactions, reviewing of key meteorological parameters and their unique effects on performance, and analyzing archival records for Abuja, Lagos, and Kano airports, relevant simulation models and technologies is used in recognizing the gaps that justify the study and selection the Boeing 737-800 as a case study. The Boeing 737-800,

which is a popular narrow-body aircraft in domestic and regional air transport settings, is the case study aircraft because of its dominance in Nigerian commercial fleets. The background for its popularity produces geospatial and data-informed examination of aircraft performance to focus on actual environmental conditions in Nigeria's principal airports.

An empirical review of aircraft accidents in Nigeria from 2000–2013 revealed that technical failures, human error, and weather particularly fog, low visibility, and thunderstorms were primary causes. Lagos and Abuja had the highest accident rates, especially during takeoff and landing. The study identified poor weather reporting and lack of precision landing aids as critical factors, underscoring the operational risks posed by adverse weather and the need for improved meteorological infrastructure [5]. Using nationwide meteorological and operational data, this study found that fog, thunderstorms, and rainfall accounted for 77.8% of variance in flight disruptions, with Lagos most affected. Low visibility from fog and harmattan was the leading cause of delays, highlighting the urgent need for enhanced forecasting tools, real-time monitoring, and pilot briefings to improve aviation safety in Nigeria [6]. Focused on Port Harcourt Airport, the study showed strong correlations between thunderstorms, rainfall, fog, and operational delays, with thunderstorms having the highest impact ($r = 0.951$). Seasonal rainfall reduced visibility and runway friction, increasing takeoff distances and causing cancellations. Infrastructure gaps like poor drainage and limited forecasting capabilities worsened these effects [2].

At Abuja Airport, harmattan from December–February reduced visibility, while rainy season brought wet runway hazards, both contributing to delays. Visibility and wind direction were the most influential weather factors, with peak disruptions during mornings and evenings. The findings stress the importance of seasonal forecasting and wind vector analysis for operational planning [7].

Examining Port Harcourt Airport, the study found that rain and fog during the rainy season caused significant delays, diversions, and safety risks. Lack of modern weather monitoring systems, inadequate runway lighting, and poor drainage worsened disruptions. The work emphasizes the need for real-time monitoring and runway condition management [8].

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Analyzing multiple Nigerian airports, the study highlighted crosswinds, fog, thunderstorms, and rainfall as key hazards. Harmattan-driven crosswinds and low visibility repeatedly caused operational delays, while infrastructure and institutional shortcomings—such as inadequate navigational aids—limited mitigation. Recommendations included improved hazard forecasting and airport design adjustments for wind alignment [10].

This trend analysis of Abuja Airport (2010–2017) found harmattan to be the primary driver of cancellations, with fog and haze lowering Runway Visual Range below operational minimums. Cancellations peaked in dry months, reinforcing visibility—not precipitation—as the main disruptor. The study called for advanced landing aids and precise forecasting. [11]

Linking climate change to aviation in Abuja, the study identified rising temperatures, more frequent fog, and harmattan dust haze as growing operational challenges. Higher dry-season temperatures

reduced engine thrust and extended takeoff distances, while visibility loss caused delays. It positioned climate change as an immediate—not future—threat to aviation performance [12].

Investigating maintenance-related incidents across Nigeria, the study found deficiencies in protocols, documentation, and diagnostic tools as major causes. Weather-related factors, like corrosion and thermal stress, indirectly contributed to failures. Recommendations included predictive diagnostics and weather-aware inspection schedules to improve aircraft reliability [13].

At Lagos' Murtala Mohammed International Airport, weather especially storms and low visibility disrupted both takeoff and approach operations. The lack of automated scheduling and weather-responsive air traffic management increased delays and reduced safety margins. Integration of real-time weather data into ATC systems was recommended to improve predictability and coordination [14].

This study linked weather-related delays, holding patterns, and extended takeoff rolls to higher carbon emissions in Nigerian aviation, identifying Lagos and Abuja as emission hotspots. It recommended weather-optimized flight planning, fleet upgrades, and ground operation improvements to reduce CO_2 output while enhancing operational efficiency [15].

Examining Zanzibar's coastal tropical airport, this study found that frequent rainfall, high humidity, fog, and crosswinds significantly impair takeoff and landing performance, particularly for narrow-body jets. Wet runways and high-moisture air increased required takeoff distances and reduced thrust, while morning fog often delayed departures or caused go-arounds. The findings parallel Lagos' climatic conditions, offering practical insight into humidity-driven performance loss and the importance of early-morning fog modeling [16].

This engineering concept paper explored the potential of MagLev-assisted runways to reduce aircraft thrust needs, shorten takeoff distances, and mitigate environmental impact. While promising for hot-and-high or weather-affected airports, adoption faces challenges including infrastructure retrofitting, integration with ATC, and control under variable weather like crosswinds and low visibility. The work adds a future-technology perspective to weather-adaptive takeoff performance solutions [17].

Focusing on Greek airports, the authors showed that rising temperatures and changing wind patterns especially tailwinds force payload reductions, longer takeoff rolls, and operational restrictions, with smaller runways most affected. The study's insights are directly relevant to Kano, where high heat and limited runway length similarly constrain Boeing 737-800 operations, reinforcing the need to model runway length and weight trade-offs [18].

Using climate model projections, this Canadian study found that warmer conditions will extend takeoff distances by 150–400 meters and increase payload restrictions, especially for narrow-body aircraft. By 2070, many airports may face dozens more days each year when full-capacity takeoffs are not possible. The quantified link between temperature rise and performance loss aligns with simulation goals for hot, elevated Nigerian airports like Kano and Abuja [19].

Assessing 19 major U.S. airports, this study showed that rising temperatures will create more days when takeoff limits are exceeded, particularly for short-runway or high-elevation sites. Narrow-body aircraft like the Boeing 737 will require payload cuts, schedule changes, or fuel offloads. The emphasis on time-of-day and seasonal planning directly supports modeling strategies for Nigerian airports [20].

This global review synthesizes research on visibility loss, wind effects, precipitation, and icing, detailing how each impacts different flight phases. For takeoff, low visibility reduces RVR, tailwinds hinder acceleration, and wet runways increase roll distances. The study underscores inadequacies in forecasting and instrumentation, particularly in tropical regions validating the simulator's parameterization of visibility, wind, and surface conditions [21].

Simulating climate impacts on Boeing 737-800 takeoff performance under RCP8.5 scenarios, this study found tropical and high-elevation airports will see reduced thrust, longer takeoff distances, and more payload limits by 2050. The operational mismatch between aircraft designed for cooler climates and African airport realities highlights the importance of scenario-based modeling in the current study [22]. Using Boeing Performance Software and climate projections, this study quantified how higher temperatures nonlinearly increase takeoff roll and maximum takeoff weight restrictions, with hot-and-high airports most affected. Some sites could see dozens more weight-restricted days annually by the 2070s. These results reinforce the model's inclusion of MTOW penalties and temperature-driven feasibility limits for Nigerian case study airports [23].

Most of the world's research for examples [18], [19], [22], focus on mid-latitude or temperate regions such as Canada, Greece, or the United States, whose climatic dynamics are quite different from those in the tropics. Such simulations model increasing temperatures and wind variation but are unable to capture the operational dynamics of equatorial and semi-arid climates in cities such as Abuja, Lagos, and Kano.

Furthermore, whereas [19] and [23] examine the impacts of extreme heat and wind pattern shifts, they neglect local-scale meteorological events such as harmattan, which significantly lowers visibility throughout northern Nigeria during the dry season. Likewise, the impact of humidity on engine power and runway traction caused by rainfall, which are essential considerations in coastal cities such as Lagos, are not given much attention in global simulation research.

Apart from lack of climate-contextualized aviation models for the Nigerian airspace environment, there is absence of aircraft-focused modeling in local research. Regional and local research for instance, [2], [6], [23] has well-documented occurrence and the operational implications of inclement weather. Such instances range from delays in flight operations caused by fog in Abuja, thunderstorms in Lagos, and intense rainfall in Port Harcourt. These studies, however, adopt qualitative or correlational positions and fail to expand their focus to include aircraft-specific performance measures. This is contemporary attempt in Nigerian literature to integrate Boeing 737-800 flight performance curves under real weather conditions. This Simulation-based modeling employs programming paradigms, including Python tools, quantification of the influence of meteorological conditions on V1, Vr, or takeoff distance. It is noted that most aircraft being utilized in Nigeria's commercial aviation sector, restricts operational insight, hence, inadequate aircraft-type-specific modeling and simulation environments in Nigerian aviation research are not available. These are coupled with lack of integrated Simulation Tools and Data-Driven Models

There have been global simulation studies like [22]; [23] demonstrating the usefulness of predictive modeling with respect to climate change scenarios. These kinds of studies apply climate projections to forecast degraded aircraft performance across various time horizons. These simulation practices are lacking, however, in any of the Nigerian studies examined. While studies like [10], [11] and [24] have provided valuable empirical findings, none of these integrates the same into interactive real-time simulation platforms. There is not much use of METAR/TAF datasets in Nigerian literature either, which means that there is a gap in the real-time applicability of the studies given rise to restricted use of weather-incorporated simulation platforms for example, Python-Streamlit models for predictive takeoff analysis in Nigerian applications.

Another area is in the infrastructure and data collection constraints where several studies carried out in Nigeria such as [9], [25], underscored the infrastructural deficiencies of Nigerian airports, which include automated weather observing systems (AWOS), inadequately maintained runway friction measuring equipment, semi-digitized or non-digitized meteorological records. These result in reduced spatial

resolution and weak real-time responsiveness, which makes it hard for pilots and airlines to obtain actionable takeoff performance data that reflects prevailing weather conditions. Gap: Institutional and equipment shortages prevent the real-time relevance of existing weather-aviation research

Amongst other parameters considered are the insufficiently investigated interplay among integrated meteorological variables where studies by [6], [16] report on a number of meteorological conditions of temperature in addition to precipitation or visibility along with wind; yet, there is a lack of research on their synergistic or additive effects on takeoff performance. Under real-world situations, aircraft are faced with complex weather conditions, especially in between the wet and dry seasons in Nigeria. For instance, high temperature + tailwind + wet runway with poor visibility combined with crosswinds and decreased thrust at high altitudes. This constitutes lack of multi-variable performance modeling to represent actual operational complexity.

Based on the gaps established, the paper simulates the takeoff performance of a Boeing 737-800 in real weather conditions at Abuja, Lagos, and Kano International Airports implemented in Python and Streamlit as an interactive simulation tool that can model and estimate takeoff distance, $\frac{V_1}{V_R}$ variations, and performance margins dynamically under dynamic weather inputs. These combined the past and present meteorological information in Nigeria to confirm and demonstrate the actual application of performance modeling in flight operations addressing the combined effect of critical weather parameters including, temperature, wind (Headwind, Tailwind), precipitation, runway wetness and visibility reductions due to fog and harmattan [26].

Thus, a review of global, regional, and Nigerian literature on the impact of weather on aircraft takeoff performance identifies some interesting research gaps. Although it is established that weather conditions have a crucial bearing on aviation operations worldwide, existing literature is lacking in key respect that is in terms of localized focus. A model-based aircraft-specific focus, and application of real-time meteorological data in simulation tools with specific references to Nigeria [27].

Theoretical Background of how weather affects takeoff performance of aircraft.

Takeoff is a flight phase that is safety-critical, demanding maximum engine performance, positive lift, and adequate runway conditions to ensure safe lift-off. Takeoff procedure can be demarcated into major phases: ground roll, rotation, liftoff, and initial climb. The aircraft, during this phase, needs to accelerate from rest to takeoff decision speed $[\![(V]\!]_1)$ rotation speed (V_R) , and takeoff safety speed (V_2) within available runway length. Several parameters affect takeoff performance, such as: Engine thrust: which must overcome rolling resistance and drag, Weight of aircraft: where heavier aircraft require more runway length. Air density (ρ): which affects engine performance and lift, controlled by the Ideal Gas Law, Runway slope and surface condition: which affect friction and rolling resistance and Flap settings that affects drag and lift coefficient. Usually, Takeoff distance is computed from the balanced field length, which accounts for both takeoff acceleration and the ability to safely reject the takeoff if necessary.

The lift (L) generated is governed by the equation:

$$L = \frac{1}{2}\rho V_R^2 S C_L \qquad \textit{Equation 1}$$

Where $\rho = air\ density$, $V_R^2 = rotation\ speed$, $S = wing\ area$, $C_L = coefficient\ of\ lift$

With increasing temperature or decreasing pressure, air density decreases, therefore higher speeds and longer distances are required to generate adequate lift. This is one of the key mechanisms through which

weather impacts takeoff performance. Since takeoff demands maximum engine performance, positive lift, and adequate runway conditions to ensure safe lift-off, the procedure are demarcated into major phases; ground roll, rotation, liftoff and initial climb. This is a flight phase that is safety-critical, hence, aircraft, during this phase, needs to accelerate from rest to takeoff decision speed $[\![(V]\!]_1)$ rotation speed (V_R) , and takeoff safety speed (V_2) within available runway length.

Table 1: Typical Aircraft Performance Parameters (Boeing 737-800)

S/No	Key specifications for takeoff Parameters considered for Boeing 737-800	
1..	Maximum Takeoff Weight (MTOW) ~	79,000 kg
2.	Takeoff field length at MTOW	(ISA, sea level): ~2,600 meters
3.	Engines:	Two CFM56-7B engines
4.	Normal rotation speed V_R	~140–155 knots (≈ 72–80 m/s), depending on weight
5.	Wing area (S)	~124.6 m²
6	Flap setting: for compromises in performance	Generally 5°–15° during takeoff

Sources: Sources: (737 Airplane Characteristics for Airport Planning Boeing Commercial Airplanes, n.d.; 737-800BCF BOEING CONVERTED FREIGHTER, n.d.) [35]

Looking at the next generation family of planes, the best-selling planes utilized in commercial flights and local fleet in the Nigerian airports are the Boeing 737 series. It is well known for being fuel-efficient and reliable, therefore, an ideal model to study from a performance point of view.it is established that takeoff performance charts of the aircraft are functions of altitude, ambient temperature, runway condition, and wind components. This may seriously deteriorate in hot and high conditions such as that of Kano airport in Northern Nigeria [28]. In fact, the interaction of weather with takeoff performance is extensively discussed in aerodynamics and aircraft theory of operations. Major variables are presented as summarized in Table 2

Table 2: Weather-Performance Interaction Principles

S/No	Weather-Performance Interaction Principles	
1.	Temperature	Temperature increase reduces air density (high-density altitude), reducing engine thrust and lift. This increases the takeoff distance and reduces climb performance.
2.	Wind Components:	
3.	Headwind	improves takeoff performance by having greater relative airspeed at lower ground speed.
4.	Tailwind	deteriorates performance, requiring longer acceleration times and distances.
5.	Precipitation and Runway Condition	Rain decreases runway friction and may lead to hydroplaning. Wet or contaminated runways decrease ground roll distance as a result of decreased braking and traction.
6	Visibility Fog or harmattan dust	creating poor visibility leads to delay departures and increases the requirement for instrument-based takeoff procedures.
7.	Pressure Altitude	Lower barometric pressure simulates a higher altitude (density altitude), i.e., adversely affects performance.

These weather events are more complex in tropical nations such as Nigeria, characterized by extreme fluctuations of weather seasonally effects such as harmattan causing special operating issues not typically experienced under temperate weathers. For instance, reduced visibility caused by harmattan has aerodynamic and procedural impacts, typically leading to increased minimums of takeoff visibility and increased taxi time. These principles are essential in knowing and simulating real flight behavior of aircraft within Nigerian weather conditions. It also assisted in facilitating the modeling and simulations of the research work done using Python and its libraries.

Critical Weather Parameters Influencing Takeoff

Weather significantly influences the aerodynamics, engine thrust production, brake capability, and decision-making circumstances during takeoff. Thus, in Nigeria, the combined effects of tropical heat, seasonal wind, heavy rain, harmattan haze, and airport microclimates present unique operational issues. For instance, each critical weather parameter and its effect on aircraft takeoff, particularly for the Boeing 737-800 are discussed as follows;

Impact of Temperature on Takeoff Dynamics

Temperature is among the primary drivers of air density, and consequently, aircraft takeoff performance. As ambient temperature increases, air density decreases (smaller air mass per volume), leading to a high-density altitude phenomenon, even at low-elevation airports. [17]. Temperature can rise up to 35–40°C in the daytime in Nigeria, particularly in Kano, which is already located in a hot, dry region. For the Boeing 737-800. Lower air density means lower engine power and lift. More runway length is needed to reach rotation speed. The aircraft requires greater true airspeed to produce adequate lift. Experiments have shown that for every 10°C rise above International Standard Atmosphere (ISA), the takeoff distance will be 5–10% greater, depending on aircraft weight and type. The operational implications are that the airlines may be forced to unload payload (passengers or cargo) or make takeoff at cooler hours (morning or evening) in Abuja and Kano during peak dry season (February–April).

Headwind and Tailwind effects on aircraft acceleration show that wind speed and direction are imperative at takeoff since they directly impact ground speed and lift generation. A headwind contributes to lift and increases the relative airspeed without adding more ground speed. A tailwind, on the other hand, detracts from effective airspeed, thus: demanding higher ground speed for liftoff, increasing takeoff roll distance and decreasing climb gradient soon after takeoff is experience. The Boeing 737-800 flight manual recommends against departure in tailwinds greater than 10 knots (5.144 m/s), especially on wet runways or at maximum gross weight.

In the Nigerian situation, Lagos usually has sea breezes, with changing wind conditions, affecting runway selection, Abuja has relatively more constant headwind conditions due to its elevation and geography and Kano may have sudden changes in wind during harmattan. The accurate wind information at the runway threshold is essential, but Nigerian airports typically lack real-time AWOS. Also under the influence of precipitation on runway friction, rain affects takeoff performance indirectly by modifying the condition of the runway surface. The primary mechanisms are reduced braking performance and traction, increased likelihood of hydroplaning especially, if drainage on the runway is inadequate and incremental requirement for greater V_1 decision margin under precipitation conditions [29]. For Boeing 737-800, wet or contaminated runway takeoff charts provide 15–20% increased takeoff distance in moderate-to-heavy rain.

Weather perspectives in the different regions

In Lagos Airport, Lagos sees over 2000 mm of rainfall annually with frequent wet runway operations. Runway friction testing and grooving are normally poor. Abuja and Kano Airports see relatively shorter wet seasons but are still impacted by rainfall in transition periods from April–June, and September–October respectively.

So under visibility challenges, fog and harmattan impact. Visibility plays a dual role in pilot situation awareness and in prompting instrument takeoff operations. Fog usually in Lagos and harmattan haze severely in Kano and periodic in Abuja reduce runway visual range (RVR) to dangerous levels. The ICAO minimum RVR for Boeing 737-800 CAT I takeoff: ~550 meters, harmattan may reduce RVR to <300 meters across several days and fog affects decision speed, visibility cues, and impacts rejected takeoff situations. In fact, Low visibility affects aircraft physics indirectly but increases pilot decision-making difficulty, stress, and risk. The mitigation measures are in the instrument runway systems, the instrument landing system (ILS) and runway centerline lighting. These are critical but not consistently present at Nigerian airports. Also, the inadequate maintenance of weather sensors leads to inaccurate reporting of visibility.

Thus, the interplay between combined weather factors increases the effects such that the interaction of high temperature, tailwinds, precipitation, and low visibility can both be additive and multiplicative. For instance, High temperature + tailwind = significantly longer takeoff roll, Rain + tailwind = high hydroplaning risk + long roll, Harmattan haze + heat = performance + decision complexity degradation. Therefore, case scenarios must consider real-time interactions among these variables to accurately forecast performance [30].

In the Python and Streamlit simulation model, using real NASA POWER and METAR/TAF data revealed compound scenarios such as:

Wet runway + +10°C ISA deviation + 8-knot tailwind → Can outperform the 737-800 certified takeoff field length in Lagos in the wet season

METHODOLOGY

The research follows a hybrid strategy in blending a simulation-based approach in modeling the dynamics of aircraft performance under environmental conditions through Python and its libraries, coupled with statistical procedures for empirical trend analysis.

Due to the safety and operations-critical nature of takeoff performance, especially with the increasing variability in weather from climate change, the research takes a hybrid approach. The simulation model, as customized for the Boeing 737-800, incorporates the aerodynamics and vulnerability of airplanes' performance to the main weather factors of temperature, wind, precipitation, and visibility. The model dynamically computes takeoff roll distance, acceleration, and thrust efficiency with regards to various real-world situations using user-specified input and batch processing of structured data sets.

Thus, the research applies quantitative statistical techniques, using, time series and correlation analysis, to analyze the past trends and seasonality of weather factors and their operational effects. Through the integration of computational simulation and data-driven analysis, the approach guarantees predictive ability and empirical soundness.

This is structured in ten sections starting with the study area description and research design, data sources, variables, model development, simulation setup, and statistical methods. Validation procedures and methodological limitations are also discussed to provide transparency and reproducibility of the research.

For aircraft performance Simulation, a computational model of a Boeing 737-800 is implemented in Python and exposed via a Streamlit web interface. The model calculates key takeoff performance measures takeoff roll distance, acceleration, and thrust against variable environmental conditions. It takes dynamic weather conditions as input in the form of ambient temperature, headwind/tailwind, runway friction as a function of surface condition, and airport elevation. Thus, complementing the simulation is a statistical data analysis module that applies descriptive statistics, time series decomposition, and correlation analysis to historical weather and flight operations data. The two-fold approach provides both scenario-based forecasts as well as empirical validation, allowing for a comprehensive understanding of the weather–performance relationship.

The case study methods enable location-specific modeling of Lagos, Abuja, and Kano according to their respective climate profiles and operational characteristics. The simulation tool is modeled after realistic takeoff scenarios with user-definable inputs, and supports single-scenario and batch-mode analysis through CSV files.

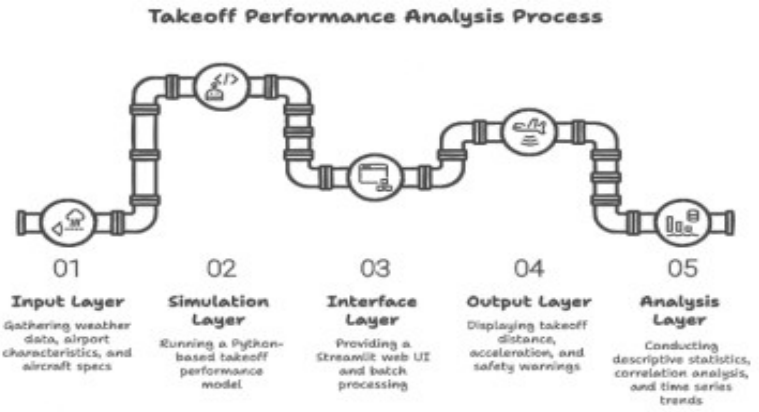


Figure 2: Takeoff Performance analysis schematic illustration for this research work

Three of Nigeria's most significant commercial airports are used for the study: Murtala Mohammed International Airport (Lagos), Nnamdi Azikiwe International Airport (Abuja), and Mallam Aminu Kano International Airport (Kano). The airports were selected due to their high frequencies of domestic and international flights, the peculiar climatic zones in which they are situated, and the spectrum of environmental conditions influencing aircraft takeoff performance. Every site is a unique combination of elevation, prevailing weather conditions, and infrastructure, which makes them perfect for comparative modeling and simulation

.

Murtala Mohammed International Airport, Lagos (DNMM)

The Murtala Mohammed International Airport is Nigeria's most congested and complicated air traffic hub. It is located at approximately 6.577°N latitude and 3.322°E longitude and it is at a low elevation of 41 meters above sea level (ASL).in the southwestern coastal part of Nigeria. Lagos has a tropical monsoon climate with high humidity, frequent rain, and coastal winds. The prolonged rainy season from March to July, with maxima in May–June creates wet runway conditions and poor visibility, which are major contributors to takeoff degradation. Fog, though less frequent than harmattan, does occur on early mornings. Two principal runways 18R/36L and 18L/36R exist at the airport, with a main operational length of over 3,900 meters, so, it is structurally capable but operationally weather-challenged.



Figure 2: Satellite Image of Lagos Airport. Accessed June 6, 2025. Google Maps [31].

Nnamdi Azikiwe International Airport, Abuja (DNAA)

The Abuja airport, located in Nigeria's central region at coordinates 9.006°N and 7.263°E, sits about 344 meters ASL. It ranks as the country's second busiest airport, serving a vital role in both domestic and international flights. The city experiences a tropical savannah climate with clearly defined wet and dry seasons. The harmattan period, typically between December and February, poses significant challenges for flight operations due to dusty haze, reduced visibility, and occasional crosswinds. During this time, the runway visual range (RVR) often drops below acceptable limits, leading to frequent flight delays and cancellations. The airport operates with a single main runway (04/22), which stretches 3,600 meters, sufficient in length, but performance can be affected during hot afternoons due to lower air density at elevation.



Figure 3: Satellite Image of Abuja Airport. Accessed June 6, 2025. Google Maps [31].

Mallam Aminu Kano International Airport, Kano (DNKN)

This airport is located in the northern Sahelian region of Nigeria, the Kano airport is found at 12.047°N latitude and 8.524°E longitude, and its elevation is about 481 meters ASL, the highest among the three study locations. Kano is exposed to semi-arid climatic conditions, very high daytime temperatures, severe seasonal winds, and low atmospheric pressure, all of which are causes of density altitude problems. The harmattan season brings very dusty winds that significantly reduce visibility. The environmental factors have a critical effect on engine thrust and takeoff performance, especially for narrow-body aircraft like the Boeing 737-800. The primary runway (06/24) is 3,000 meters long and might pose operational risks in hot-and-high conditions.



Figure 4: Satellite Image of Kano Airport. Accessed June 6, 2025. Google Maps [31].

Data Sources and Collection Methods

The data sources, methods, and preprocessing involve gathering and preparing the data to be used in simulating the impact of weather parameters on aircraft takeoff performance in Nigeria. It relied on both meteorological data sets and aircraft performance specifications, aided by customized rationale for friction and visibility inference. The meteorological data capture the diverse weather conditions at the three Nigeria's major airports of Abuja, Lagos, and Kano on daily weather data spanning from 2020 to 2025. These was retrieved using the Meteostat Python library. The tool offers structured and programmed access to worldwide weather station archives, enabling consistent, automated, and repeatable data extraction for long-term performance simulations. Basically, use of public or repository and open-source data was adopted so, all datasets used in this study are the meteorological records, airport infrastructure data, and aircraft performance parameters sourced primarily from publicly accessible platforms such as Meteostat Python Library for historical weather data, OpenAIP and OurAirports for airport elevation and runway details, Boeing open-source aircraft documentation for performance benchmarks, Streamlit, Plotly, NumPy, and Pandas for simulation logic and visualization. Each of these sources is cited appropriately, and no proprietary or restricted datasets were accessed. Thus, the retrieval process was done using the following command prompt:

I. The Stations().nearby() function identified the most relevant high-resolution weather station for each airport location.
II. The Daily class was used to download critical daily weather variables, including:
   - ✓ Average temperature (°C)
   - ✓ Precipitation (mm)
   - ✓ Relative humidity (%)
   - ✓ Wind speed (km/h)

In using fog detection technique to better simulate real-life challenges like low visibility during the harmattan, especially, in northern airports like Kano and Abuja, the study incorporated a simple but effective heuristic method to tag foggy days. A day was considered fog-affected if all of the following conditions were met:

- ✓ Relative humidity of 95% or more
- ✓ Average daily temperature at or below 20 °C
- ✓ Wind speeds not exceeding 10.8 km/h (equivalent to 3 m/s)

This approach ensures that the takeoff model accurately reflects poor visibility events, enhancing the realism of simulation outputs.

In order to estimate runway friction (μ) since friction between the aircraft tires and the runway plays a crucial role in takeoff acceleration, a custom logic was implemented to assign estimated friction coefficients based on prevailing weather conditions:

Table 3 designated and assigned friction coefficients

Weather Condition	Assigned Friction Coefficient (μ)
Fog	0.30
Rainfall	0.50
Clear/Dry	0.75

These values were factored into the simulation's rolling resistance calculations to reflect real-world surface conditions that could impact takeoff distance and safety margins.

Meanwhile, the data formatting and standardization involves consistency and clarity across all datasets so, wind speed data was converted from km/h to m/s. All precipitation was standardized in millimeters. Friction values were rounded to two decimal places for modeling accuracy. These cleaned and organized datasets were saved in CSV format for each airport. In terms of the aircraft type, the Boeing 737-800 was selected as the benchmark aircraft for this simulation, given its widespread use across Nigerian domestic and regional routes. To accurately, model its performance under varying weather conditions, the study referenced official performance specifications from authoritative sources such as Boeing aircraft performance manuals, International civil aviation organization (ICAO) and Federal aviation administration (FAA) aircraft performance and characteristics databases. The key performance inputs integrated into the simulation include maximum takeoff weight (MTOW), wing surface area and aerodynamic lift coefficients. Others are engine thrust values under both standard and derived power settings, Rotation speed (V_R) and initial climb gradients as well as required ground roll distance and airborne segment length. These parameters enabled dynamic modeling of how environmental changes affect thrust, lift, and overall takeoff performance.

Similarly, to contextualize aircraft performance within specific operational environments, detailed information was gathered for the runway infrastructure and elevation characteristics of each airport. Airport infrastructure data sources included; the federal airports authority of Nigeria (FAAN), Jeppesen airport charts widely used for flight planning and navigation as well as Open-access aviation and geographic platforms like OpenAIP and OurAirports. These information are essential to simulate the impact of elevation on air density i.e., density altitude adjustments and also evaluate whether runway lengths were sufficient under varying environmental stressors incorporating real-world runway orientations and surface conditions into the takeoff model.

Perhaps, variables and parameters used were defined and categorized into independent variables as environment/input factors and dependent variables as aircraft performance outcomes. The variable's interactions form the basis for the models, in the simulation and statistical analyses of the impact of weather on takeoff performance of aircraft. The independent variables that is the input variables that represent environmental and aircraft operational conditions at the time of takeoff are summarized as follows in Table 4

Table 4 Summary of independent variables as inputs

Variable	Unit	Description
Ambient Temperature (T)	°C	Affects air density and engine thrust. High temperatures reduce lift and increase takeoff distance.
Wind Component	m/s	Positive = headwind; Negative = tailwind. Headwind reduces ground roll; tailwind increases it.
Airport Elevation	meters	Influences air pressure and density; higher elevations reduce engine performance and lift.
Runway Surface Condition	Categorical (Dry, Wet, Contaminated)	Determines the rolling resistance coefficient (μ), affecting acceleration.
Relative Humidity	%	Used to detect fog when ≥ 95%. Impacts visibility and may influence thrust if high moisture content.
Visibility / Fog Indicator	Binary (0 = Clear, 1 = Foggy)	Derived from humidity, wind, and temperature; used to adjust runway friction.
Precipitation	mm/day	Affects surface condition and rolling resistance (μ). Used to detect wet or contaminated runways.
Throttle Setting	%	Pilot-determined engine power during takeoff (modeled from 70% to 100%). Impacts available thrust.

These inputs are controlled either via the Streamlit interface or batch CSV inputs for multi-scenario simulations, however, some variables were computed using formulas based on the above inputs as derived or processed variables. These are represented in Table 5.

Table 5 Derived / Processed Variables as inputs

Variable	Unit	Description
Air Density (ρ)	kg/m^3	Calculated using the barometric formula and temperature; essential for lift and drag computation.
Pressure at Altitude	Pa	Determines the density altitude condition.
Runway Friction Coefficient (μ)	Unitless	Derived from weather data; affects rolling resistance. Adjusted for rain, fog, or dry conditions.

Similarly the dependent variables as takeoff performance outputs were generated by the simulation model based on the environmental conditions as the outcome variables. This is shown in Table 6

Table 6 Dependent variables as takeoff performance outputs

Variable	Unit	Description
Takeoff Ground Roll Distance (S_{GR})	meters	Distance required to reach rotation speed (VR) during the takeoff roll.
Airborne Distance (S_{air})	meters	Distance required to reach the regulatory climb height of 35 ft (10.67 m).
Total Takeoff Distance (S_{total})	meters	Combined ground roll and airborne distance, adjusted by a safety factor.
Percentage of Runway Used	%	Ratio of required ground roll to available runway length. Critical for operational feasibility.
Acceleration During Roll	m/s^2	Derived from thrust, drag, and friction forces; determines how fast aircraft reaches VR.
Time to Rotation Speed	seconds	Indicates time needed to reach (V_R) from rest.
Thrust Available	Newtons	Net engine thrust corrected for temperature and throttle setting.
Warning Flag	Boolean	Triggered when total takeoff distance exceeds runway length or uses ≥ 90% of available length.

These variables form the computational core of your model and are also used in your statistical analysis to assess correlations and performance trends under different weather conditions.

Model Development and Simulation Framework

The development and Simulation Framework started with mathematical foundations, software development, user interface, and scenario configuration of the Boeing 737-800 simulation model. The simulation solver was developed in Python and served as an interactive web application using Streamlit. The model was designed to calculate important takeoff performance parameters such as ground roll, airborne distance, and acceleration under various weather conditions and airport configurations. These require modeling equations and assumptions.

Modeling Equations and Assumptions

The model is built on classical equations of aircraft performance, especially focusing on takeoff roll and airborne distance. The following are the core computations:

In atmospheric calculations, the ambient temperature of the existing environment at the airport, the pressure differences are expressed as shown in Equations 2, 3 and 4

$T_{Kelvin} = 273.15 + T_{Celsius}$ …… *Equation 2*

Where T_{Kelvin} is temperature in degrees Kelvin and $T_{Celsius}$ is outside air temperature in degrees Celsius. From here the density equation can be expressed as

$\rho = 101325 \,.\, (1 - \frac{0.0065 \,.\, h}{T_{Kelvin}})^{5.2561}$ …… *Equation 3*

Where ρ is Air density in kg/m^3 and p is the prevailing atmospheric or air pressure in $Pascals\ (Pa)$

$\rho = \frac{p}{287.05 \,.\, T_{Kelvin}}$ …… *Equation 4*

In terms of aerodynamic forces at $Rotation\ speed$ V_R in(m/s) , the lift and drag coefficients are expressed as Equations 5 and 6

$l = \frac{1}{2}\rho V_R^2 C_L S_{wing}$ …… *Equation 5*

Where l is lift force in (N) , ρ is density, V_R^2 rotation speed, C_L lift coefficient and S_{wing} is wing reference area in (m^2).

$D = \frac{1}{2}\rho V_R^2 C_D S_{wing}$ …… *Equation 6*

Where D is drag force in (N) , ρ is density, V_R^2 rotation speed squared, C_D drag coefficient and S_{wing} is wing reference area at (m^2) . The rolling resistance (F_R) is expressed as;

$F_R = \mu.(M_{TOW} \,.\, g - L)$ …… *Equation 7*

Where F_R is the rolling resistance, μ is the coefficient of rolling resistance, M_{TOW} is the maximum takeoff weight in(kg) , g is the gravitational acceleration approximately $9.80665m/s\text{^}2$.

In the buildup, Thrust setting with temperature correction is determined and can be expressed as;

$temp_{correction} = max\,(0, T_{Celsius} - 15)\ .0.003$ …… *Equation 8*

$Thrust = T_{max} \,.\, (1 - temp_{correction}) \,.\, throttle_{setting}$ …. *Equation 9*

The Acceleration (a) is expressed as a function of the thrust setting as;

$a = \frac{Thrust - D - F_R}{M_{TOW}}$ …… *Equation 10*

Thus, the Ground speed relative to ground and the Ground roll are expressed. The ground speed as;

$V_{ground} = V_R - V_{wind}$ …… *Equation 11*

V_{ground} is the speed relative to the runway surface at rotation in (m/s) , V_{wind} is the headwind or tailwind component in $(m/s); positive\ if\ headwind$.

For the Ground Roll Distance (S_{GR}) the boundary conditions are taken to satisfy the modelling performance involving (a) Average net acceleration along the runway in (m/s^2) as;

$if\ a > 0\ and\ V_{ground} > 0:$ …… *Equation 12*

$S_{GR} = \frac{V_{ground}^2}{2A}$ …… *Equation 13*

Where S_{GR} is the Ground roll distance in (m) . Hence,

$V_{ground} = V_R - Wind\ component$

…… *Equation 14*

Else:

$S_{GR} = \infty$ …… *Equation 15*

Based on these analysis, the takeoff time is considered to be;

Takeoff time $t_{TO} = \frac{V_{ground}}{a}$ …… *Equation 16*

t_{TO} is the time from brake release to rotation in (s)

The airborne distance (S_{air}) is set as shown in equation 17

$S_{air} = \frac{H_{target}}{Climb\ Gradient}$ …… *Equation 17*

In this equation 17, H_{target} is the target or clearance height. The Total Takeoff Distance (S_{total}) is therefore computed as;

$S_{total} = (S_{GR} + S_{air}) . Safety\ Factor$

…… *Equation 18*

Thus, the runway usage percentage was calculated as;

$\%_{runway\ used} = \frac{S_{GR}}{Runway\ Length} . 100$ …… *Equation 19*

The Python-Based Model Simulation Engine accepts either user-defined inputs or batch inputs for multiple scenario testing. It dynamically adjusts takeoff performance outputs based on real-world environmental conditions and pilot-selected parameters like throttle setting. The Streamlit Web interface integration provided the graphical interface that allows real-time input of temperature, wind, elevation surface condition (dry/wet/contaminated), throttle setting, aircraft weight, and safety factor.

Graphical plotting of temperature vs takeoff distance and many other results were achieved. These are shown in Figures 5 and 6.



Figure 5 UI Diagram of Streamlit App

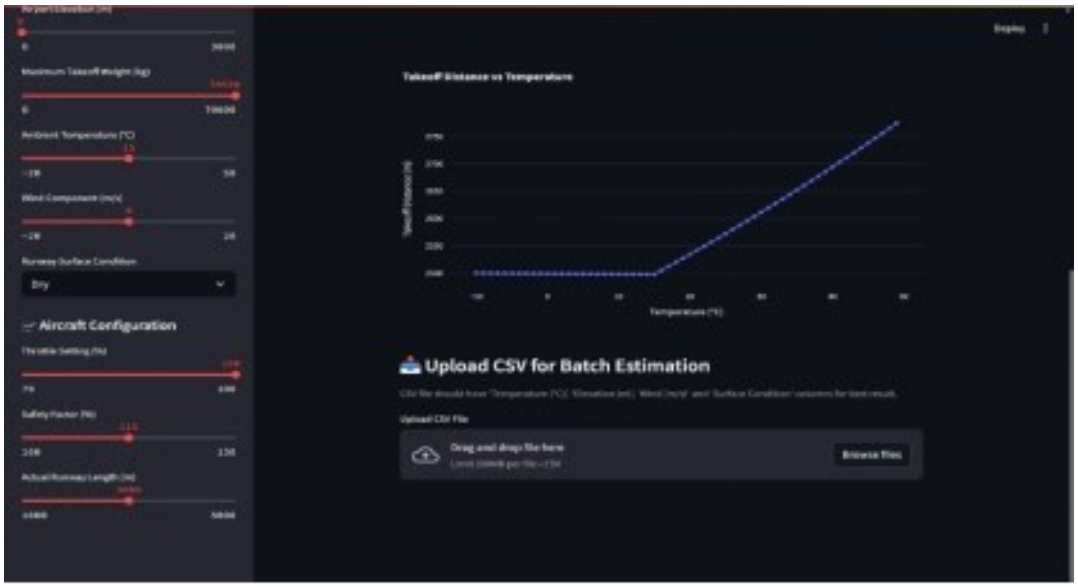


Figure 6 UI Diagram of Streamlit App for CSV Batch

Typical Simulation Configurations

The three airports were modeled using their real-world, elevations, runway lengths, typical weather conditions as captured in their datasets. Multiple weather scenarios are simulated, including hot day operations from 30–37°C, harmattan with mornings low visibility, low wind, low temp and rainy conditions with friction degradation, tailwind versus headwind takeoff comparison to replicate operational behavior of the Boeing 737-800 under conditions commonly encountered at Nigerian

airports. Therefore the statistical analyses provide empirical grounding for the simulation outcomes and identify key weather-related variables that impact aircraft operability and safety based on 6,000 observations. Key measurement indicators extracted included measures of central tendency and dispersion such as minimum, mean, maximum, and standard deviation values for parameters like temperature, air density, wind component, runway friction coefficient (μ), acceleration, ground roll distance, and total takeoff distance.

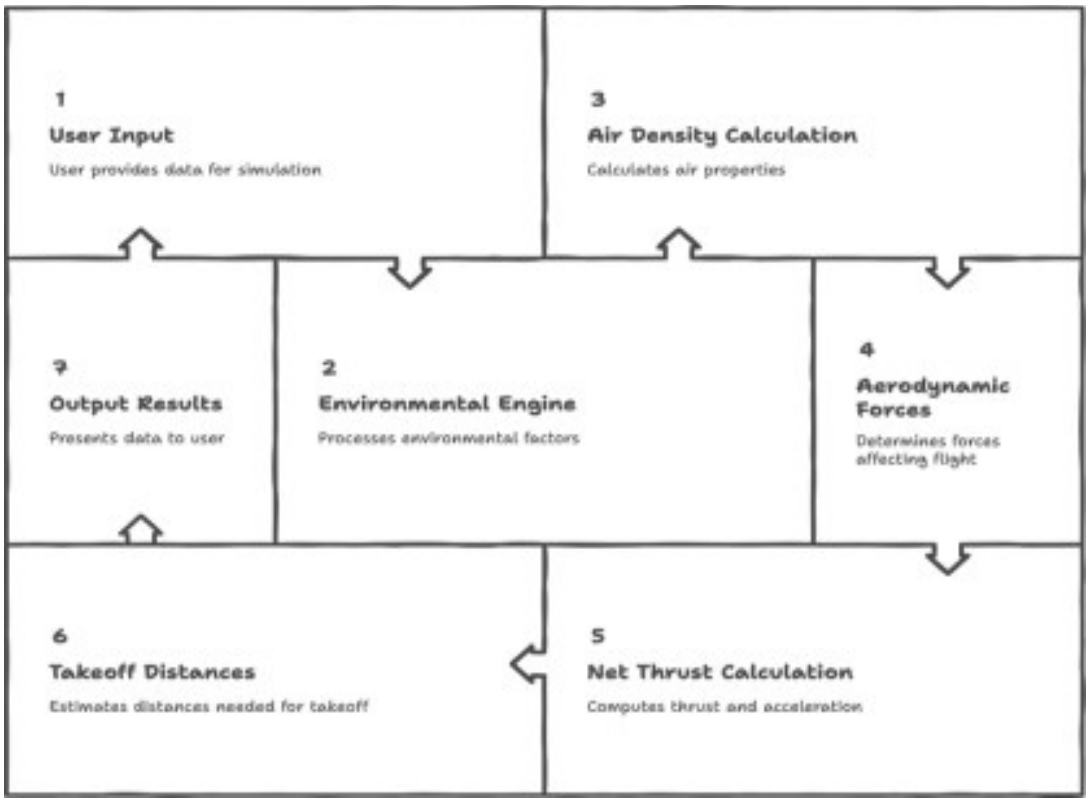


Figure 7.The Boeing 737-800 Takeoff Performance Estimator/Simulator Model Logic and Simulation Cycle

On the other hand, grouped statistics by location included airport-specific summaries that allowed comparisons between Lagos (coastal, rainy), Abuja (central, moderate elevation) and Kano (northern, high elevation and arid conditions. Thus, Pearson correlation analysis was used to explore statistical relationships between environmental inputs and takeoff performance metrics where the strongest and most relevant relationships observed included Temperature vs. Thrust with strong negative correlation of approximate –1.000. This shows how higher ambient temperature reduces engine thrust output.

Figure 8 Temperature vs thrust with negative correlation.
Also moderate negative correlation of approximately –0.49, indicating performance degradation under wet or foggy runway conditions shows friction coefficient vs. acceleration.
The acceleration vs. ground roll distance gave strong inverse correlation of about –0.92, confirming that higher acceleration results in shorter takeoff rolls. Hence a correlation matrix and heat map were generated to visualize and interpret the inter-variable dependencies from where Time series analysis

was used to explore temperature, friction, and takeoff distances over the 5-year period was carried out using line graphs and seasonal grouping. The monthly and annual patterns revealed harmattan dips in temperature in Kano during December–February, seasonal friction reductions in Lagos during the rainy months of May–August and peaks in takeoff roll during the hottest months of March–May. These patterns informed recommendations for operational scheduling and highlighted risk-prone periods requiring mitigation [33].

Rather than using multivariate regression, a scenario profiling approach was applied known as scenario-based group analysis. Here grouped data by friction category for example dry, wet, foggy and wind type involving headwind or tailwind as well as mean takeoff roll and acceleration values were calculated under each grouped condition. This allowed the creation of profiles such as "Wet + Tailwind = Longest Ground Roll" and "Dry + Headwind = Optimal Takeoff" that a non-parametric grouping technique was chosen due to the categorical nature of runway surfaces and wind direction variables.

Testing and Validation

The baseline consistency of the model was initially tested under international standard atmospheric (ISA) conditions of 15°C at sea level, dry runway, no wind, MTOW = 65,000 kg full throttle. The outputs rotation speed (V_R) with thrust of approximately 121,000 N and takeoff distance which fell within ±5% of Boeing's published data was validated with Boeing 737-800 Performance Data. These validated the accuracy of performance equations and aerodynamic assumptions. It also ensure the credibility and robustness of the takeoff simulation model built where, several layers of validation were applied. The model integrates theoretical aerodynamic calculations with empirical weather inputs and benchmarked against known aircraft performance standards.

To ensure more model predictions, empirical weather and airport data comparison were qualitatively compared with typical weather patterns and known operational challenges like fog and low visibility in Kano and Abuja during harmattan where modeled friction and acceleration values were low. Heavy rainfall in Lagos: correlated with the lowest average runway friction and longest ground roll values while high afternoon temperatures in Kano led to reduced thrust and increased takeoff distance given enhance confidence in the model's situational realism and predictive utility [32].

Apart from these, sensitivity testing or checks were conducted to evaluate the response of takeoff performance to key input changes like temperature increase from 15°C to 35°C which resulted in drop in air density and thrust increase in takeoff distance. There was also wind reversal (headwind → tailwind) that increased ground roll by up to 20%. On friction drop test that is from dry to wet, reduced acceleration and extended ground roll by over 200 meters in some cases were observed confirming the physical reality and stability of the simulation under various operational envelopes.

Validation with safety margins were achieved by simulation outputs under different operational configurations like full payload vs. derated thrust settings 100% vs. 130% regulatory safety margins. The results showed consistent warnings when takeoff distance exceeded runway availability, and predicted performance scaled appropriately with operational constraints.

RESULTS ANALYSIS AND DISCUSSIONS

Temperature showed clear geographic and seasonal differences across the three airports. Lagos, located in the humid tropical zone, consistently recorded the highest average temperatures (26.76 °C), while Kano, situated in the semi-arid north, had the widest range of temperatures with peaks up to 35.18 °C and lows of 13.18 °C. Abuja exhibited moderate temperature variability, with values ranging from

20.61 °C to 32.97 °C. Higher temperatures were associated with lower air density, thereby reducing both lift and engine thrust. This directly impacted the aircraft's ability to accelerate, resulting in longer takeoff distances.

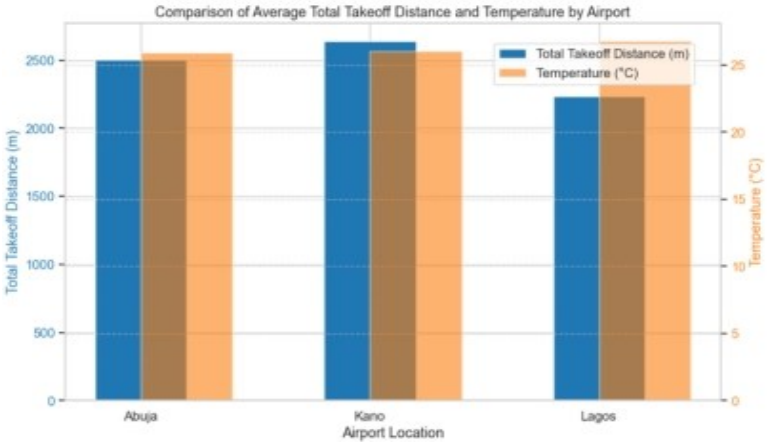


Figure 9 comparing average total takeoff distance and temperature across Lagos, Abuja, and Kano

The analysis further disaggregated takeoff performance into dry and rainy seasons. Interestingly, some airports performed marginally better during the rainy season, which is counterintuitive until air density is factored in. This is as shown in Figure 10.

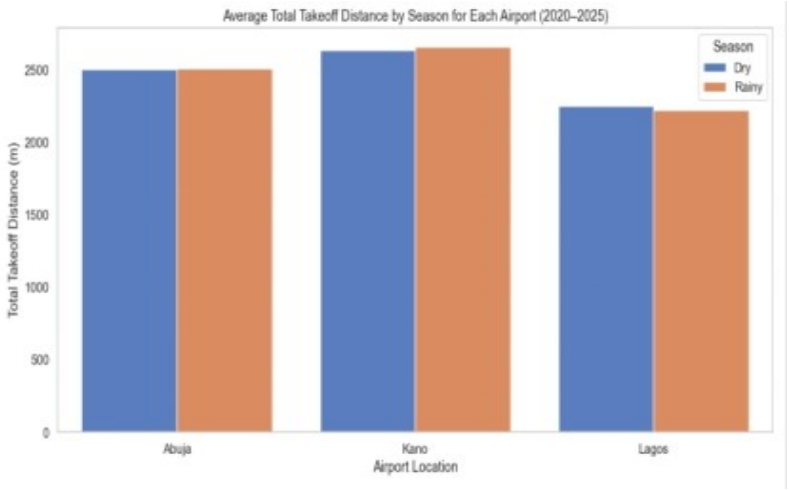


Figure 10 Total Takeoff Distance by Season for each airport

The results show that Kano poses the highest thermal risk for takeoff performance, especially during the rainy season when temperatures peak and air density drops sharply. Lagos on the other hand, is the least affected by thermal conditions, owing to sea-level elevation and humidity stabilizing air density. However, Abuja falls in between, but operational caution is still necessary in the hot season as from March–May. The implication of this temperature-linked is significant for Nigerian flight operations in that morning or evening departures should be prioritized during peak-heat months in Kano and Abuja. Therefore, airlines and dispatchers should enforce derated takeoff weight policies when ambient temperatures exceed 30 °C.

For runway extension planning in Kano, this may be required if full-load takeoffs are expected under hotter climate projections. Thus, weather-aware takeoff briefings and seasonal performance charts should be adopted to replace generalized original equipment manufacturer (OEM) charts that do not reflect local conditions.

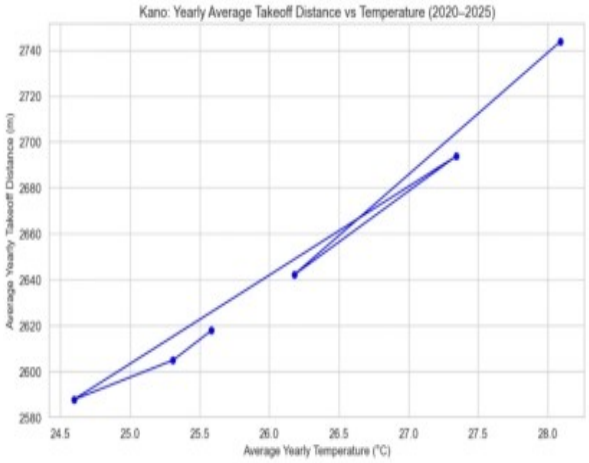


Figure 11Takeoff Distance vs. Temperature for Kano airport to show linear increase.

On how wind influences acceleration and ground roll distance under conventional takeoff runway orientation at the three selected Nigerian airports in the simulation, takeoffs were modeled assuming the airports' standard runway orientation (i.e., without dynamically rotating to align with wind), reflecting common real-world operational settings. In practice, runway direction may be changed to optimize for wind, this controlled simulation helps isolate the inherent effects of prevailing wind profiles at each location.

The data obtained show that Lagos enjoys a consistent headwind advantage with the strongest headwind of +1.33 m/s, had the shortest average ground roll and highest acceleration that highlights the aerodynamic benefit of opposing wind.

Kano has light average headwinds despite a small headwind of +0.28 m/s, experienced the longest takeoff roll, due to compounded effects of lower air density and lower acceleration. While Abuja which consistently faces mild tailwinds of −0.24 m/s on average, had longer ground roll than Lagos and slightly reduced acceleration. These conditions provide the basis for comparing wind-induced performance effects

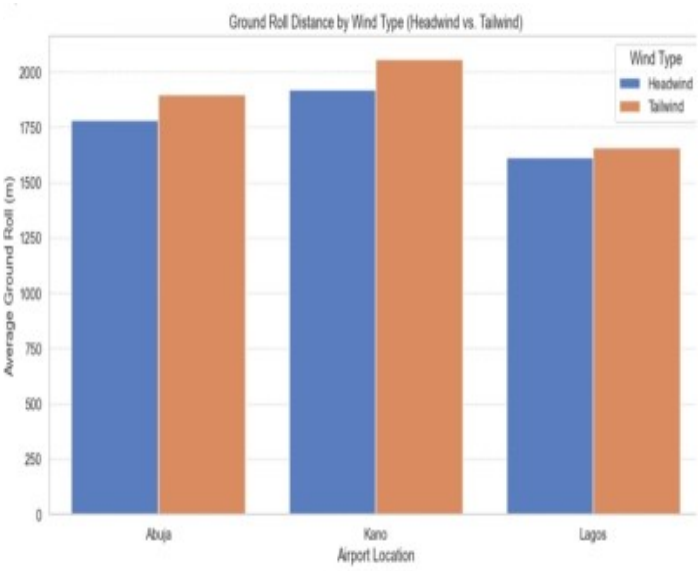


Figure 12 Average Ground Roll Distance vs. Wind Condition (Headwind/Tailwind) for Abuja, Kano, Lagos.

A line plot generated for each airport demonstrated that as the wind shifts from tailwind to headwind the relationship between wind component and takeoff distance in the wind-speed sensitivity and performance curve is further visualize. Here the ground roll distance decreases linearly while the acceleration improves steadily, proving that

headwinds help generate lift earlier and reduce takeoff run length, while tailwinds delay lift-off speed and increase distance.

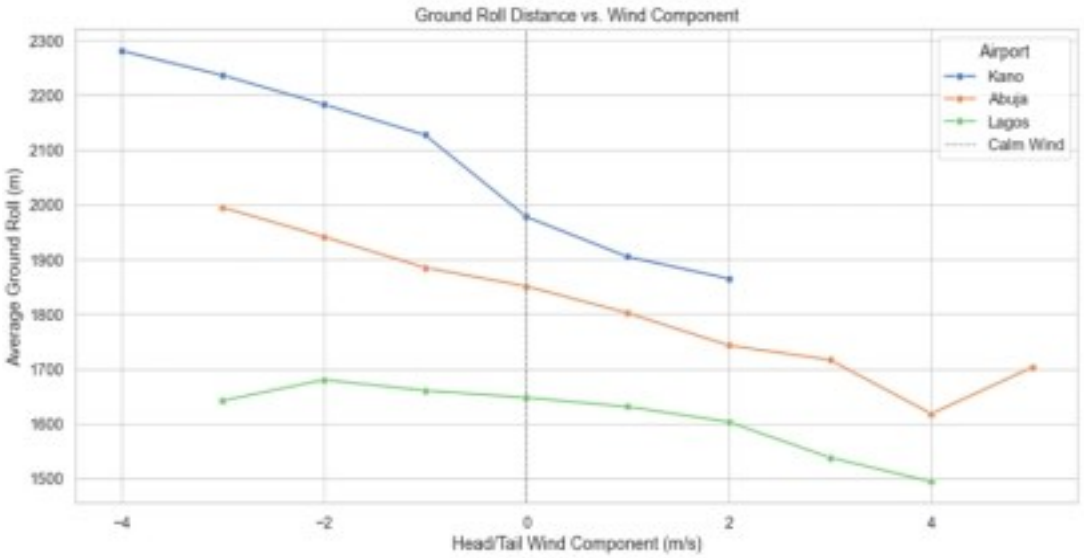


Figure 13 Ground Roll Distance vs. Wind Component (m/s) from Tailwind to Headwind transition.

On runway friction and precipitation effect on roll distance, runway surface condition, are primarily affected by precipitation and reduced visibility events such as fog. When runways are wet or contaminated, the friction coefficient (μ) between aircraft tires and the surface is significantly reduced, thereby increasing ground roll distance, decreasing acceleration, and raising the risk of hydroplaning or delayed rotation. The takeoff performance responds to different levels of runway friction across Abuja, Kano, and Lagos airports, is as shown in Figure 14

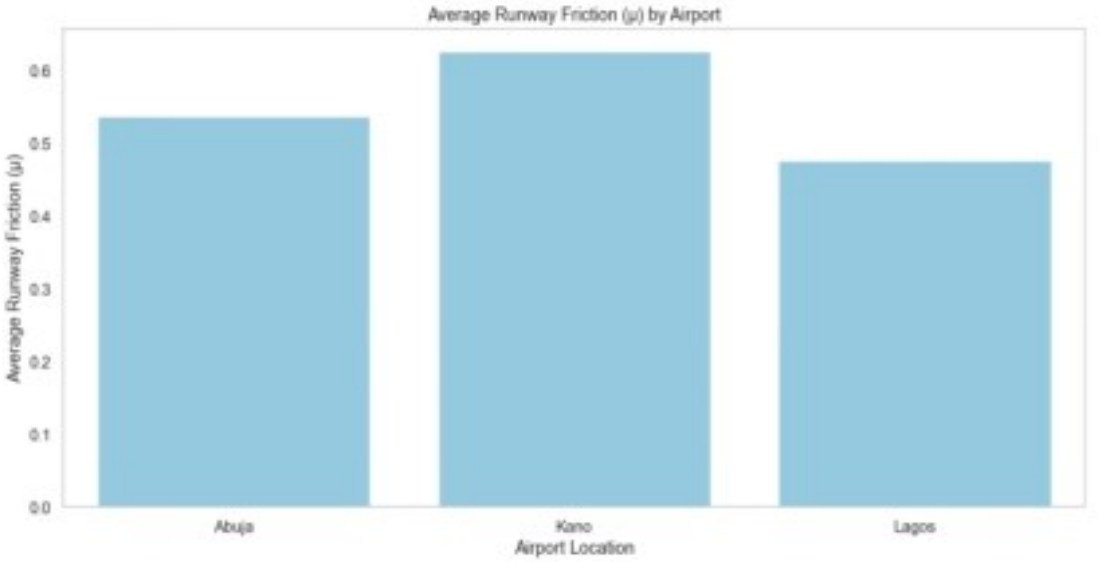


Figure 14 Average Friction (μ) by Airport.

Here Lagos had the lowest average friction, consistent with its high rainfall frequency and humidity, especially during the rainy season from April–October. Kano, with relatively dry and stable weather, recorded the highest friction, implying more favorable surface conditions for takeoff. Abuja however, fell in between, with mixed wet and dry seasonal influence.

Despite having the lowest friction, Lagos showed the shortest ground roll, due to its high air density at sea level. However, when runway friction dropped below 0.50, simulated takeoff rolls increased by over 100 meters.

Kano, with better surface conditions (μ = 0.627), still experienced longer ground roll distances due to lower air density and temperature extremes, especially during harmattan.

Abuja, with a friction average of 0.538, performed moderately but was sensitive to rain-induced μ drops particularly during April to July. These are shown in Figure 15

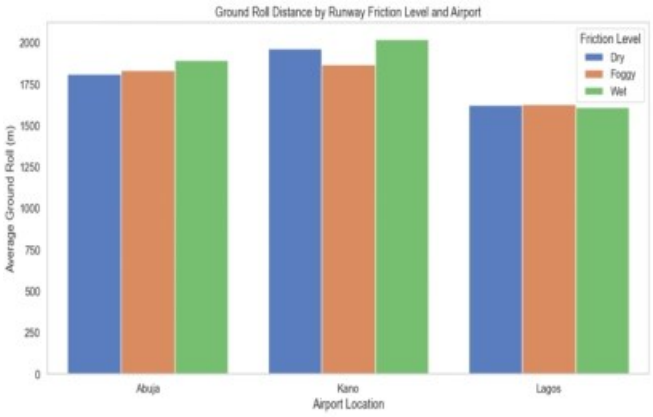


Figure 15Ground Roll vs. Friction Level by Airport (Dry, Wet, Foggy).

The presence of rain or fog was simulated by reducing μ to 0.50 and 0.30, respectively. Results showed up to 12–15% increase in ground roll distance when transitioning from dry μ = 0.75 to wet μ = 0.50. Acceleration reduced by 0.2 to 0.3 m/s², caused longer time to reach V_R . While Fog conditions μ = 0.30 simulated in Lagos and Abuja showed critical runway performance degradation, pushing total takeoff distances close to 2,500–2,700 meters, especially when paired with tailwind or high temperature.

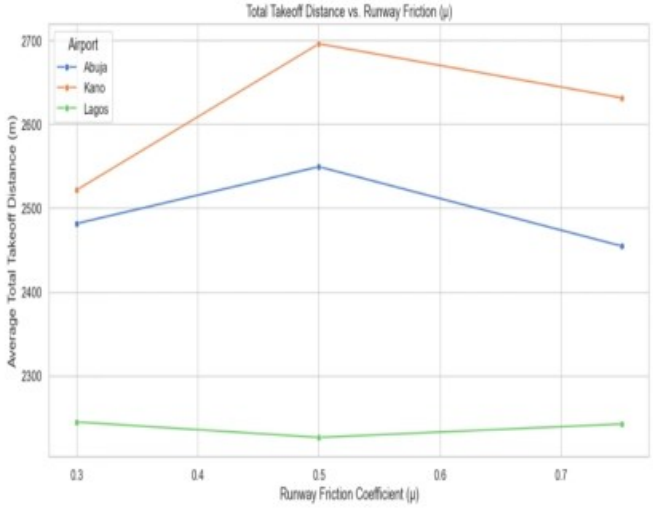


Figure 16 Takeoff Distance vs. Friction Coefficient under constant weight.

In the results, Lagos have high-risk wet runway case as the most rainfall-prone of the three locations, it experienced the most frequent low-friction simulations. Here wet conditions pushed the runway μ below 0.50 for extended periods in the wet season especially May–July, resulting in increased ground roll up to 1,700 m and reduced safety margin, particularly during peak operations making Lagos a high-risk category for takeoff overrun or accelerated-stop decision delays, if aircraft operate at or near Maximum Takeoff Weight. Lagos in a high-risk category for takeoff overrun or accelerate-stop decision delays, if aircraft

operate at or near Maximum Takeoff Weight. These demonstrate that runway friction coefficient significantly affects takeoff performance, especially when compounded with temperature or wind effects. While Lagos is most exposed to wet runway conditions, even airports like Abuja and Kano require careful surface condition monitoring during rainy or foggy seasons hence,. There is need for real-time runway condition data, at Nigerian airports with aging infrastructure and limited runway grooving.

On descriptive and correlation analysis of weather and performance, the operational environment at Abuja, Kano, and Lagos airports, focused on the variables that directly influence takeoff distance and acceleration. These are wide temperature range 13.18 °C to 35.18 °C, which aligns with Nigeria's regional climate variability. The mean of 26.22 °C represents typical tropical values, but the upper quartile above 27.78 °C suggests significant thermal stress during peak periods especially in Kano and Abuja.

Another is runway friction with a mean μ of 0.547 and minimum values as low as 0.30, which confirms the frequent occurrence of wet or low-traction runway conditions, particularly relevant to Lagos during the rainy season. Under wind, although the mean wind component is modest at 0.46 m/s, the range from −4.13 m/s (tailwind) to 4.75 m/s (headwind) indicates that wind shifts significantly impact takeoff conditions, an operational factor to be closely monitored at Abuja.

Others are acceleration & ground roll where expected, acceleration and ground roll show an inverse relationship. High-performing conditions like dense air, dry runway, headwind yield higher acceleration of >1.6 m/s² and shorter rolls of <1,600 m, while worst-case combinations that is high temperature, wet runway and tailwind extend takeoff distances beyond 2,400 m. This varies air density moderately, from 1.085–1.187 kg/m³, but its strong correlation to acceleration and takeoff distance is critical as confirmed in the correlation matrix. Pearson correlation analysis was performed to quantify the strength and direction of relationships among critical parameters such as temperature, elevation, wind, runway friction, air density, thrust, acceleration, and takeoff distance.

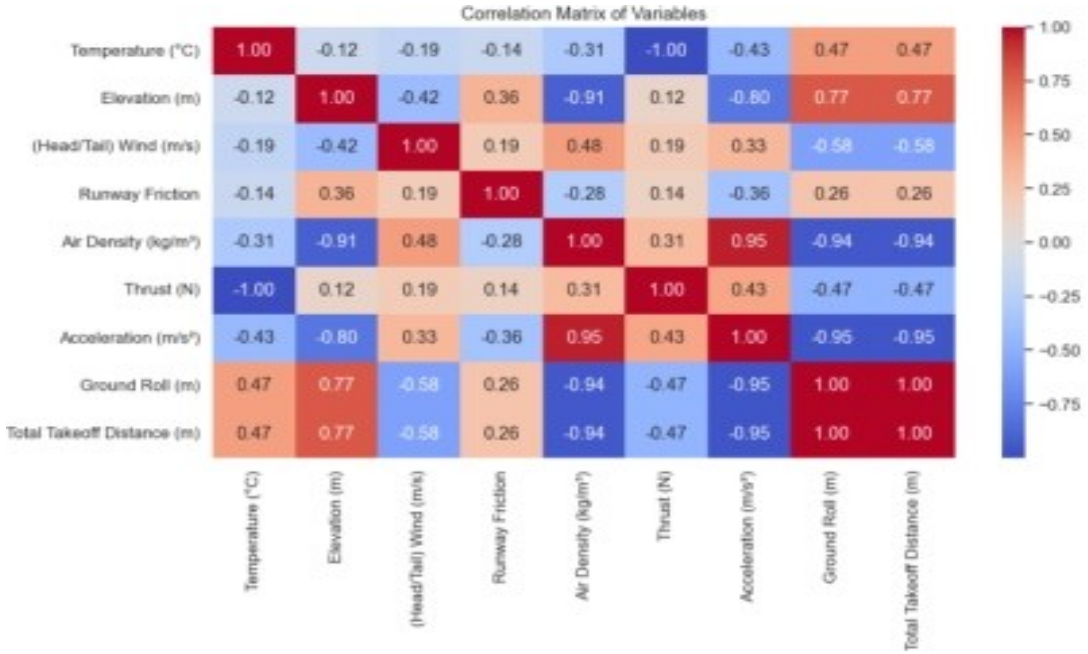


Figure 17 Correlation Matrix of Key Weather and Performance Variables.

This heat map illustrates the Pearson correlation coefficients among the simulated variables over 6,048 records. Strong positive correlations are represented in deep red, while strong negative correlations are shown in deep blue. Values closer to ±1 indicate stronger relationships.

Table 7 key summary of how environmental variables influence Boeing 737-800 takeoff behavior in Nigerian conditions

Acceleration Loss	**Air Density**	**+0.95**	**High-altitude airports require greater performance margin**
Takeoff Distance Increase	Ground Roll	+1.00	Plan runway use with seasonal weather in mind
Performance Degradation	Elevation + Wind	+0.77 / −0.58	Prioritize headwind alignment and monitor field altitude
Friction Sensitivity	Friction vs. Acceleration	+0.33	Monitor rainfall, fog, and surface reports

The result shows time-series analysis that revealed an upward trend in takeoff distance over the years, likely influenced by progressive climatic warming. March–May (hot season) and June–August (wet season) emerged as the most critical operational periods, requiring enhanced performance planning and safety buffers. Temperature had a perfect negative correlation −1.00 with engine thrust, highlighting the need for derating in hot weather conditions. Air density was strongly correlated with acceleration +0.95 and inversely with ground roll −0.94, making it the most influential atmospheric factor. Elevation, wind, and runway friction also showed moderate to strong statistical relationships with takeoff metrics. Acceleration had a −0.95 correlation with takeoff roll, confirming it as the most sensitive performance variable in the dataset.

VI FINDINGS

Reduced air density at high temperatures decreased lift generation, requiring higher ground speed and longer runway roll. So, aircraft performance is most compromised during the dry-hot season March–May and midday operations in Nigeria.

Analysis of headwind vs. tailwind components showed that headwinds reduced takeoff distance by aiding lift and reducing required ground speed. Conversely, tailwinds increased takeoff roll, particularly at Lagos, where prevailing southwestern wind during the rainy season are more pronounced. This confirmed a negative correlation ($r = -0.58$) between wind component and takeoff roll.

Wet season operations in Lagos pose elevated risks for hydroplaning and reduced acceleration, warranting operational caution.

Also, higher temperatures reduce thrust generation, thus, acceleration and ground roll were strongly negatively correlated $r = -0.95$ indicating acceleration drops performance loss.

Friction was also moderately correlated $r = -0.36$, confirming precipitation-related performance degradation.

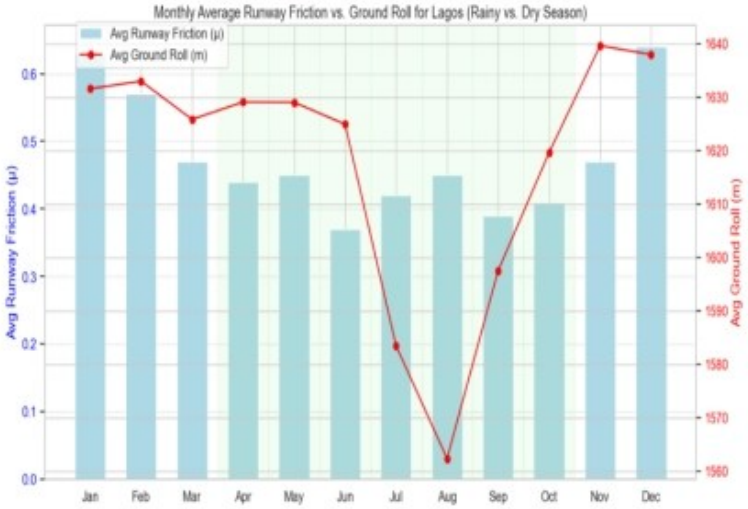


Figure 18 Monthly Average Friction vs. Ground Roll for Lagos (Rainy vs. Dry Season)

The weather variability in Nigeria presents measurable and location-specific challenges to aircraft takeoff performance by linking meteorological variables to aircraft behavior through both quantitative simulations and correlation analysis. The results affirm that ambient temperature, wind components, and runway friction significantly affect takeoff performance. Thus, higher temperatures increase takeoff roll distances due to decreased air density and reduced thrust. Similarly, tailwinds extend takeoff distance and reduce safety margins, whereas headwinds improve performance. Though visibility could not be quantitatively analyzed due to data limitations, meteorological approximations highlighted critical risk periods related to fog and dust particularly, during the harmattan season in Northern airports like Kano and Abuja.

Hence, environmental adaptability must be central to Nigerian aviation strategy. Of course, operational policies, pilot decision-making tools, and regulatory standards should increasingly integrate weather-adaptive models to mitigate the performance losses and safety risks posed by extreme or changing environmental conditions.

FUTURE WORK

To incorporate real-time weather-adaptive tools for flight planning by integrating performance models like the one developed in this study to dynamically adjust takeoff parameters based on environmental data.

Future studies should incorporate real visibility observations, particularly runway visual range (RVR), from advanced airport sensors.

Quantitative modeling of visibility-related constraints for example reduced situational awareness, delayed acceleration, these can enhance predictive models, under harmattan and fog conditions typical in Northern Nigeria.

CONCLUSION

The study investigated how key environmental parameters such as temperature, wind, precipitation, and runway surface conditions influence the takeoff performance of commercial aircraft in tropical areas for the Nigerian airports. A simulated model and statistical analysis for real historical weather data from Abuja, Kano, and Lagos covering from 2020–2025 were examined. The result showed the effect of high ambient temperature on takeoff performance. It revealed that takeoff distance increased significantly with rising temperature, especially above 30 °C.

Kano and Abuja, with high-density altitudes due to elevation and heat, recorded greater takeoff roll distances than Lagos.

Also, that precipitation impact on surface friction reducing acceleration and increasing ground roll making Lagos airports particularly, vulnerable during the rainy season.

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