ANALYSIS OF THE EFFECTS OF WIND ON AIRCRAFT OPERATION AT BRAZILIAN AIRPORTS: A CASE STUDY

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ABSTRACT

This study analyzes the current situation of runway orientation, in relation to wind effects, for 18 Brazilian airports, using meteorological data collected over 10 years (2013-2023). Wind, especially windshear and microbursts, pose significant challenges to aviation due to their ability to cause sudden changes in wind speed and direction. The data were processed and analyzed to determine the optimal orientation of the runways at each airport, aiming to improve the safety and efficiency of operations. Using data analysis and visualization tools, it was possible to identify prevailing wind patterns and trends, facilitating airport planning and management.

Keywords: *Wind in aviation; Windshear; Microbursts; Airport security; Weather analysis.*

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ANÁLISE DOS EFEITOS DO VENTO NA OPERAÇÃO DE AERONAVES EM AEROPORTOS BRASILEIROS: UM ESTUDO DE CASO

RESUMO

Este estudo analisa a situação atual da orientação das pistas, em relação aos efeitos do vento, para 18 aeroportos brasileiros, usando dados meteorológicos coletados ao longo de 10 anos (2013-2023). O vento, especialmente o cisalhamento e as microrráfagas, representam desafios significativos para a aviação devido à sua capacidade de causar mudanças bruscas na velocidade e direção do vento. Os dados foram processados e analisados para determinar a orientação ideal das pistas em cada aeroporto, visando melhorar a segurança e a eficiência das operações. Usando ferramentas de análise e visualização de dados, foi possível identificar padrões e tendências de vento predominantes, facilitando o planejamento e a gestão do aeroporto.

Palavras-chave: *Vento na aviação; Cisalhamento; Microrráfagas; Segurança aeroportuária; Análise do clima.*

1 INTRODUCTION

In aviation, landing and takeoff are critical flight phases with little room for maneuver due to proximity to the ground. Data from Sipaer (2024) corroborate this, showing that between 2014 and 2023, 33.72% of flight accidents in Brazil occurred during the landing or takeoff phase. This highlights the importance of an adequate runway to ensure safe operations.

Wind is a crucial meteorological factor in aviation, presenting significant challenges to pilots, especially in critical phases of flight, where there is little room for correction of descents or sudden ascents caused by unexpected events (Ribeiro et al., 2020). Windshear (WS), characterized by a sudden change in wind speed and/or direction, can be classified as either vertical or horizontal. This phenomenon is particularly worrying at low altitudes, up to 2,000 feet (approximately 600 m) high, due to the limited altitude and time for maneuvering (ANAC, 2021).

The National Civil Aviation Agency (ANAC, 2021) classifies the vertical cutter into four intensities: light (0 to 4kt/100ft), moderate (5 to 8kt/100ft), severe (9 to

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12kt/100ft), and extreme (> 12kt/100ft). In Aeronautical Meteorology, the units of measurement feet (ft) and knots (kt) are generally used to indicate distances and speeds (Soria, 1998). In addition, microbursts, associated with storms of great intensity, resulting from descending air masses that disperse radially over the surface. These short-duration phenomena are difficult to detect by WS warning systems resulting from descending air masses that disperse radially over the surface. These phenomena are difficult to identify by WS warning systems due to their short duration and can make it impossible for aircraft of different sizes to take off (Ribeiro et al., 2020).

Regarding the execution of adequate airport runway projects, one of the aspects considered is their orientation. According to Sória (1998), ideally, planes should land and take off totally against the direction of the wind so as not to suffer from the effect of their transverse component and to rely on the wind as part of their aerodynamic speed. However, because wind direction and speed uncontrollable factors, and for this reason it is very unlikely for a runway to be perfectly always aligned with the winds. Thus, a certain transverse component of speed from the winds over the speed of the plane in which it is still safe to operate is accepted. Thus, there is the determination of ICAO, which requires that the runway be built in a direction that allows at least 95% of operational time.

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In addition, another factor to be considered is climate change. Climate change causes changes in wind patterns and weather variability, which can affect the effectiveness of these track orientations overall. Studies indicate that climate change can result in changes in wind patterns, which may require revisions in airport runway design guidelines and strategies to maintain safety and operational efficiency (Smith, 2020).

The anemometer is the main equipment used to collect data on wind intensity, direction, and character, and it plays a essential role by providing accurate wind speed information. The data obtained by the anemometer allows the creation of anemograms, detailed graphical representations of the behavior of the winds over time. The reading of the anemograms allows engineers and airport planners to analyze the prevailing wind regime in a specific area, facilitating the determination of the optimal orientation of the runways (Soria, 1998). This analysis is essential to ensure that runways are aligned with prevailing winds, reducing risks and improving aircraft performance during the critical landing and takeoff phases.

This work aims to analyze the wind characteristics of 18 national airports between 2013 and 2023 and, thus, determine the appropriate direction of their respective runways. These results will be compared with the current runway orientations to assess the compatibility of prevailing wind directions with the runways. The analysis of historical wind data will allow identifying seasonal patterns and possible changes in wind behavior over the years, offering a broader perspective on the safety and efficiency of airport operations.

The objective of the study is to analyze the current runway orientations against current meteorology data. In addition, the proper orientation of the runways can contribute to the reduction of delays and increase the operational efficiency of airports, resulting in economic and operational benefits. Finally, this study can serve as a basis for future research and improvements in airport planning regulations and practices, promoting a safer and more efficient aviation environment in Brazil.

2 METHODOLOGY

To achieve the desired results, a detailed processing of data collected by Iowa State University, in the United States, through the Iowa Environmental Mesonet program was performed. This program gathers wind data and guidance from various airports around the world, providing a solid foundation for climate and operational analysis. In the present study, 18 Brazilian airports were selected for analysis, as listed below:

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1. SBGR: Guarulhos International Airport – SP
2. SBKP: Viracopos International Airport – SP
3. SBBR: Brasília International Airport – DF
4. SBSP: São Paulo-Congonhas Airport – SP
5. SBRJ: Santos Dumont Airport – RJ
6. SBCF: Belo Horizonte-Confins International Airport – MG
7. SBRF: Recife-Guararapes International Airport – PE
8. SBGL: Rio de Janeiro International Airport – Galeão – RJ
9. SBSV: Salvador International Airport – BA
10. SBPA: Porto Alegre International Airport – RS
11. SBCT: Afonso Pena-Curitiba International Airport – PR
12. SBFZ: Fortaleza International Airport – CE
13. SBEG: Eduardo Gomes International Airport - Manaus – AM
14. SBBE: Val de Cans-Belém International Airport – PA
15. SBFL: Hercílio Luz-Florianópolis International Airport – SC
16. SBCY: Marechal Rondon-Cuiabá International Airport – MT
17. SBVT: Eurico de Aguiar Salles-Vitória International Airport – ES
18. SBGO: Santa Genoveva-Goiânia International Airport – GO.

Data processing was performed using an Panda script, an Python library, in the RStudio Online program on the Posit Cloud platform. This process involved several key steps: Several R libraries were installed to facilitate data manipulation and analysis. Among them, pandas for data manipulation stand out, being ‘readr’, ‘dplyr’, ‘ggplot2’, ‘opneair’, ‘tidyverse’, ‘REdaS’, ‘grid’, among others.

The data were downloaded covering a period from 2013 to 2023, totaling 10 years of time records. This data included information on wind speed and direction for each of the 18 selected airports. The raw data was then converted to numerical values and categorized into five main variables: location, date, time, direction, and wind speed.

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Incomplete records or records with missing values were omitted to ensure the completeness and accuracy of subsequent analyses. This process involved the identification and removal of null or inconsistent values found by the acronym "NA" in the provision of data by the search URL of each Airport.

The wind speed data was categorized into four ranges: below 10 knots, 10-13 knots, 13-20 knots, and above 20 knots. Each range corresponds to different aircraft operational capabilities. For wind speeds above 20 knots, larger aircraft with advanced stability systems, such as those from the Boeing and Airbus families, are used. In weaker winds, smaller aircraft are sufficient, as they require less stability for landing and takeoff (ANAC, 2023).

With the data categorized, a consolidated table was generated. Then, the data was converted into percentages to facilitate comparative analysis between different wind speed ranges and airports. Charts were created for clear visualization of patterns and trends throughout the study period. These visualizations helped identify periods and places with a higher incidence of intense winds, allowing inferences about the operating conditions of each airport.

For data analysis, only values within the reference limits, between 95% and 100% coverage, were considered. In addition, for optimal track positioning, the points with a higher coverage are considered, especially when considering the winds of 10 and 13 knots. It was done this way, because the most favorable positioning for a runway is the one that is in the same direction as the largest winds, where headwinds are presented (Anac, 2021), which contributes to the safety and efficiency of operations since it increases lift and reduces the distance necessary for takeoff.

During takeoff, an airplane needs to reach a specific air speed to generate sufficient lift and lift. When the plane takes off against the wind, the air speed in relation to the ground is lower, reducing the necessary takeoff distance on the runway. In addition, landing and taking off against the wind improves the stability and

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control of the plane, providing better control of speed and angle of attack, which allows the pilot to adjust the descent or ascent more accurately.

Landing against the wind also reduces the ground speed, meaning that the plane will need a shorter distance to stop completely after touching the runway. Wind speed helps to decrease the speed of the plane more quickly, increasing the efficiency of braking and improving the safety of the operation (ICAO, 2016). The runway orientation toward prevailing winds maximizes the operational efficiency and safety of flight operations.

3 RESULTS

With the processing of the code for each of the airports, 18 graphs were generated representing all the airports analyzed. In general, they presented a similar behavior, such as a sinusoidal, with different amplitudes for each speed and having 2 points of greater coverage. In relation to the graph for the speed of 20 knots, the coverage presented is always higher, being close to 100%. The graph that showed a more different behavior was for SBBE, as shown below in Graph 1.

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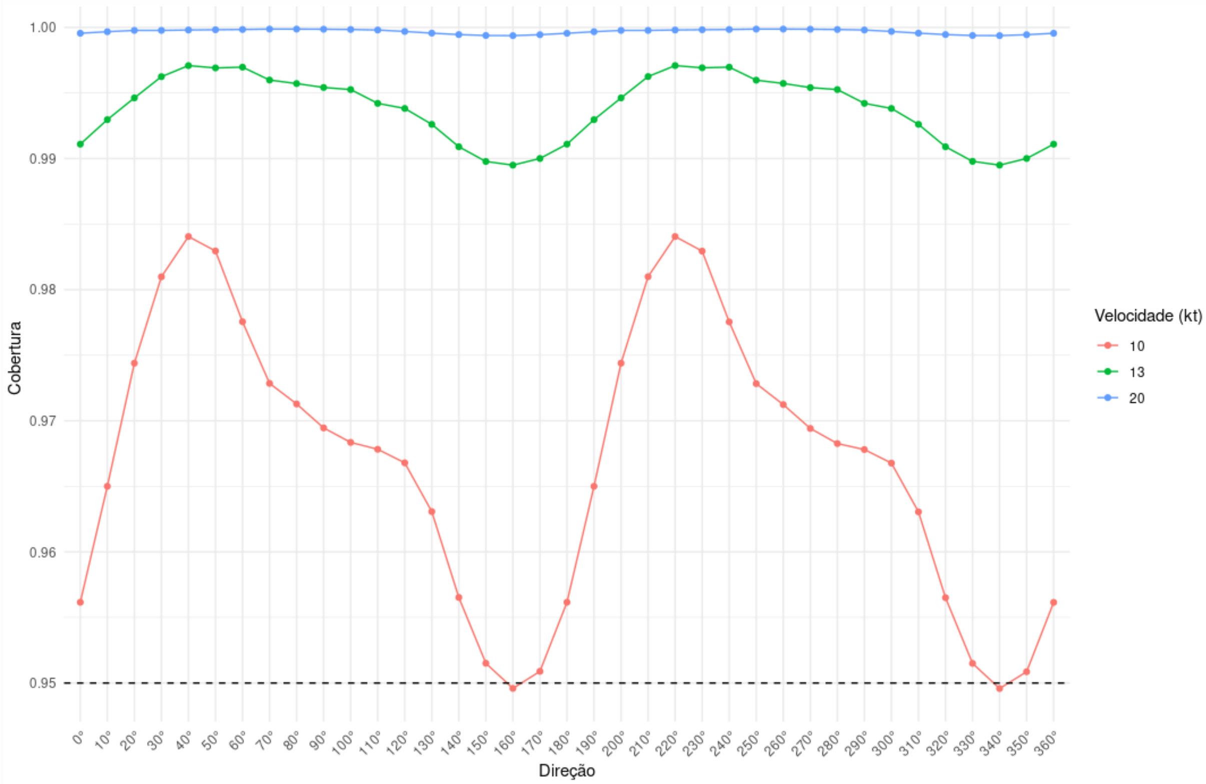
Graph 1 – Weather data from 2013 to 2023 for SBBE.



Source: Elaborated by the authors, 2024.

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To interpret the data obtained and compare them with reality, the Airspace Control Department (AISWEB, 2024) was consulted for the actual runway directions of the airports. To facilitate interpretation, airports were grouped by regions, not only because of their proximity, but also because of the similar physical characteristics that each state has. In addition, the results and track placements were gathered in

Table 1:

Table 1 - Summary of results

Region	Airport	Track positioning according to AISWEB, 2024	Wind intervals through with greater coverage	Results

			according to survey results	
Northeast and North	SBBE	02 and 20	40° to 120°	Runway aligned with wind conditions.
		06 and 24	210° to 280°	
	SBFZ	13 and 31	100° to 110° 280° to 290°	Runway not totally aligned with wind direction, influenced by other factors.
	SBSV	10 and 28 17 and 35	80° to 120°	Runways 10 and 28 aligned with wind conditions. Runways 17 and 35 not aligned with wind direction, influenced by other factors.
			250° to 300°	
	SBRF	11 and 29	100° to 190°	Runway aligned with wind conditions.
			300° to 10°	
	SBEG	18 and 36	100° to 190°	Runway aligned with wind conditions.
			300° to 10°	
Southeast	SBGR	10 and 28	90° to 130°	Runway aligned with wind conditions.
			270 to 310°	
	SBKP	15 and 33	110° to 160°	Runway aligned with wind conditions.
			290° to 340°	
	SBSP	17 and 35	130° to 190°	Runway aligned with wind conditions.
			300° to 360°	
	SBRJ	02 and 20	320° to 30°	Runway aligned with wind conditions.
			150° to 210°	
	SBCF	16 and 34	60° to 140°	Runway aligned with wind conditions.
			240° to 330°	
	SBGL	10 and 15	330° to 20°	Runway aligned with wind conditions.
			70° to 110°	
		28 and 33	150° to 200°	
			250° to 300°	
	SBVT	06 and 24	320° to 30°	Runways 02 and 20 aligned with wind conditions. Runways 06 and 24 not aligned with wind direction,
		02 and 20	150° to 210°	

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				influenced by other factors.
Midwest	SBBR	11 and 29	70° to 120°	Runway aligned with wind conditions.
			250° to 310°	
	SBCY	17 and 35	150° to 160°	Runway aligned with wind conditions.
			330° to 340°	
	SBGO	14 and 32	90° to 110°	Runway not totally aligned with wind direction, influenced by other factors.
			270° to 300°	
South	SBPA	11 and 29	70° to 130°	Runway aligned with wind conditions.
			260° to 310°	
	SBCT	15 and 33	100° to 130°	Runways 11 and 29 aligned with wind conditions. Runways 15 and 33 not totally aligned with wind direction, influenced by other factors.
		11 and 29	270 to 310°	
	SBFL	14 and 32	140° to 190°	Runway aligned with wind conditions.
		03 and 21	320° to 30°	

Source: Elaborated by authors (2024) and AISWEB (2024).

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a. NORTHEAST AND NORTH

The graphs of these regions for wind conditions with speed up to 10kt the coverage amplitude is large, mostly greater than 0.98. Also, the maximum coverage amplitude for SBSV was close to the reference value 0.95, this is justified due to the surrounding relief, Parque das Dunas. The nodes from 10kt to 13kt have coverage ranging from 0.96 to 1.00, for SBBE and SBEG this amplitude showed values greater than 0.99.

The runways at SBBE, SBRF and SBEG fall within the areas of highest wind coverage, likely due to factors such as their location in relatively flat areas and their proximity to the sea. In contrast, the runway alignment at SBFZ does not coincide with the area of highest wind coverage. This suggests that external factors, such as the surrounding mountainous and rugged terrain, must be considered in its position.

As for SBSV, the airport has it's runways positioned at 17, 35, 10 and 28. The runways 17 and 35 are not aligned with the area of highest wind coverage, unlike the runways 10 and 28. The presence of Parque das Dunas surrounding the airport is an important factor to consider for the existence of runways with these characteristics, given that the positioning of sand dunes can change unpredictably. As a result, the wind can be channeled between the dunes in various areas, altering its direction and speed.

In SBBE, the runway orientations, presented by AISWEB in Table 2 , are 02, 20, 06 and 24. When analyzing the winds of up to 10 knots and between 10 and 13 knots, in Graph 1, it is possible to notice that the points of greatest incidence vary between 40° to 220° equally and 60° to 240° for winds between 10 and 13 knots. Therefore, orientations 06 and 24 correspond to the data collected if we consider such wind conditions.

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Table 2 – SBBE Runway Data

RWY	TORA (m)	TODA (m)	ASDA (m)	Geoidal Height (m)	Coordinates
2	1830	1830	1830	-24,17	S01 23 26 W048 28 38
20	1830	1830	1830	-24,17	S01 22 27 W048 28 33
6	2800	2800	2800	-24,17	S01 23 17 W048 29 06
24	2800	2800	2800	-24,17	S01 22 13 W048 28 01

Source: Airspace Control Department, 2024

b. SOUTHEAST

Among the airports in this region, in general, the graphs generated for the wind analysis have similar characteristics, except for Rio de Janeiro-Galeão (SBGL), which, due to the characteristics of the relief, presents a slightly more different wind graph. While the others have two higher points for winds of 10 knots and between 10 and 13 well-defined knots, SBGL presents a graph with greater variations.

The runways in this region are generally aligned with the areas of highest wind coverage, with the only exception being runways 06 and 24 at SBVT airport. It has a slightly different alignment, likely influenced by its location, considering that the expansion was limited due to the large urban area and the sea surrounding it. This runway positioning may have been a response to the need to expand without encroaching on nearby areas.

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c. MIDWEST

When analyzing the graphs of the central-west region, the amplitude of the wind coverage is greater for a speed of up to 10 knots. For knots from 10 knots to 13 knots, coverage ranging from 1.0 to 0.99 is seen, demonstrating a slightly greater amplitude in SBBR.

The runways in this region are generally aligned with the areas of highest wind coverage, with the only exception being runways 14 and 32 at SBGO airport. Its slightly different alignment was likely influenced by the predominantly flat terrain and the need to minimize environmental impact, given its proximity to Altamiro de Moura Pacheco State Park.

d. SOUTH

The charts for this region show a wide range concerning winds up to 10 knots. For winds up to 13 knots, the range becomes slightly more variable. The points with the highest coverage are well-defined, while the coverage for winds above 20 knots remain reasonably constant.

The airports in this region are mostly aligned with areas of highest wind coverage, due to their proximity to the coast. However, at SBCT, runways 15 and 33 are not aligned, like one of the runways at SBVT. Its construction was likely driven by the need to meet traffic demand. However, factors such as its location near the coast and urban areas limit its expansion, making it necessary to build the runway in an area with less wind coverage.

4 CONCLUSION

It is important to note that all airports studied have a high incidence of winds above 20 knots, which restricts operations to larger aircraft. This feature is consistent with the classification of international airports, which are designed to accommodate aircraft that perform long-haul flights and carry a greater number of passengers. The predominance of strong winds makes it essential to focus on the analysis of winds at lower speeds, specifically up to 10 knots and between 10 and 13 knots, as the winds of 20 knots are constant, presenting a coverage of 1.00 in all cases analyzed.

In addition, a pattern of track positioning was identified in the north and northeast regions of the country. It has been observed that, in airports like SBRF, the runway is strategically positioned near the valleys in the graphs of wind coverage, indicating an efficient adaptation to local conditions. This pattern suggests that, besides prevailing winds, regional factors such as terrain and altitude play a crucial role in runway alignment. In Brazil, the varied topography and different altitudes of the regions can cause significant changes in wind direction and intensity, directly

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affecting runway planning, as they significantly influence wind behavior, impacting the safety and efficiency of airport operations.

For example, São Paulo-Congonhas Airport (SBSP) has its runway heavily influenced by the region's topography, requiring a detailed analysis of local winds. In a similar manner, in airports such as Brasília (SBBR) and Salvador (SBSV), regional characteristics also condition the runway alignment, reflecting the need for planning that considers both wind direction and local geography.

The presence of urban areas, parks, and nature reserves can limit expansion or guide the runway location to minimize environmental impacts and noise. Existing infrastructure, such as roads and railways, can also determine the most viable runway position, facilitating access and integration with other means of transportation. Environmental considerations, such as bodies of water and wildlife habitats, can restrict runway placement and require specific mitigating measures.

Furthermore, it's important to emphasize that runway planning must consider the future growth of the airport, its expandability, and local meteorological factors such as fog and storms, which can impact the operations. Given this, there is a need for a comprehensive analysis using aviation standards and regulations, as well as the available navigation technology and approach systems, to ensure efficient and safe runway planning at Brazilian airports. Therefore, integrating these factors into a comprehensive analysis is essential for efficient and safe runway planning at Brazilian airports.

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