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Windrose Based of Surface Wind Profiles Over a Decade at Soekarno – Hatta International Airport

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Abstract

The study of surface wind characteristics in the airport area is needed to support flight operations in terms of safety and economy. Surface wind data is required during the aircraft take-off and landing phases. The information on surface wind characteristics is used for planning flight operations or the construction and expansion of an airport runway. Using the frequency distribution method, a description of the monthly surface wind pattern was obtained. The results in Soekarno-Hatta International Airport area over 10 years period showed that in January - April the surface wind direction is dominated from the west, May - September is dominated from the east. The months of October, November, and December are a transition from easterly to return to the west (dominated from the south and southwest). This is in line with the general pattern of Indonesia's climate which is influenced by the west monsoon and east monsoon phenomena.

Keywords: aviation safety, frequency distribution, monsoon, Soekarno-Hatta Airport, surface wind, windrose.

Abstrak

Profil Angin Permukaan Berdasarkan Distribusi Frekuensi Di Bandara Internasional Soekarno-Hatta: *Studi tentang karakteristik angin permukaan di area bandara sangat diperlukan untuk mendukung operasional penerbangan baik dari segi keselamatan maupun ekonomi. Data angin permukaan diperlukan pada saat pesawat akan lepas landas dan mendarat. Informasi mengenai karakteristik angin permukaan juga dapat digunakan untuk perencanaan operasi penerbangan atau pembangunan dan perluasan landasan pacu bandara. Dengan menggunakan metode distribusi frekuensi, akan diperoleh deskripsi pola angin permukaan bulanan. Hasil penelitian di area Bandara Internasional Soekarno-Hatta selama periode 10 tahun terakhir menunjukkan bahwa pada bulan Januari - April arah angin permukaan didominasi dari arah barat, bulan Mei - September didominasi dari arah timur. Bulan Oktober, November, dan Desember merupakan peralihan dari arah timur untuk kembali ke arah barat (didominasi dari arah selatan dan barat daya). Hal ini sesuai dengan pola umum iklim Indonesia yang dipengaruhi oleh fenomena monsun barat dan monsun timur.*

***Kata kunci**: angin permukaan, Bandara Soekarno-Hatta, distribusi frekuensi, keselamatan penerbangan, monsun, Windrose*

1. Introduction

According to a report by official airlines guide (OAG) Aviation, Soekarno-Hatta Airport is the busiest airport in ASEAN with a flight seat capacity of 2.15 million seats in December 2022. Not only regarding the level of passenger service, Soekarno-Hatta Airport was also lined up to be the 9th busiest airport in the world in terms of the number of flights served. This figure was obtained at the same time in December 2022. Soekarno-Hatta Airport serves an average of 579 flights every day during December 2022. This is higher than Charlotte airport in the United States [1]. This is certainly an achievement for the manager/operator of Soekarno-Hatta Airport. In order for this achievement to be maintained or even improved, the safety factor in flight operational services is crucial.

According to Zhao and shusama, temperature and wind are major meteorological factors that affect the takeoff and landing performance of aircraft. Warmer temperatures and the associated decrease in air density in future climate, and changes to crosswind and tailwind, can potentially impact aircraft performance [2]. In line with the results of research by the Transportation Research and Development Agency through the Air Transportation Research and Development Centre conducted in 2020 related to the influence of meteorological conditions for flight path planning stated that flight activities are closely related to weather and climate conditions. Both conditions can have an economic impact and an impact on flight safety. One of these weather or climate elements is surface wind. Surface wind direction data will determine the direction from which the aircraft lands or takes off. The aircraft will take off and land in the opposite direction to the wind direction. In the take-off phase this is to get the maximum lift force.

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While in the landing phase to get a drag force, if the aircraft moves in the direction of the surface wind, it will be able to have a higher speed and it is difficult to brake safely. This can make it difficult for the aircraft to stop on the runway and cause an accident or overshooting [3].

In the other side, the consistently growing demand for airline transportation has resulted in increased air traffic and air operations in airports across the world. According to the International Air Transport Association, forecasts assume that in the year 2036 about 7.8 billion passengers will travel using air transport. In Europe, it is estimated that 16.2 million flights will take place in 2040, 53% more than in 2017. One of the crucial factors that significantly affect air transportation is the weather [4].

Soekarno-Hatta Airport is geographically located at coordinates 6.1265° S, and 106.6555° E. The first runway (07L/25R) is 3,660 metres long and 60 metres wide, the second runway (07R/25L) is 3,600 metres long and 60 metres wide, while the third runway (06/24) is 3,000 metres long and 60 metres wide. The airport has been in operation since 1985 [5].

It is interesting to study and research how the surface wind pattern or profile in the Soekarno-Hatta Airport area over the past decade period. This is because, for more than 30 years until now, there have been many physical environmental changes both in terms of internal airport infrastructure and the environment around the airport when compared to the initial period of airport operations. Unfortunately, until now there has been no research specifically discussing how the surface wind pattern at Soekarno-Hatta International Airport during the last 10 years and its implications for flight operations both in terms of economy and flight safety operations. For this reason, in this study, the author tries to do it. The author chose to use a quantitative descriptive approach in this research. As for data processing using statistical methods in the form of frequency distribution. The frequency distribution will show the dominant surface wind direction along with the percentage of speed. Representation of data processing results in the form of graphs will describe the surface wind profile on a month-by-month basis in the Soekarno-Hatta Airport area. The statistical method of frequency distribution was chosen by the author because there have never been previous studies that used the frequency distribution method with long-term time series data and specifically focused on the monthly wind pattern at Soekarno-Hatta International Airport.

According to Soerjadi and Yunus [6], if there is no other explanation, wind is the motion of air in a horizontal direction. Surface wind is wind at a height near the earth's surface. Wind values are obtained from measurements using an anemometer that is 10-12 metres high. Wind has two values, namely direction and speed. Wind direction is expressed by the degree from which it comes. A value of 0 (zero) indicates calm winds, 360° indicates winds from the north, 90° indicates winds from the east, 180° indicates winds from the south, and 270° indicates winds from the west. Wind speed is expressed in knots (1 knot = 1.8 km/h) or in metres per second (m/s). 1 knot = 0.5 m/sec.

Some general characteristics of surface winds in the tropics include: generally low speed, except in areas experiencing thunderstorms, tropical storms, etc., but little relation to air pressure; regular changes in direction and speed and daily scale related to local conditions, such as land winds-sea breezes, and valley breezes-mountain breezes; daily variations in wind are very dominant, depending on the location of the station (measurement site). On the coast, the sea breeze starts around 11am and the land breeze starts around 7 pm. In mountain valleys, valley winds start around 11 am and mountain winds start around 10 pm. In Annex 3, ICAO states that surface winds for flight operational purposes are surface winds that must be observed at a height of 10 m (30 ft) above the ground [7].

The authors used statistical method frequency distribution to processing data. A frequency distribution is a representation, either in graphical or tabular format that is used to display the number of observations in a particular interval. The size of the interval depends on the data being analysed and the purpose of the analyst. Intervals must be exclusive and complete. Frequency distributions are commonly used in a statistical contex [8].

The frequency distribution will show the dominant surface wind direction along with the percentage of speed [9]. Representation of the results of data processing in graphical form will describe the surface wind profile on a month-by-month basis in the Soekarno-Hatta Airport area.

Several previous researches that examined wind patterns at an airport using the frequency distribution method and windrose software produced some important information that can be used by airport authorities and airline operators in realizing flight operations that are safety, regularity, economy, and efficient. The first is research conducted by Fadholi. A research about wind data analysis is used for determining existence pattern. In Depati Amir Airport, Pangkalpinang conducted a research of wind data analysis to show runway surface wind pattern in order to reduce flight accident potential. The research's result which analyzed used wind rose method and data range between 2000 to 2012, showed that the dominant surface wind of Depati Amir Airport almost during a year flew from 135 to 165^0 (South-East) with 1 - 4 knot acceleration. Although, in November until April various wind is high. Beside that, from the morning to afternoon, the dominant surface wind flew from East and from afternoon to night the surface wind flew from South-East [10]. Second, research conducted by Arum at al. By knowing the dominant wind direction based on the month and season, it can be determined which runway will be used at Budiarto Airport. By using hourly wind direction and speed data from the Budiarto Meteorological Station for a five-year period from January 2015 to December 2019, it was concluded that based on the value of headwind and crosswind events during 2015-2019, the use of Runway 04 was used both during the rainy season and Runway 12 during the dry season, while in the transition season the best Runway was used was Runway 04 [11]. Third, research conducted by Fatkhuroyan at al, research conducted to determine the characteristics of wind direction and speed and temperature around the prospective Kulon Progo airport. The method used is to install four AWS (Automatic Weather Stations) at the ends and middle of the prospective runway to be built so that weather elements such as wind and temperature are known. The wind data is then processed and analyzed with windrose. The observation results show that the wind direction at posts 1 and 2 blows from the west, at post 3 it blows from the northwest and at post 4 blows from the Northeast, with a maximum speed of 1-4 knots. Meanwhile, the temperature at Post 1 is between 22.7^0C - 31.7^0C, Post 2 is between 23.1^0C - 33.4^0C, Post 3 is between 22^0C - 31.5^0C, and Post 4 is between 22.8^0C - 31.9^0C, so it is concluded that the direction and speed of the wind and the temperature around the area support the need for aircraft take-off and landing later [12].

Fourth, the research conducted by Bambang et al. results from the analysis of monthly wind profiles and the potential for crosswind using windrose in the New Yogyakarta International Airport area from March to September 2017 showed that the wind pattern in the period March – May had a variable direction with an average speed of 5 – 8 knots. In June – September, the wind pattern blows from the East – Southeast with an average speed of 6 – 9 knots. During the observation period, the maximum wind speed occurred between 14 – 20 knots and no potential for cross winds was found for a runway length of 3,600 meters [13]. Fifth, research conducted by Titis D Pratica and Ahmad Fauzan. An analysis of surface wind patterns at Juwata Tarakan Airport for the 2014-2020 period was carried out in order to determine the surface wind patterns in the corresponding period using the windrose method. The results of the study show that in February, March, April, May, August, September, November, December in 2014-2020, the wind direction tends to come from the east followed by a speed of 1-5 knots. In June and July, the wind direction tends to come from the South and January from the northwest. This does not have a significant impact on the flight, as the wind speeds are most outstanding at the two calm and 1-5 knots. However, it should be noted that during these months, the wind direction is not in line with the runway. Meanwhile, in the wind direction from January 2014 - December 2020, it tends to come from the east with a speed of 1-5 knots [14].

2. Methodology

Research on surface wind patterns focuses on researching surface wind data obtained from observations. Surface wind data is numerical data, so the type of research method used is quantitative method. The nature of the research is descriptive.

Quantitative research methods are defined as part of a series of systematic investigations of phenomena by collecting data to be measured by mathematical or computational statistical techniques. this research is mostly carried out using statistical methods in collecting quantitative data through research studies. While descriptive quantitative is used to convey facts by giving an explanation of what is seen, obtained to experience and feel. The researcher simply writes or reports the results of the report in the form of observations made [15]. In this case the researcher only needs to describe the object being studied without engineering.

2.1. Data Collection Methods

The data used in this study comes from surface wind observations made by weather observers at Soekarno-Hatta Meteorological Station. Wind observations are carried out every one hour for one full day, seven days a week (7/24, non-stop). The instrument used is an anemometer attached to a digital AWS. The number of data periods used is ten years, from 2013 to 2022.

The purpose of this study is to determine the surface wind profile in the Soekarno-Hatta Airport area during the last ten years, so the original measurement data is used entirely not only samples or modelling data. The hope is to provide a real description of the condition of the object of research.

2.2. Data Processing

Surface wind data has two values, namely direction and speed. The total amount of data over a ten-year period is 175,200 data. To facilitate the processing of data based on the frequency distribution method, researchers used the help of Windrose software.

The stages in using the Windrose application in wind data processing are as follows [9]. First, prepare the data. Begin by organizing your wind data in a Microsoft Office Excel spreadsheet. Ensure the data adheres to a standard format for compatibility with the Windrose application. The format should be as follows: Year_Month_Date_Hour_WindDirection_WindSpeed. Second step, install and open the Application. Download and install the Windrose application on your computer. Once installation is complete, open the application to begin the import process. Next step, import the data. Navigate to the main page of the Windrose application and select the "Import from Excel" option under the Tools menu. This function allows you to import your prepared Excel file into the application. Last, generate the diagram. After importing the data, the Windrose application will process the information and generate a diagram based on the wind data provided. This visual representation will help in analyzing the wind patterns effectively. These steps ensure a smooth transition from raw wind data to a comprehensive visual diagram, aiding in accurate data analysis and interpretation. Figure 1 [9] is a look at the image for WRPLOT View, the main dasboard, view of data processing, and the windrose graph.

2.3. Data Analysis

Windrose is an application released by Lakes Enviromental. It is fully operational for meteorological data, particularly wind data. Windrose provides visual wind plots, frequency analysis, and plots for several other meteorological data formats [9]. Windrose itself depicts the frequency of wind occurrence in each specified wind direction sector and the wind speed class for a given location and time period.

3. Results and Discussions

The following are the results of processing surface wind data using the windrose application. The results of this processing also become a monthly wind profile in the Soekarno-Hatta Airport area for the period 2013 to 2022.

3.1. January

The profile of wind direction and speed in January for the 10-year period (2013-2022) shows that the wind direction is dominated by southwest to northwest. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 33% and the average value of wind speed is 5.5 knots. The maximum wind speed recorded in 10 years reached 24 knots. This condition is in line with the characteristics of the Indonesian region where in January, the active monsoon is the Asian monsoon so that the dominant wind blowing is the west wind.

3.2. February

The profile of wind direction and speed in February for the 10-year period (2013-2022) shows that the wind direction is dominated by west to northwest with significant variations in southwest direction. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 34% and the average

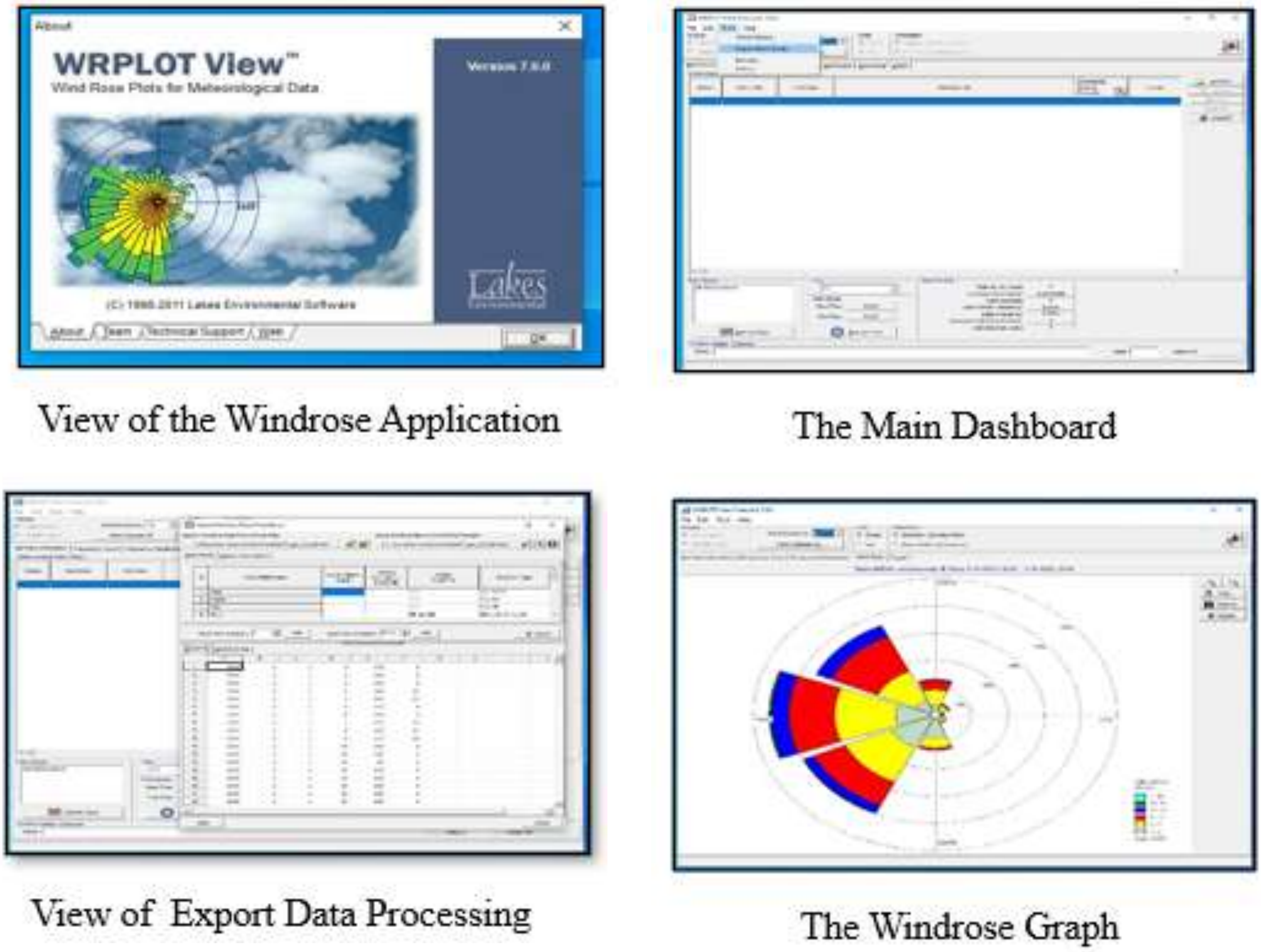

Figure 1. Windrose application.

value of wind speed is 4.8 knots. The maximum wind speed recorded in 10 years reached 22 knots. The characteristic conditions of February winds in the Indonesian region are still dominated by westerly winds, in line with the active monsoon, namely the Asian monsoon.

3.3. March

The profile of wind direction and speed in March for the 10-year period (2013-2022) shows that the wind direction is dominated by southwest to west directions with significant variations in south and northwest directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 33% and the average value of wind speed is 4.6 knots. The maximum wind speed recorded in 10 years reached 24 knots. The characteristic conditions of March winds in the Indonesian region are still influenced by the Asian monsoon which is dominated by west winds. However, easterly winds began to blow with significant speed.

3.4. April

The profile of wind direction and speed in April for the 10-year period (2013-2022) shows that the wind direction is dominated by the southwest. However, variations in the direction of the west and east winds are quite significant. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 34% and the average value of wind speed is 4.8 knots. The maximum wind speed recorded in 10 years reached 23 knots. The characteristic conditions of April winds in the Indonesian region began to vary with weakening and decreasing westerly winds, and strengthening easterly winds. Figure 2 are the profile of wind direction and speed in January, February, March, and April for the last 10 years (2013-2022).

3.5. May

The profile of wind direction and speed in May for the 10-year period (2013-2022) shows that the wind direction is dominated by northeast with significant variations in east, south and southwest wind directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 32% and the average value of wind speed is 4.7 knots. The maximum wind speed recorded in 10 years reached 20 knots. The characteristic wind conditions in May in the Indonesian region began to strengthen with easterly winds, but there were still variations from the west wind.

3.6. June

The profile of wind direction and speed in June for the 10-year period (2013-2022) shows that the wind direction is dominated by the northeast with significant variations in the east, south and southwest wind directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 31% and the average value of wind speed is 4.5 knots. The maximum wind speed recorded in 10 years reached 25 knots. The characteristic conditions of June winds in the Indonesian region are influenced by the Australian monsoon with predominantly east winds. The variation of westerly winds is still significant but starting to weaken.

3.7. July

The profile of wind direction and speed in July for the 10-year period (2013-2022) shows that the wind direction is dominated by northeast to east with variations in south and southwest wind directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 34% and the average value of wind speed is 4.8 knots. The maximum wind speed recorded in 10 years reached 18 knots. The characteristic conditions of July winds in the Indonesian region are influenced by the Australian monsoon with predominantly east winds. The variation of the west wind has weakened but the intensity is still quite a lot.

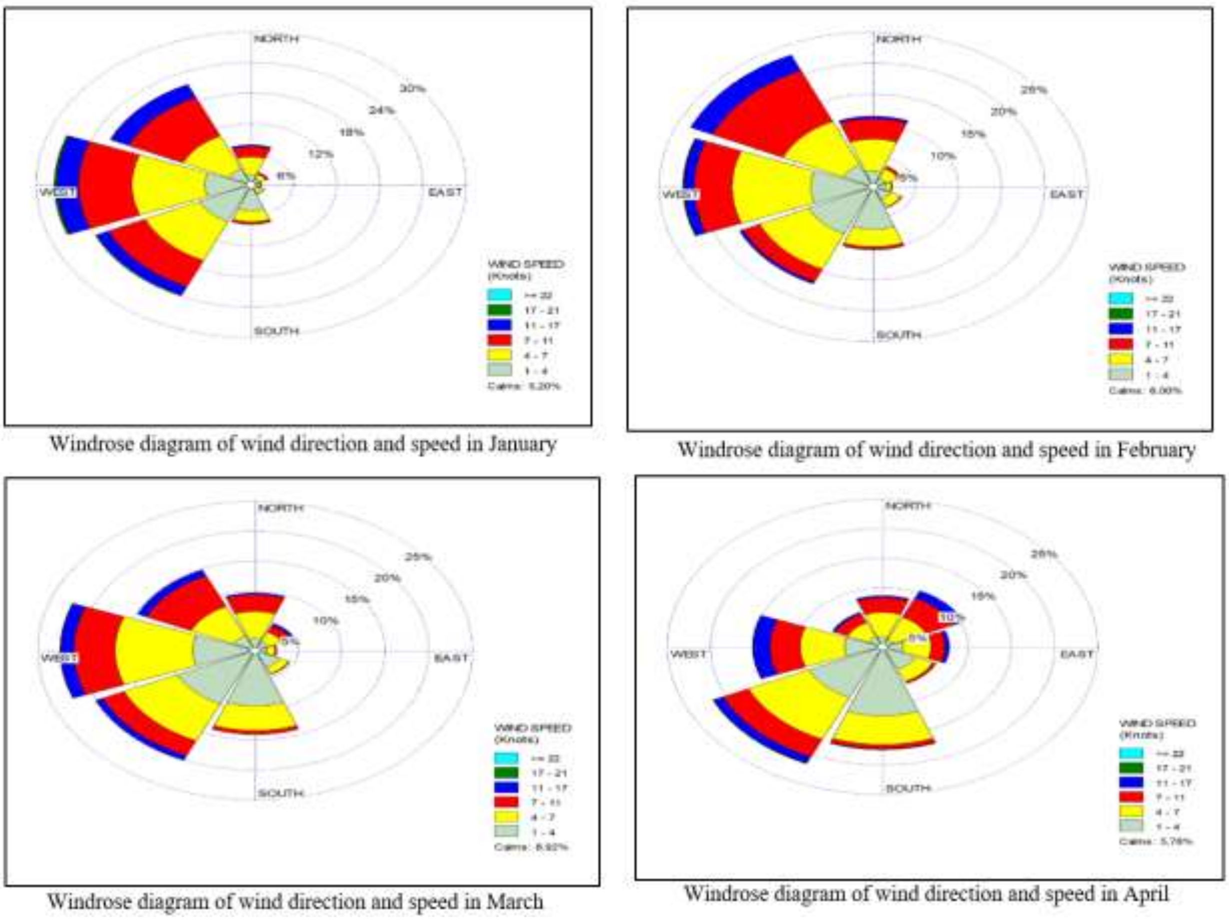

Figure 2. Windrose diagram of wind direction and speed.

3.8. August

The profile of wind direction and speed in August for the 10-year period (2013-2022) shows that the wind direction is dominated by northeast to east with variations in south wind direction. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 33% and the average value of wind speed is 5.2 knots. The maximum wind speed recorded in 10 years reached 24 knots. The characteristic conditions of August winds in the Indonesian region are influenced by the Australian monsoon with predominantly east winds.

3.9. September

The profile of wind direction and speed in September for the 10-year period (2013-2022) shows that the wind direction is dominated by northeast with variations in north, east, and south wind directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 33% and the average value of wind speed is 5.2 knots. The maximum wind speed recorded in 10 years reached 20 knots. The characteristic conditions of September winds in the Indonesian region are influenced by the Australian monsoon with predominantly east winds. Variations of westerly winds still blow but the speed is not significant. Figure 3 are the profile of wind direction and speed in May, June, July, August, and September for the last 10 years (2013-2022).

3.10. October

The profile of wind direction and speed in October for the 10-year period (2013-2022) shows that the wind direction is dominated by south to southwest with variations in north, northeast wind direction. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 36% and the average value of wind speed is 4.7 knots. The maximum wind speed recorded in 10 years reached 25 knots. The characteristic conditions of October winds in the Indonesian region have variations where the intensity of the west wind has begun to dominate. However, the easterly wind is still quite significant, characterised by its strong wind speed.

3.11. November

The profile of wind direction and speed in November for the 10-year period (2013-2022) shows that the wind direction is dominated by south to west with variations from north to northeast wind direction. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 36% and the average value of wind speed is 4.8 knots. The maximum wind speed recorded in 10 years reached 25 knots. The condition of November wind characteristics in the Indonesian region is experiencing a transition where the intensity of the west wind has begun to dominate. However, the easterly wind is still quite significant, characterised by its strong wind speed.

3.12. December

The profile of wind direction and speed in December for the 10-year period (2013-2022) shows that the wind direction is dominated by southwest to northwest with variations in north and south wind directions. Then the dominating wind speed is in the interval 4-7 knots with a percentage of 41% and the average value of wind speed is 5.5 knots. The maximum wind speed recorded in 10 years reached 23 knots. The characteristic conditions of December winds are dominated by westerly winds. This condition is in line with the characteristics of the Indonesian region where in December, the active monsoon is the Asian monsoon so that the dominant wind blowing is the west wind. Figure 4 are the profile of wind direction and speed in October, November and December for the last 10 years (2013-2022).

As a meteorologist, the authors will outline the ways in which this data contributes to optimizing airport operations and reducing costs. First, enhanced flight safety and efficiency. Surface wind data is integral in ensuring the safety and efficiency of aircraft operations, particularly during takeoff and landing. Accurate wind information helps pilots make informed decisions about runway selection and approach paths, reducing the likelihood of accidents and improving overall flight efficiency. This leads to fewer delays and cancellations, which not only enhances passenger satisfaction but also reduces the costs associated with disruptions in airport operations.

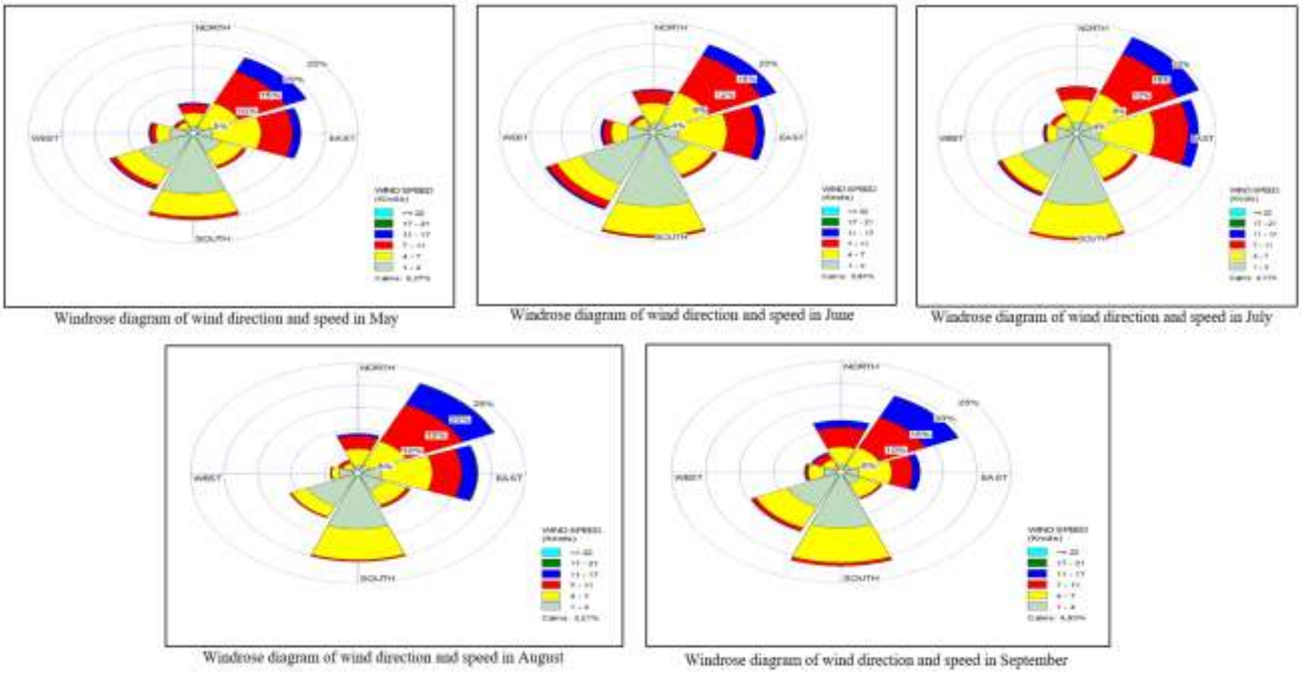

Figure 3. Windrose diagram of wind direction and speed.

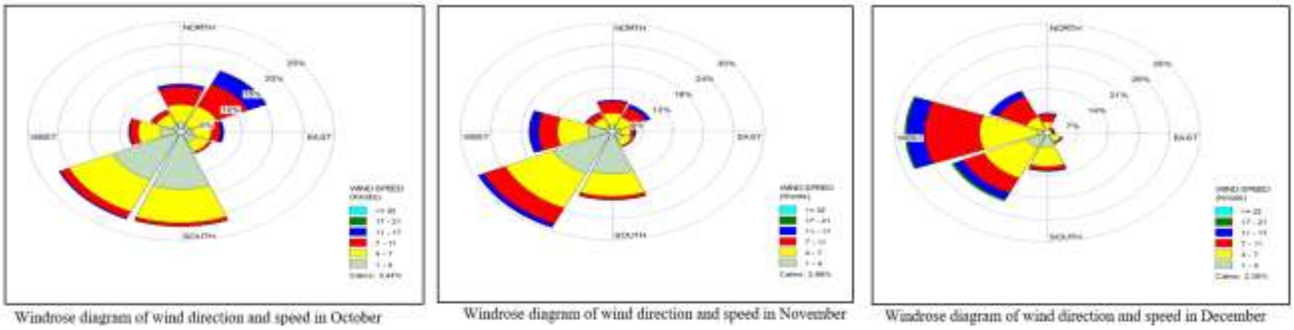

Figure 4. Windrose diagram of wind direction and speed.

Second, optimized fuel consumption. By providing precise information about wind speed and direction, surface wind data allows airlines to optimize fuel consumption. Pilots can adjust flight paths to take advantage of tailwinds or avoid headwinds, resulting in significant fuel savings. This reduction in fuel usage lowers operational costs for airlines, contributing to greater profitability and a more sustainable aviation industry.

Third, reduction in maintenance costs. Surface wind data helps in anticipating and mitigating wear and tear on aircraft caused by adverse weather conditions. By avoiding rough landings and ensuring smoother takeoffs, the strain on aircraft components is minimized, leading to reduced maintenance costs. Over time, this can translate into substantial savings for airlines, which can then reinvest in other areas of operation.

Fourth, informed infrastructure development. For airport authorities, surface wind data is essential in making informed decisions about infrastructure development. Understanding prevailing wind patterns allows for the optimal placement and orientation of runways, reducing the need for costly adjustments or expansions in the future. This forward-looking approach ensures that airports are better equipped to handle current and future traffic, enhancing their economic viability.

Fifth, improved Air Traffic Management. Air traffic controllers rely heavily on surface wind data to manage the flow of aircraft efficiently. By coordinating takeoffs and landings based on real-time wind information, controllers can minimize delays and improve the throughput of aircraft at busy airports. This leads to better utilization of airport resources and increased capacity, directly contributing to higher revenues.

4. Conclusion

For more than 30 years until now, there have been many physical environmental changes both in terms of internal airport infrastructure and the environment around the airport when compared to the initial period of airport operations. Unfortunately, until now there has been no research specifically discussing how the surface wind pattern at Soekarno-Hatta International Airport during the last 10 years and its implications for flight operations both in terms of economy and flight safety operations. The statistical method of frequency distribution was chosen by the author because there have never been previous studies that used the frequency distribution method with long-term time series data and specifically focused on the monthly wind pattern at Soekarno-Hatta International Airport. Surface wind is the wind at a height near the surface of the earth obtained from measurements using an anemometer that is 10-12 metres high. Wind has two values, namely direction and speed. By using frequency distribution analysis of surface wind data, information can be obtained that is easy to read and understand the characteristics of the data. Processing of surface wind data in the Soekarno-Hatta Airport area shows that from January to April the surface wind direction is westerly (dominated from the west) with maximum wind speeds during the 10-year period being from 22 - 24 knots. The months of May to September are easterly (dominated from the east) with maximum wind speeds between 18 - 25 knots. The months of October, November, and December are a transition from easterly to westerly (dominated from the south and southwest) with maximum wind speeds between 23 - 25 knots. This is in line with the general pattern of Indonesia's climate which is influenced by the west monsoon and east monsoon phenomena. This monthly surface wind profile information is expected to be used by stakeholders in the Soekarno-Hatta Airport environment to support flight operations from both security and economic aspects. They are: enhanced flight safety and efficiency, optimized fuel consumption, reduction in maintenance costs, informed infrastructure development, and improved air traffic management. This research methodology can also be used for other airport areas in Indonesia, of course by making spatial and temporal adjustments.

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References

[1] Admin, "Bandara Soekarno-Hatta Raih Posisi Pertama Bandara Tersibuk di ASEAN," [Online]. Available: https://angkasapura2.co.id/id/news
[2] Y. Zhao and L. Sushama, "Aircraft takeoffperformance in a changing climate for canadian airports," *Atmosphere (Basel)*, vol. 11, no. 4, Apr. 2020, doi: 10.3390/ATMOS11040418.
[3] Admin, "Meteorologi dan Jalur Penerbangan," [Online]. Available: https://bakertrans.dephub.go.id
[4] M. Taszarek, S. Kendzierski, and N. Pilguj, "Hazardous weather affecting European airports: Climatological estimates of situations with limited visibility, thunderstorm, low-level wind shear and snowfall from ERA5," *Weather Clim Extrem*, vol. 28, Jun. 2020, doi: 10.1016/j.wace.2020.100243.
[5] DitjendHubud, "Daftar Bandar Udara Di Indonesia," [Online]. Available: https://hubud.dephub.go.id
[6] Soerjadi Wirjohamidjojo, *Meteorologi Praktik*, vol. 1. Jakarta: BMKG, 2006.
[7] "Annex ICAO".
[8] A. Wahab and A. Syahid, "Education and Learning Journal Penyajian Data Dalam Tabel Distribusi Frekuensi Dan Aplikasinya Pada Ilmu Pendidikan," vol. 2, no. 1, pp. 40–48, 2021, [Online]. Available: http://jurnal.fai@umi.ac.id
[9] Admin Lakes Software, "Wind Rose Plots for Meteorological Data," https://www.weblakes.com/software/freeware/wrplot-view/.
[10] A. Fadholi, "Jurnal Geografi," 2013. [Online]. Available: http://id.wikipedia.org/wiki/Bandara_Depat
[11] A.Hidayati *et al.*, "Pemilihan Runway Berdasarkan Arah Angin Tiap Musim", doi: 10.54147/langitbiru.v16i01.
[12] F. Fatkhuroyan, T. Wati, and A. Kamid, "Karakteristik Angin Dan Temperatur Disekitar Calon Bandara Kulon Progo Untuk Keperluan Take Off dan Landing Pesawat," Universitas Negeri Jakarta, 2018, pp. SNF2018-PA-85-SNF2018-PA-91. doi: 10.21009/03.snf2018.02.pa.11.
[13] B. Wijayanto, "Identifikasi Angin Silang (Cross Wind) di Sekitar New Yogyakarta International Airport Memakai Plot Wind Rose," Prosiding SNFA (Seminar Nasional Fisika dan Aplikasinya), 2020.

[14] T. Dwi Pratica and A. Fauzan, "Analysis of Surface Wind Patterns at Juwata Tarakan Airport for The Period of 2014-2020," [Online]. Available: http://digital.library.ump.ac.id/view/divisions/BookChapterISTED/2021.html

[15] J. W. Creswell, *Educational Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publication, Inc., 2014.