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# Incorporating Real Aircraft Safety Data Projects into Aerospace and Aviation Education

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# Incorporating Real Aircraft Safety Data Projects into Aerospace and Aviation Education

## Introduction

The use of data in aerospace programs is appealing to many students who want to learn data-driven analysis methods. Learning statistical analysis using data from real aircraft safety events may be even more appealing. In many programs, both Aerospace Engineering and Aviation Technology students are required to take courses in statistics to better develop an understanding of data and data analysis. Through these activities, students may be inspired to participate in future research. These activities may be used to scaffold students' knowledge and skills to become more interested in developing research questions. One way to do this is to develop an activity where students are participants in active learning exercises.

The project presented in this paper has already been completed, and this paper discusses the project and its results. Students can use this project as an example of how to do their own projects. This paper demonstrates one way that research techniques can be learned in the classroom for undergraduate students who may later use these analysis methods. Included in this paper is a suggested guideline for a six-week timeline for a research project.

An example in this paper is a project for students to develop and discuss practical use of weather data as a factor in aircraft incidents (runway excursions and near collisions) and accidents. Extreme weather data from rainfall and crosswinds is assessed to determine if there is a potential effect on aerospace safety at airports. The use of extreme value method (EVM), and correlation analyses were used in these exercises. EVM was used to identify the extreme cases of rainfall and crosswind; that is, when pre-determined thresholds of these weather phenomena were exceeded. Correlation analysis between the aircraft accidents and incidents versus the exceedances of the weather phenomena were conducted to ascertain whether these two variables are related in any way. The study area was Jomo Kenyatta International Airport (JKIA), Kenya, Africa; with its ICAO airport code being HKJK.

The data analysis may be used to demonstrate how heavy rains and extreme crosswinds affect aviation safety at airports. These types of projects may be used to enhance student knowledge in data analysis using data from those countries with available published data such as the Federal Aviation Administration (FAA), and many other aviation safety organizations. This paper could serve as a foundation for incorporating practical analyses and aviation safety information into courses in educational settings.

## A Project Example

This project is an example for a classroom activity to formulate a problem, get data, analyze data, identify results, and summarize. This project is designed to help undergraduate students develop skills in project execution and report writing. The project (see Table I) begins with an introduction that provides a brief overview of the project's background, objectives, and significance. The methods employed, including data collecting and analytic approaches, are described in the methodology section. Key findings are presented using visuals such as graphs, tables and charts to illustrate major results. Based on these findings, practical or theoretical recommendations are offered. A summary of the main conclusions and recommendations for additional research are included in the project's conclusion. Finally, a Q&A session will be held to address questions from peers and evaluators.

TABLE I.
EXAMPLE OF A SIX-WEEK TIMELINE

| Week | Activities | Deliverables |
|---|---|---|
| **1** | Finalize project topic and objectives; Identify scope and research questions; Discuss methodology and deliverables with the instructor | Project Proposal: Document with objectives, scope, timeline, and resources; Class presentation |
| **2** | Conduct literature review; Identify key theories, data sources, and case studies | Literature Review Report: Summary of key insights and gaps |
| **3** | Gather data from databases, field observations, and surveys; Conduct preliminary analysis to check data integrity | Data Collection Report: Sources, process, and initial findings |
| **4** | Apply trend analysis and identify key results; Address any challenges from initial findings | Interim Report: Summary of methods, results, and challenges; interim progress presentation |
| **5** | Develop solutions or recommendations based on analysis; Draft the final report | Draft Project Report: Includes methodology, results, and conclusions |
| **6** | Finalize report, prepare presentation, and deliver findings to the audience | Final Project Report and Presentation |

***Project Introduction***

Aircraft landings and take-offs are seriously endangered by rainfall and crosswinds, especially when aircraft and airport operating thresholds are surpassed by the conditions associated with these weather phenomena. Many facets of runway operations and aircraft safety are impacted by the effects of strong winds and heavy rain. Runway excursions are significantly more likely when strong winds and heavy rain are exceeded. It is difficult for airplanes to safely decelerate upon landing on wet or slick runways brought on by heavy rainfall because they decrease braking efficiency and raise the risk of hydroplaning [1]. Loss of runway control results from high crosswinds and wind shear, which impair landing stability [2]. Researchers found that unfavorable extreme rainfall and crosswinds were responsible for over 25% of runway excursions globally [1].

Weather conditions associated with rain and crosswinds can cause near collisions on the ground as well as in the air. Heavy rains reduce visibility, which impairs pilots' situational awareness, particularly during crucial stages like landing and departure. Furthermore, turbulence and strong winds make it more difficult to maintain a steady approach, which raises the possibility of deviating from the planned flight route [3]. Aircraft may occasionally need to make abrupt maneuvers to avoid severe weather, which increases the possibility of a near-collision with another aircraft [4]. According to pilot-reported occurrences, one of the main causes of near collisions in high-traffic airspace during rainfall and crosswinds is abrupt evasive maneuvers [2].

The research project presented in this paper is related to these airport operational studies [1], [3]. The sole distinction is that, whereas these studies were conducted in countries primarily in the north latitudes (such as China, Europe, and the United States), this study was conducted in Kenya, Africa, where the equator crosses that region. Understanding how rainfall and crosswinds effects differ in temperate and tropical regions is essential. The effects of rainfall and crosswinds on aviation and safety operations vary significantly in different latitudes. Equatorial and tropical regions often experience frequent and intense convective storms driven by high surface heating and moisture availability, resulting in heavy rainfall, strong gust fronts, and rapidly shifting crosswinds. In contrast, temperate regions generally experience less frequent but occasionally severe frontal and convective storm systems [5]. Higher-latitude regions encounter comparatively less convective activity but face distinct meteorological hazards, including icing, turbulence, and reduced visibility. Understanding these regional atmospheric differences is essential for effective flight planning, safety procedures, and the design of weather monitoring systems tailored to local climatological conditions [6].

This study is significant because exceeding rainfall and crosswind-related limits in aviation operations may have serious repercussions and impact airport operations. Strict adherence to operational limits during these conditions is critical to mitigate these risks and uphold the safety of passengers and crew [7].

The study's scope includes, among other things, meteorological phenomena, the study's period and the location of the airport. Rainfall and crosswinds were examined. Each of these phenomena has boundaries set by the International Civil Aviation Organization (ICAO). In the rain gauge, rainfall limits correspond to 7.6 mm of precipitation per hour; any quantity above that is regarded as heavy or extreme rainfall [8]. Most airports adhere to the recommended crosswind component limit of 15 knots for light aircraft [9]. The direct and indirect consequences of rainfall and crosswinds that went outside its limits on runway excursions, near collisions, and accidents were investigated. In Kenya, rainfall and crosswinds are most severe and common, especially during the two main rainy seasons (October–December and March–May), which presents substantial difficulties for aviation safety [10]. March, April, and May were the study's months (from 2008 to 2017) which coincided with the year's first extended rainfall.

Kenya was the study region. Kenya is in Africa between longitudes 34ºE and 42ºE and latitudes 4 1/2ºN and 4 1/2ºS. The airport under investigation was Jomo Kenyatta International airport (HKJK).

***Project Research Questions***

The project's main objective was to introduce extreme value method to determine the effects of heavy rains and extreme crosswinds on aviation accidents and incidents at HKJK. The specific research questions pursued to accomplish the overall objective were:

1. What are the March, April and May characteristics of heavy rains and extreme crosswinds at HKJK for a 10-year period (2008-2017)?
2. How many exceedances of rainfall and crosswind hours are there at HKJK during airport operation hours for the 10-year study period?
3. What is the relationship between exceedance of rainfall and crosswind hours and aircraft incidents and accidents at HKJK?

### *Project Data and Methodology*

The types of data that were gathered and the techniques employed to accomplish goals are presented in this section.

## Project Data Types and Sources

The dataset for the study includes hourly rainfall totals, wind directions and speeds, and components of aircraft accidents and incidents for HKJK. All the data collected about rainfall and crosswinds as well as incidents and accidents involving airplanes were secondary data. The data sources and data types available vary by country. In the USA, the Federal Aviation Administration, the US Department of Transportation, and the National Weather Service have data, transportation, and airport information. This example used data from Kenya.

### *Project Data for Rainfall and Crosswinds*

Global Precipitation Measurement, or GPM, provided the rainfall data [11]. These data are data from satellites. The airport location latitudes and longitudes were determined by using publicly available maps, then the rainfall amounts for that specific location was found. Millimeters (mm) were used to measure rainfall data. Hourly crosswinds data were obtained from Meteorological Terminal Air Report (METAR) in the Ogimet website [12].

$$\text{Crosswind} = V \sin \theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Equation (1)}$$

Where

$V$ is the wind speed measured in knots (nm/hr, nautical miles per hour).
$\theta$ is the angle formed by the wind and runway directions, both measured from true north.

Runway orientation at airports is typically determined based on prevailing wind conditions to minimize crosswind components and enhance operational safety. At Jomo Kenyatta International Airport (HKJK), the runway is oriented along 06/24 (approximately 060°/240°), which aligns closely with the dominant northeasterly wind direction observed in the Windrose (Fig. 1). This alignment indicates that the runway configuration is consistent with the persistent wind patterns at the site, thereby reducing crosswind exposure during most operations. The Windrose therefore plays a critical role in this study by visually confirming the prevailing wind direction and supporting the interpretation of crosswind behavior and exceedance patterns observed in the dataset [13].

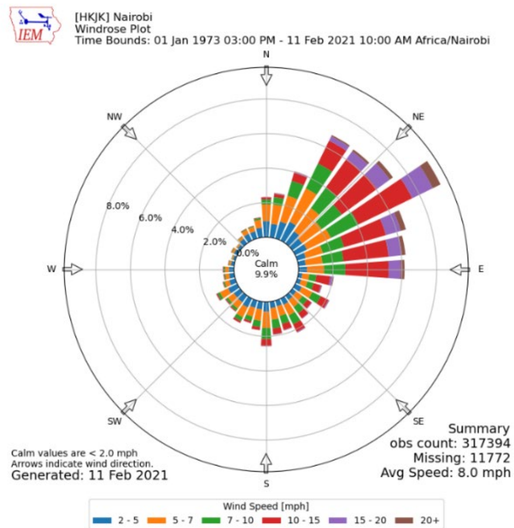


Fig. 1: Map showing a Windrose for HKJK airport, indicating the persistent wind direction.

Source: The data are from "Iowa Environmental Mesonet", by Iowa State University. *Publicly available and acceptable educational resource maps for use.*

***Project Data for Aircraft Accidents and Incidents***

The Kenyan Ministry of Transportation, Infrastructure, Housing, Urban Development, and Public Works; the State Department of Transportation; and the Air Investigation Department were the sources of the accident data. The Kenya Airports Authority (KAA) were the sources of the incident data. Both these data covered the study period (2008-2017).

## Project Methodology

The project steps are to brainstorm ideas, come up with a topic, identify scope and research questions. Thereafter, work on literature review and methodology. Later, collect the data for rainfall amounts, crosswinds, and accidents and incidents (or use data provided by the instructor), perform temporal trend analysis, perform extreme value method analysis and perform correlation analysis. The analysis results are presented in the results and discussion sections. The project concludes with conclusions and recommendations. The report can then be presented to the audience.

***Temporal Trend Analysis***

To ascertain if the frequency of rainfall and crosswinds events was rising, falling, or staying constant on monthly and seasonal timescales, time series plots were employed. It was determined whether there was a trend for rainfall and crosswinds occurrences during March-

April-May seasons with a 95% confidence level using the Mann-Kendall (MK) non-parametric trend test. When used to identify stations with considerable or extensive deviations and to qualify these findings, the MK test performs best [14].

Analysis of wind roses was also done by identifying the runway alignment of a particular airport and the winds to determine how crosswinds will be calculated. Moreover, these data explained the factors influencing wind speeds and direction.

### *Extreme Value Method Analysis*

The focus is on the exceedances $Y = X - u$, $(X > u)$

Where,

$Y$ is the exceedance
$X$ is a random variable of interest (e.g., rainfall measurement, crosswind measurement) and
$u$ is the threshold [15].

The days where exceeded rainfall and crosswind data limits were determined and counted.

### *Project Results and Discussion*

The following sections present the weather findings derived from the analyses, beginning with rainfall and its observed relationship to aircraft accident and incident patterns.

### Rainfall

The results showed that a sizable portion (99.17%) of the hourly rainfall did not exceed the limit of 7.6mm, as shown in Fig. 2. The days with no rainfall were represented by numerous hours with zero (0) mm of precipitation, as seen by the data along the bottom of the chart in Fig. 2. The x-axis represents time in each of the 3-month rainy seasons from March-May 2008 through March-May 2017. In this study, only a limited number of hourly rainfall values exceeded the defined threshold; 0.83% of the total study hours (10 years*92 days in March-April-May season*24 hours a day which comes to 22,080 hours) which is 183 rainfall hours. These exceedance periods were identified and analyzed against aircraft accident and incident occurrences using correlation technique.

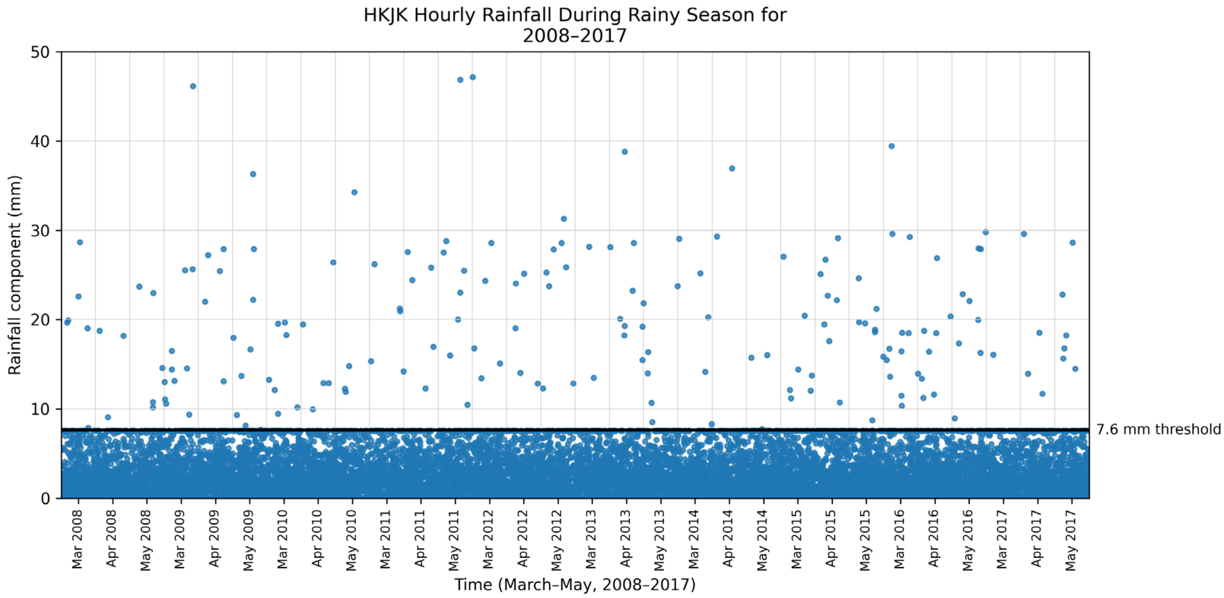


Fig. 2 shows HKJK's hourly rainfall (mm) for March–May (2008–2017), with the ICAO 7.6 mm threshold indicated by a bold line.

## Crosswinds

Most of crosswind component data were 15 knots or less, as shown in Fig. 3. 1.09% of total crosswind hours exceeded the threshold limits, which is 240 crosswind hours (1.09/100*22,080). The Windrose indicates that wind direction is mostly from northeastern directions. In extreme cases of windshear due to thunderstorms, rainfall or other weather phenomena, winds may flow in a different direction.

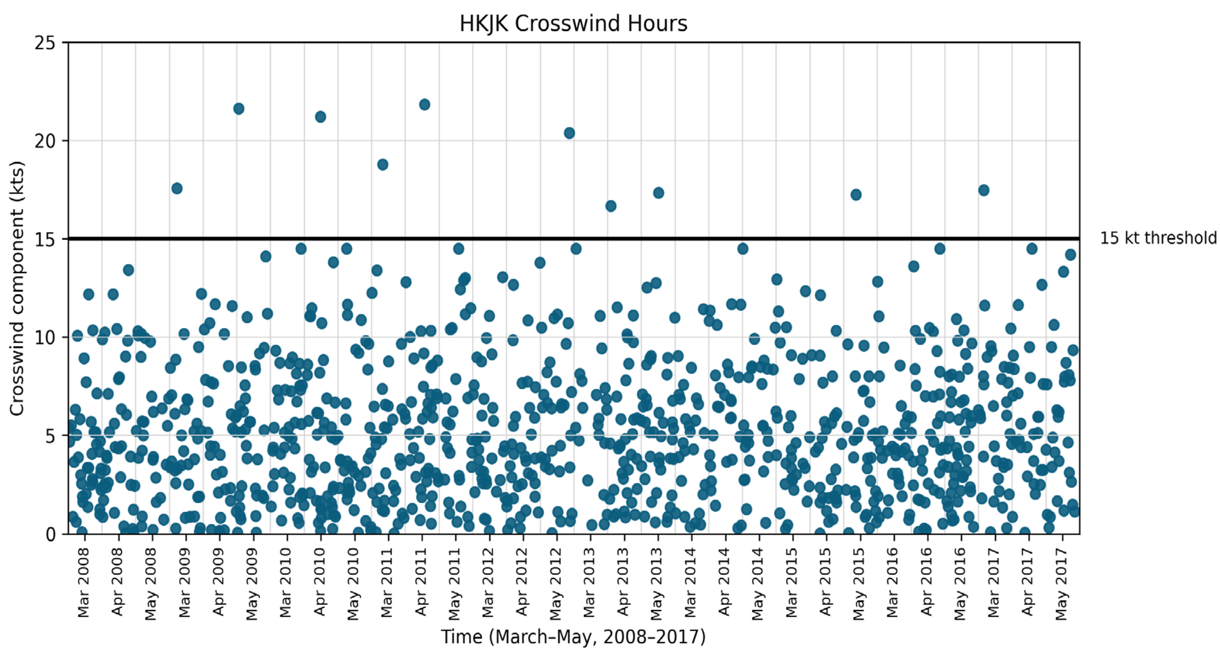

Fig. 3. The graph shows the maximum crosswind hours for each day during the March, April, and May rainy season for HKJK from 2008 to 2017. The ICAO's 15 knot cross wind limit is shown by the black continuous bold line.

**Project Data for Aircraft Accidents and Incidents during March-April-May 2008-2017 for HKJK**

HKJK had 39 incidents of near-collision and 46 incidents of runway excursions during the study period. The 39 near collisions occurred in 7 days while the 46 runway excursions occurred in 18 days. HKJK had average of 145 flights (landings and takeoffs) per day. Table II shows the day, flights, incidents (near collisions), percentage of an incident per flight and the weather phenomena (where rainfall or crosswind exceedance the limits). There were no accidents reported at this airport for the study period caused by either rainfall or crosswinds. On the other hand, Table III shows same features as Table II, but the difference is the type of incident, for Table III being runway excursions.

TABLE II
AIRCRAFT INCIDENTS (NEAR COLLISIONS) AGAINST THE EXCEEDANCE OF A WEATHER PHENOMENON THAT OCCURRED DURING MARCH-APRIL-MAY FROM 2008 TO 2017 FOR HKJK

| Day | Flights | Near collisions | % of near collisions/flight | Exceeded Rainfall Hours | Exceeded Crosswinds hours |
|---|---|---|---|---|---|
| 1 | 145 | 1 | 0.0069 | 7 | 3 |
| 2 | 147 | 8 | 0.0544 | 9 | 4 |
| 3 | 146 | 2 | 0.0137 | 5 | 5 |
| 4 | 148 | 2 | 0.0135 | 3 | 3 |
| 5 | 150 | 1 | 0.0067 | 8 | 8 |
| 6 | 142 | 10 | 0.0704 | 7 | 7 |
| 7 | 143 | 15 | 0.1049 | 8 | 9 |

TABLE III
AIRCRAFT INCIDENTS (RUNWAY EXCURSIONS) AGAINST THE EXCEEDANCE OF A WEATHER PHENOMENON THAT OCCURRED DURING MARCH-APRIL-MAY FROM 2008 TO 2017 FOR HKJK

| Day | Flights | Runway excursions | % of runway excursions /flight | Exceeded Rainfall Hours | Exceeded Crosswinds hours |
|---|---|---|---|---|---|
| 1 | 141 | 2 | 0.0142 | 1 | 1 |
| 2 | 141 | 2 | 0.0142 | 0 | 3 |
| 3 | 141 | 3 | 0.0213 | 3 | 1 |
| 4 | 145 | 3 | 0.0207 | 3 | 5 |
| 5 | 146 | 1 | 0.0069 | 1 | 1 |
| 6 | 143 | 1 | 0.0070 | 1 | 0 |
| 7 | 142 | 1 | 0.0070 | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | 143 | 2 | 0.0114 | 1 | 5 |
| 9 | 145 | 3 | 0.0207 | 1 | 2 |
| 10 | 145 | 7 | 0.0483 | 1 | 0 |
| 11 | 145 | 1 | 0.0069 | 1 | 5 |
| 12 | 146 | 3 | 0.0206 | 2 | 2 |
| 13 | 146 | 4 | 0.0274 | 5 | 4 |
| 14 | 144 | 2 | 0.0139 | 7 | 3 |
| 15 | 142 | 7 | 0.0493 | 5 | 3 |
| 16 | 144 | 1 | 0.0069 | 1 | 2 |
| 17 | 144 | 2 | 0.0139 | 2 | 1 |
| 18 | 145 | 1 | 0.0069 | 1 | 0 |

**Project Thunderstorm-related Phenomena Exceedances Over a Particular Limit**

There were exceedances of rainfall and crosswind limits from HKJK. Table IV illustrates that there were few exceedances, confirming that weather extremes are typically uncommon but can pose serious risks when they do occur.

Rainfall and crosswinds exceedances were approximately 1%. Less than 2% of all observations were made up of each exceedance. This study concurs the findings in another report [16] that found that less than 2.2% of the rainfall at Nnamdi Azikiwe International Airport in Nigeria exceeded the permissible limits [16].

TABLE IV
EXCEEDANCES OF RAINFALL AND CROSSWINDS DURING MARCH-APRIL-MAY FROM 2008 TO 2017 FOR HKJK AIRPORT

| **Airport** | **Rainfall exceedances per total rainfall data hours** | **Crosswind exceedances per total crosswind hours** |
|---|---|---|
| **HKJK airport** | 0.83% | 1.09% |

**Relationship between exceedance of rainfall and crosswinds with aircraft incidents and accidents at HKJK**

Correlation analyses were conducted between these two variables (weather phenomena and aircraft accidents and incidents) to ascertain the relationship between them.

***Correlation Analysis***

As shown in Table II, correlations were examined between % of near collisions/flight vs exceeded rainfall hours as well as vs exceeded crosswind hours. Correlation was also done, as shown in Table III, on % of runway excursions/flight vs exceeded rainfall hours and vs exceeded crosswind hours. The correlation coefficients are shown in Table V, which indicate that both heavy rainfall and substantial crosswind events were significantly associated with the occurrence of aircraft incidents.

TABLE V
SHOWING CORRELATION COEFFICIENTS BETWEEN RAINFALL AND CROSSWINDS-RELATED EXCEEDANCES AND AIRCRAFT INCIDENTS AT HKJK AIRPORT

| Aircraft Incident | Correlation of Rainfall exceedances to events | Correlation of Crosswind exceedances to events |
|---|---|---|
| **Near collisions** | **0.454** | **0.585** |
| **Runway excursions** | **0.383** | **0.042** |

For most of them, there was a moderate correlation between meteorological phenomena and aircraft incidents at this airport. Both heavy rains and crosswinds affected near collisions at 0.454 and 0.585 respectively. On the other hand, only heavy rains affected runway excursions at 0.383; the results suggest that hydroplaning from rainfall on runways may be a significant contributor as shown in Table V. Crosswinds did not affect the runway excursions as evidence by the weak correlation of 0.042. The results may suggest that either the crosswinds weren't strong enough or the pilots had sufficient training to deal with these crosswinds. No accident occurred at HKJK, therefore any relationship between the weather components and aircraft accidents could not be determined.

In general, HKJK aircraft incidents were impacted by heavy rainfall and to some extent by crosswinds. This indicates that more aircraft incidents occurred when rainfall and crosswinds tended toward the extremes than when the weather phenomena are in normal range. This is consistent with a previous research study [17].

***Project Conclusion and Future Work***

The goal of the project was to use real data in a classroom or homework exercise to answer three research questions:

1. What are the March, April and May characteristics of heavy rains and extreme crosswinds at HKJK for a 10-year period (2008-2017)?

2. What is the quantity of exceedances of rainfall and crosswinds limits at HKJK during airport operation hours?

3. What relationship exists between aircraft incidents and accidents at HKJK and exceeding rainfall and crosswind limits?

Based on the analysis of data, the project team found that:

1. The temporal characteristics of heavy rain data and extreme crosswind data at HKJK airport were presented using dot graphs of these data versus time over the rainy

seasons in years 2008-2017. The results showed that an overwhelming portion of the rainfall hours did not exceed the ICAO limits. Time periods with no rainfall were represented by zero (0) mm of precipitation. Relatively few hours exceeded the rainfall threshold limit.

2. The exceedance of rainfall and crosswinds limits at HKJK were estimated using real data from satellite downloads. About 0.83% of the rainfall data collected exceeded ICAO's 7.6 mm hourly rainfall limit. About 99% of the crosswind data were 15 knots or less. Only 1.09% of the data collected showed an exceedance of the threshold amount of 15 knots. This indicates that wind direction is majorly persistent in a specific direction and only in extreme cases of windshear due to thunderstorm, rainfall or other weather phenomena when winds may flow faster and/or in a different direction.

3. Correlation analysis was used to examine the association between aircraft incidents and accidents at HKJK and exceeding rainfall and crosswind restrictions. Data used were from the results of research questions 1 and 2. With 85 incidents of near collisions and runway excursions, and a total of 133,478 flights, HKJK had less than a tenth of a percentage (0.06%) of flights with these events during this timeframe and associated with rainfall or crosswind exceedances. There were no accidents at HKJK due to rainfall or crosswind exceedances during the study period. The project used extreme value method to determine the effects of heavy rains and extreme crosswinds on aviation accidents and incidents at HKJK. The study found out that exceeding the threshold values for rainfall and crosswinds had a negative impact on aviation by increasing the number of aircraft incidents. Exceedances may result in fatalities, a range of injuries from minor to serious, and significant financial losses for both individuals and the government due to aircraft damage or potential wing or hull loss.

Most of this study supports the findings of the Jagero study [10], which showed that rainfall and crosswinds are correlated with accidents and incidents, with an analysis of damage and injuries showing that weather-related hazards were the associated cause [10].

Future work may expand the scope of this study to other meteorological phenomena, other potential causes of accidents and incidents, and other airports in Kenya or other countries. A cross-comparison of accident and incident data with rainfall and crosswinds, and other meteorological conditions may provide insights into the effectiveness of exceedances, operational limits, and airport configurations [18].

## Discussion and Future Work

When presented with real data and real scenarios, students may become more interested in statistics and use of data-driven techniques. Developing an interest and honing their skills could aid them in solving problems or in their quest for answers through investigation. It is our opinion that aviation safety issues and their mitigation may become more interesting to students by integrating real aircraft safety data projects into aerospace and aviation education. Similar opinions are shared by other researchers in the use of real data in statistics instruction [19], [20].

Future work may include self-efficacy measurement comparisons for pre-test levels versus post-test levels to determine an estimate of students' beliefs about their knowledge of the techniques, their ability to perform the analyses, and on their ability to develop and answer their own research questions using these analysis techniques.

**Conclusions**

This paper presents a project example that can be applied in aerospace and aviation courses using real data from a specific airport. The project demonstrates how certain conditions relate to aviation safety events. Such assignments can help improve students' understanding of data analysis, particularly when using published datasets from organizations like the Federal Aviation Administration (FAA) and other aviation safety bodies worldwide. Overall, the paper provides a basis for integrating practical analysis and aviation safety concepts into classroom learning.

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