COMPARATIVE ANALYSIS OF THE EFFECTS OF MEASURED AND CALCULATED WIND SHEAR ON AIRCRAFT OPERATIONS IN SAM MBAKWE AIRPORT, IMO STATE, NIGERIA

[1] ONWUADIOCHI, I.C., [2] IJIOMA, M. A., [3] OZOEMENE, M. L.
[1,2,3] Department of Geography and Meteorology, Nnamdi Azikiwe University, Awka, Nigeria
Corresponding Author: ci.onwuadiochi@unizik.edu.ng

Abstract
This paper examined the relative effects of wind shear characteristics and its relationship with aircraft operations using Sam Mbakwe Airport, Imo State as a case study. The study discussed the differences between wind shear measured at 20m above ground level and wind shear calculated at 100m above ground level using power-law equation. Data on wind shear and aircraft operations (flight delays and cancellations) were obtained from Nigerian Meteorological Agency (NIMET) and Nigerian Civil Aviation Authority (NCAA) respectively. Correlation and Regression Analyses were carried out for the calculated wind shear and flight delays and cancellations. Scatter plots were used to present the observations of wind shear, flight delays and cancellations. The study revealed that wind shear increases as altitude increases. It also revealed that the calculated wind shear had weak positive relationship with flight delays and cancellations. This implies that as wind shear increases, both flight delays and cancellations also increase. The correlation between wind shear calculated at 100m AGL and flight delays and cancellations were 0.193 and 0.394 respectively, showing that the calculated wind shear contributed to 51.3 percent and 67.3 percent of the flight delays and cancellations respectively. The regression relationship formulated was significant for the entire hypotheses because the P-values of the ANOVA were less than 0.05. Since the relationship was significant, the expressions can be used to predict the extent of flight delays and cancellations if the wind shear is known. The study therefore recommended that there should be training and retraining of the observers, meteorologists and engineers working with NIMET. By so doing, the aviation industry can be freed from the negative effects of wind shear.

KEYWORDS: Wind Shear, Characteristics, Comparative Analysis, Flight Delays, Flight Cancellations.

INTRODUCTION

Wind shear, otherwise known as wind gradient, is a weather phenomenon which adversely affects the aviation industry and aircraft operations (Azad, Rasul, Islam and Shishir, 2015). It is a factor of great importance in controlling the formation of hurricane and thunderstorm formation and destructive effects on the environment (Harding, 2011). It is

not surprising that many researchers have given it various definitions. For instance, Wilson, Goodrich and Carson (2005), in Aviation Meteorology, stated that wind shear is a change in the winds which is sufficiently abrupt to affect the performance of an aircraft so significantly that it challenges the compensation capabilities of the pilot and the aircraft.

While there could be a vertical and horizontal wind shear, the former is a critical factor in the determination of thunderstorm type and potential storm severity and airplane pilots regard the later as change in airspeed of 30 knots (15m/s) for light aircrafts, and near 45 knots (22m/s) for airliners at flight altitudes (Azad et al., 2015). Thus low level wind shear can affect aircraft airspeed during take-off and landing in disastrous ways, a condition which makes airliner pilots to be trained to avoid all microburst wind shear, that is, headwind loss in excess of 30 knots.

Wind shear is caused by a number of factors, but ground surface roughness and obstacles stand out in bold relief. For example, land and sea breezes trigger wind shear. It is therefore not surprising that pilots passing across the coastlines are always very careful, because this is where the breezes predominate (Mathew, 2006).Another controlling factor which influences wind shear by offsetting the pressure gradient force is friction on the earth's surface. With increasing wind speeds, friction between the air and the surface increases. Frictional resistance to wind provided by the surface of the earth is influenced by many variables such as: elevation, terrain roughness and topography (Abdulla, 2014).

The impact of wind shear on an aircraft is understood through the change in the aircraft's total energy, the sum of its kinetic and potential energy (Wilson et al., 2005). Changes in kinetic energy are related to changes in the airspeed, and changes in the potential energy are related to changes in altitude.Under certain conditions, the atmosphere is capable of producing dramatic shears very close to the ground. One of the atmospheric conditions capable of producing dramatic shears is the downburst from convective or cumuliform clouds (U.S Department of Transportation, Federal Aviation Administration, 2005).

To this end, this paper seeks to show the difference in wind shear at various heights. It will also show the relationships between wind shear calculated at 100m above ground level and flight delays and cancellations. The result of this paper will be very salient to the development of the aviation industry, especially now Nigerians lack knowledge of this phenomenon and is currently planning to boost her aviation industry.

MATERIALS AND METHODS

The Study Area

Sam Mbakwe Airport is in Ngor-OkpalaLocal Government Area of Imo State. Ngor-Okpala Local Government Area (L.G.A) is located between

latitudes $5^{0}21^{1}$and 5^{0} 71^{1}N and between longitudes 7^{0} 101^{1} and 7^{0} 131^{1}E. It is bounded to the east and west by Abia State and Ohaji-Egbema respectively and in the north and south by Owerri, Abor Mbaise and Rivers State respectively. The hydrogeophysical survey revealed that the study area is underlain by Benin Formation. This Formation consists of fine sand, medium sand, coarse sand to gravel, with clay and silt lenses (Opara, Onu and Okereafor, 2012).The area is a lowland area with humid tropical climate having a rainfall of over 2500 mm and mean annual temperature of 27.5^{0}C (Mathews-Njoku and Onweremadu, 2007). The mean annual relative humidity is 75 percent (Onyeagocha et al., 2014).



Fig. 1: Map of Nigeria Showing Imo State. Source: Ministry of Lands and Survey.Source: Ministry of Lands and Survey.

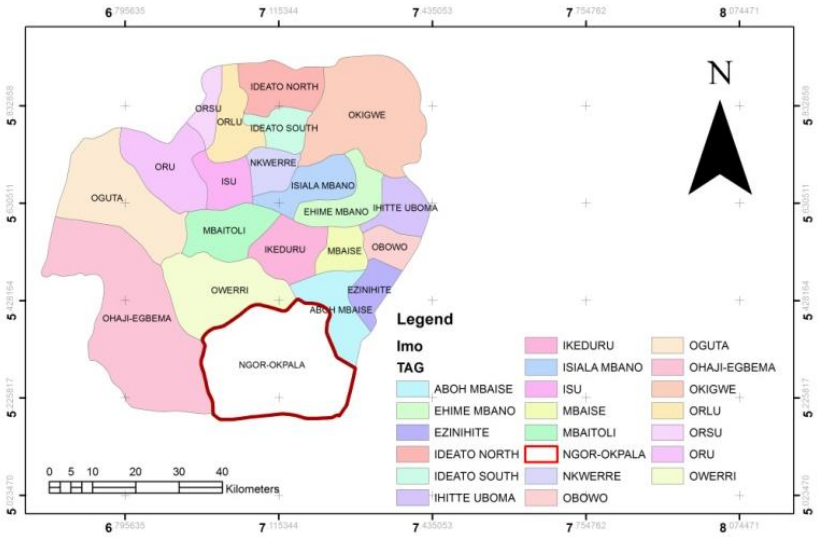


Fig. : Map of Imo State Showing Ngor-Okpala L.G.A.
Source: Ministry of Lands and Survey.Source: Ministry of Lands and Survey.

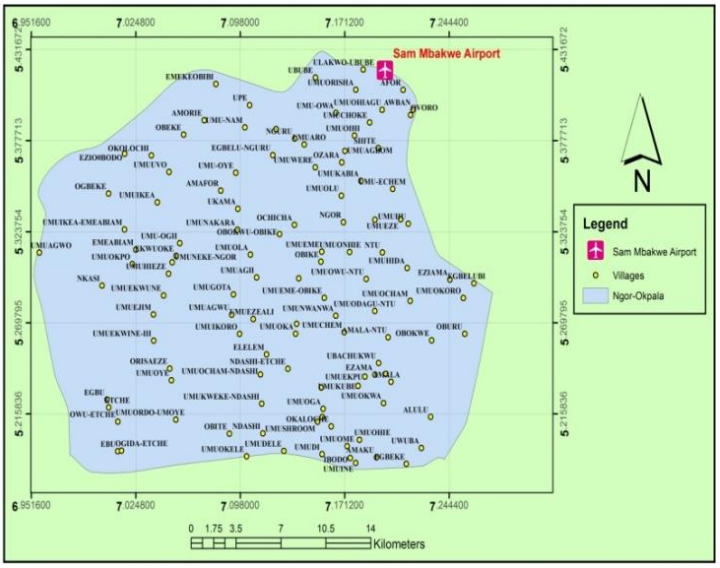


Fig.3: Map of Ngor-Okpala L.G.A Showing Sam Mbakwe Airport. Source: Ministry of Lands and Survey. Source: GIS Lab., Surveying and Geoinformatics Department, Unizik, Awka



Fig.4: Satellite Image of Sam Mbakwe Airport. Source: Ministry of Lands and Survey. Source: GIS Lab., Surveying and Geoinformatics Department, Unizik, Awka

Method of Data Collection

The data needed for this study were wind shear data measured at 20m above ground level, wind shear data calculated at 100m above ground level and data on flight delays and cancellations at Sam Mbakwe Airport, Imo State for the period of one and half years, from January 2014 to June 2015.The 20m height was chosen because this is the height at which wind shear is measured at Sam Mbakwe Airport, whereas 100m height was chosen because it is within the troposphere where aircrafts ply.The study

relied on data from secondary sources. The data on wind shear was obtained from the Nigerian Meteorological Agency (NIMET), while data on flight delays and cancellations were obtained from Nigerian Civil Aviation Authority (NCAA), both of them from Sam Mbakwe International Cargo Airport, Ngor-Okpala. Data on wind shear at the airport were recorded using Low Level Wind Shear Alert System (LLWAS). The Low-Level Wind Shear Alert System (LLWAS) detects low-level wind shear in the terminal area, thus, significantly increasing the operational efficiency and safety of the airport. The ground-based system provides both audio and visual alarms to Air Traffic Control (ATC) personnel in clearly represented numerical and graphical form.

Method of Data Analysis

There are two models used to calculate wind shear at an estimated height. These include power law and logarithmic law. In this study, to calculate the wind shear at 100 meters above ground level, the power-law which is represented by equation (1) was used. This is because it is a very simple and appropriate mathematical model to evaluate the wind shear at different heights using only one parameter (Wagner et al., 2011). The exponent (α) which is 1/7 comes from laboratory studies and has been found to give a good approximation of the wind profile in the natural atmospheric boundary layer (Abdulla,2014). Equation 1 presents the formula for power law.

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^{\propto} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where V_1 is the wind speed measured at certain height Z_1, V_2 is the wind speed measured at certain height Z_2, α is the wind shear exponent obtained empirically.

$$\propto = \frac{In(V_2/V_1)}{In(Z_2/Z_1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

The wind shear exponent (α) is not constant and depends on numerous factors, including atmospheric conditions, time of day, season, wind speed, nature of terrain, temperature, mechanical mixing parameters, and wind shear exponent can also differ by measurement heights (Abdulla, 2014). To examine the relationship between flight delays due to wind shear, the statistical technique that was employed is the Pearson's Product Moment Correlation method. This is because it is the most powerful correlation statistic. In order to estimate the proportion of the variations in flight delays and cancellations that are as a result of the variations in wind shear, the R-square, which is the coefficient of determination, was calculated. To test the significance of the Correlation Coefficient, F-test

(ANOVA) was employed. Regression analyses were carried out so as to determine the strength of relationship between wind shear and flight delays and cancellations.

Hypothesis Testing

H_O: There is no significant relationship between wind shear calculated at 100m above ground level and flight delays.

H_1: There is significant relationship between wind shear calculated at 100m above ground level and flight delays.

H_O: There is no significant relationship between wind shear calculated at 100m above ground level and flight cancellations.

H_1: There is significant relationship between wind shear calculated at 100m above ground level and flight cancellations.

RESULTS AND DISCUSSION

Comparative analysis between measured and calculated wind Shear

The result of field data on the comparative analysis between measured and calculated wind shear at 20m and 100m respectively is shown in table 1.

Table 1: Measured and calculated wind shear

Months	Wind shear measured at 20m AGL (Knots)	Wind shear calculated at 100m AGL (Knots)
J	46	58
F	30	38
M	50	63
A	84	106
M	34	43
J	46	58
J	75	95
A	175	221
S	113	142
O	44	55
N	2	3
D	2	3
J	94	118
F	96	121
M	36	45
A	121	152
M	64	81
J	9	11
Total	1121	1413

Source: Researcher's Work, 2015

Table 1 shows monthly variations of wind shear measured at 20m Above Ground Level (AGL) and wind shear calculated at 100m AGL using power-law equation. Wind shear measured at 20m above ground level ranges from 2to 175 knots with 0.178 percent and 15.61 percent respectively. Similarly, wind shear calculated at 100m above ground level ranges from 3 to 221 knots with 0.21 percent and 15.64 percent respectively. The calculated wind shear data showed increasing values. This means that wind shear increases with altitude. It implies that increase in altitude leads to increase in wind shear, as 100m is higher than 20m.This finding concurs with that of Abdulla (2014), that wind shear increases with increasing height above the ground. The increased wind shear values at 100m above ground level were as a result of the reduced influences on the turbulent flow of wind shear by the earth's surface. The result of field data on the relationship between wind shear calculated at 100m above ground level and flight delays is shown in table 2.

Table 2: Relationship between Wind Shear calculated at 100m AGL and Flight Delays

Months	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Wind Shear(X)	58	38	63	106	43	58	95	221	142	55	3	3	118	121	45	152	81	11
flight Delay(Y)	8	4	3	5	5	8	10	8	9	4	6	22	39	22	25	22	18	8

Source: Researcher's work, 2015.

As the rule suggests, accept the null hypothesis if the P-value of the test is greater than 0.05, otherwise, reject. Wind shear calculated at 100m is the independent variable whereas flight delay is the dependent variable. Correlation analysis was employed to show the nature of relationship and degree of relationship between the variables. The calculated relationship is shown in table 3.

Table 3: Correlation of Wind Shear and Flight Delay

	Wind Shear	***flight Delay***
Wind Shear	1	
flight Delay	0.193181	1

Source: researcher's work, 2015.

3 indicates that correlation between a variable and itself is perfect correlation which is 1. Correlation between wind shear and flight delay is

0.193 which is less than 0.5. This implies there exists weak relationship between the variables but positive in nature. The positivity can be interpreted as a unit increase in wind shear leading to unit increase in flight delay. The illustration of field data on the relationship between wind shear calculated at 100m above ground level and flight delays is shown in figure 1.

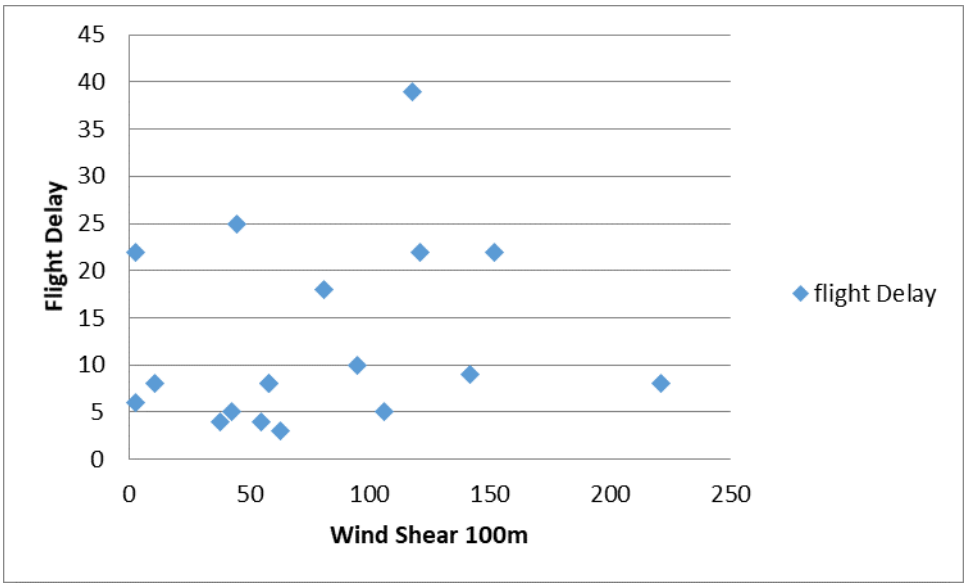


Fig.5: Scatter Plot of wind shear and flight delay

The regression model (Best Line of Fit) used to explain the proportion of the variations in flight delays as a result of the variations in wind shear is shown in table 4.

Table 4: Regression Model (Best Line of Fit)

Regression Statistics	
Multiple R	0.716533
R Square	0.513419
Adjusted R Square	0.454596
Standard Error	11.33138
Observations	18

Source: Researcher's work, 2015.

Regression model performed had a standard error of 11.3. This shows that the number of flight delays estimated from the regression equation will have a 95 percent chance of falling within +/-11.3 of the actual value. Obviously, the low value of the standard error of the estimate indicates that the regression model used is an accurate predictor of the estimate.Again, R-Square shows percentage of variation in the dependent

variable that can be explained by the independent variable. In the model used, the R-Square is 51.3 percent which implies wind shear is responsible for 51 percent of the flight delay. The result of the test of adequacy of the model using F-test (ANOVA) is shown in table 5.

Table 5: Test of Adequacy of the model using F-test (ANOVA)

	df	*SS*	*MS*	*F*	*Significant F*
Regression	1	2303.199	2303.199	17.93767	0.00063
Residual	17	2182.801	128.4001		
Total	18	4486			

Source: researcher's work, 2015.

Regression relationship is said to be significant if the P-value of the ANOVA is less than 0.05, otherwise, the model is insignificant. This then means thatthe P-value of the F-test is 0.0006 which is less than 0.05. There exists enough evidence to conclude that the model formulated is significant. The result for the extent of predictability of flight delay is shown in table 6.

Table 6: Model Specification

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Wind Shear	0.117552	0.027755	4.235289	0.000558	0.058993	0.176111

Source: Researcher's work, 2015.

The model can be written as

Y = 0.118X …… (3)

This could be interpreted to mean that a unit increase in wind shear is leading to 0.118unit increase in flight delay. Since the relationship is significant, the expression can be used to predict the extent of flight delay if the wind shear is known. Therefore, there is significant relationship between wind shear measured at 100m AGL and flight delay.

The result of field data on the relationship between wind shear calculated at 100m above ground level and flight cancellations is shown in table 7.

Table 7: Relationship between Wind Shear calculated at 100m AGL and Flight Cancellations

Months	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Wind Shear(X)	58	38	63	106	43	58	95	221	142	55	3	3	118	121	45	152	81	11
Flight Cancellation(Y)	2	2	2	5	2	1	2	3	1	1	2	1	2	1	1	2	2	0

Source: Researcher's work, 2015.

As the rule suggest, accept the null hypothesis if the P-value of the test is greater than 0.05, otherwise, reject. Wind shear calculated at 100m is the independent variable whereas flight delay is the dependent variable. Correlation analysis was employed to show the nature of relationship and degree of relationship between the variables. The calculated relationship is shown in table 8.

Table 8: Correlation of Wind Shear and Flight Cancellation

	Wind Shear	***Flight Cancellation***
Wind Shear	1	
Flight Cancellation	0.394286	1

Source: Researcher's work, 2015.

Correlation between a variable and itself is perfect correlation which is 1 as shown in table 8. Correlation between Wind Shear and Flight cancellation is 0.394 which is less than 0.5. This implies there exists weak relationship between the variables but positive in nature. The positivity can be interpreted as a unit increase in wind shear leading to unit increase in flight cancellation. The illustration of field data on the relationship between wind shear calculated at 100m above ground level and flight cancellations is shown in figure 2.

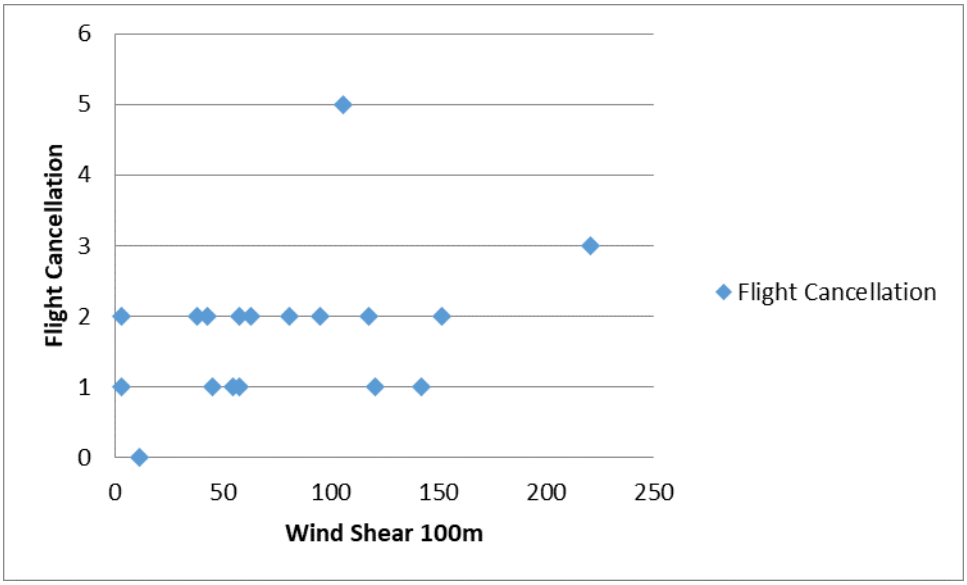


Fig. 6: Scatter Plot of wind shear and flight cancellation

The regression model (Best Line of Fit) used to explain the proportion of the variations in flight cancellations as a result of the variations in wind shear is shown in table 9.

Table 9: Regression Model (Best Line of Fit)

Regression Statistics	
Multiple R	0.820148
R Square	0.672642
Adjusted R Square	0.613819
Standard Error	1.209745
Observations	18

Source: Researcher's work, 2015.

Model performed had a standard error of 1.2. Therefore, this shows that the number of flight delays estimated from the regression equation will have a 95 percent chance of falling within +/-11.3 of the actual value. However, the low value of the standard error of the estimate indicates that the regression model used is an accurate predictor of the estimate. In addition to that, R-Square shows percentage of variation in the dependent variable that can be explained by the independent variable. In the model used, the R-Square is 67.3 percent which implies that wind shear is responsible for 67 percent of the flight cancellation. The result of the test of adequacy of the model using F-test (ANOVA) is shown in table 10.

Table 10: Test of Adequacy of the model using F-test (ANOVA)

	df	*SS*	*MS*	*F*	*Significant F*
Regression	1	51.12081	51.12081	34.93095	0.000022
Residual	17	24.87919	1.463482		
Total	18	76			

Source: Researcher's work, 2015.

Regression relationship is said to be significant if the P-value of the ANOVA is less than 0.05, otherwise, the model is insignificant. However, this then means that the P-value of the F-test is 0.000022 which is less than 0.05. There exists enough evidence to conclude that the relationship is significant. The result for the extent of predictability of flight cancellation is shown in table 11.

Table 11: Model Specification for hypothesis 4

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Wind Shear	0.017513	0.002963	5.910241	1.712105	0.011261	0.023765

Source: Researcher's work, 2015.

The model can be written as
Y = 0.018X …….. (4)

This could be interpreted to mean that a unit increase in wind shear is leading to 0.018unit increase in flight cancellation. Since the relationship is significant, the expression can be used to predict the extent of flight cancellation if the wind shear is known. Therefore, there is significant relationship between wind shear measured at 100m AGL and flight cancellation. The findings concur with Jones (2004a), Weli and Ifediba (2014) and Enete, Ajator and Nwoko (2015), that most of flight delays and cancellations were caused by weather conditions such as wind shear, thunderstorm, poor visibility and squall. However, since flight delays and cancellations show weak relationships with wind shear, there may be other significant variables in the study area, for example operational inefficiencies.

RECOMMENDATIONS

For the effects of wind shear on aircraft operations to be curbed, there should be training and retraining of Meteorologists, Air Traffic Controllers and Engineers working with Nigerian Meteorological Agency (NIMET), Federal Airports Authority of Nigeria (FAAN) and Nigerian Air Space Management Agency (NAMA), so as to update their knowledge on the negative effects of wind shear in the aviation industry in the country. The same should be done in the agencies involved in the observing, forecasting and dissemination of weather information in other countries. Also, pilots should be well trained and retrained, so that they can have good knowledge of wind shear and other hazardous weather phenomena.

CONCLUSION

This paper has tried to identify wind shear as one of the major hazards which the aircrafts and pilots encounter. It was revealed that the Atmospheric Boundary Layer (ABL) at Sam Mbakwe Airport is influenced by the presence of the earth's surface. The work showed that wind shear increased with increasing height above ground level. The paper also revealed that wind shear contributed to the delays and cancellations of flight schedules at the airport. This is because the correlation between wind shear and flight delays and cancellations were positive. The regression analyses

conducted also showed that there were significant relationships between the variables. The study also has some models formulated, which can be used to predict the extent of flight delays and cancellations if the wind shear is known.

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