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TURBULENT WEATHER EVENTS AND AIRCRAFT OPERATIONS: IMPLICATIONS FOR AVIATION SAFETY AT THE PORT HARCOURT INTERNATIONAL AIRPORT, NIGERIA

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ABSTRACT: *This study examined turbulent weather conditions and their relationship to aircraft operations as well as the influence of dry and wet seasons on weather parameters of rainfall, thunderstorm and fog at the Port Harcourt International Airport. The aim was to identify which weather parameter affects aircraft operations which entails flight delay, cancellation and diversion. Data on turbulent weather conditions (fog, thunderstorm and rainfall) were obtained from the Nigeria meteorological agency, and data on flight operations was similarly obtained from the operators of different airline (Arik air, Dana and Aero contractors). The study revealed that for all aspects of aircraft operations thunderstorm associates rainfall had significant relationship with aircraft operations, as it accounted for 90.4% variations in flight delays, ($r = 0.951$) at $p>0.05$, it also accounted for 89.68% variations in the case of flight cancellation with an r value of 0.947, thunderstorm in the case of flight divert accounted for 88.36% variation with an r value of 0.940 at $p>0.05$. Findings indicate that thunderstorm was the only turbulent weather parameter that significantly affected aircraft operations especially cancellation of flight. The study also revealed that seasons influences weather parameters. The study therefore recommends an algorithm designed to forecast turbulence models jet stream, mountain induced turbulence, and convective induced turbulence to avert most especially flight cancellation which creates opportunity for losses.*

KEYWORDS: Thunderstorm; Torrential Rainfall; Aircraft Operation; Flight Cancellation; Flight Diversion; Fog.

INTRODUCTION

Turbulent weather and climate events have constituted serious threat to global economic growth over the past few years, especially to the socio-economy of developing nations. Despite the relative conducive weather of Nigeria compared to other countries (such as Muritania, Somalia, Japan etc.) there has been a marked increase in the cases of recorded flight delay, diversion and cancellation which in most cases, are attributed to poor weather conditions (see Weli and Ifediba, 2014). Air craft accident has not been an exception, but its occurrence though resulting to very devastating losses, has been on a low rate compared to other defects, with its highest occurrence between 2003 and 2006 (Alexender et al, 2016). Most of the air crashes, delays and cancellations were caused by turbulent weather conditions such as thunderstorm occurrence, poor visibility (associated with fog, dust haze, turbulent rainfall etc) wind shear and squall (Adefolalu, 2006). Despite the relatively conducive weather of Nigeria compared to other countries (such as Mauritania, Somalia, Japan etc.), wind shear and squall. Moreover, though there are other factors that contribute to the disruptions in flight efficiency (such as technical, operational and human factors) weather-related factors have proven to be the highest cause of interruptions in the efficiency of flight operations in Nigeria with more devastating losses, hence, the International Air Transport Association (IATA) stated that 71% of air

accidents in Nigeria are due to mainly poor weather conditions with the inclusion of human errors, ageing aircraft and deficiency in safety management system (ASRS, 2007).

The Nigerian aviation industry witnessed its darkest period between 2003 and 2010 when several aircraft accidents occurred, resulting in loss of lives. ASRS (2007) noted that out of a total of 376 air fatalities that occurred in Africa in 2005 alone, Nigeria accounted for 225 of them and concluded that Nigeria accounted for 9.3% of all air accidents in Africa. However, investigations revealed that the air crashes which occurred between 2003 and 2006 were traceable to bad weather and wind shear. Most crashes were associated with poor weather conditions, pilot error, mechanical failure etc (Koetse and Rietvield, 2009; Knecht, 2005). Generally, flight delay, cancellation, division and air craft accidents affect the Nigerian Aviation Industry as Ayoade (1988) has earlier noted that 'the vagaries of weather with references of the various meteorological parameters act malevolently against most of man's socio-economic activities'. Adefolalu, (1984) have classified the three major bad weather phenomena which pose disaster to air transportation in Nigeria (Fog, Harmattan dust haze and thunderstorm) under the different seasons observed in the country with thunderstorm occurrence classified under rainy season while fog and harmattan dust haze were termed dry season events. This implies that the phenomena are tied to the two major seasons in Nigeria. NOAA (2004) affirmed that weather affects flight operations. They also stated that almost 500 fatalities and 200 injuries have resulted from wind shear crashes since 1964 and that since 1985; wind shear also has caused numerous near accidents in which aircraft recovered just before ground contact. Rockwell et al (1981); Frank et al, (1997); Jones (2004), Griffiths (2006); NASA, ASRS (2007) and Hardy, (2011) attributed the dust haze induced visibility conditions, thunder-associated wind shear, fog and harmattan dust haze and the severe thunderstorm with associated electricity (lightning and thunder), hailstones, icing, low-level wind shear effect, Gustiness etc as weather related phenomena responsible for air craft accidents globally. Weli and Ifediba, (2014) examined various weather hazards which include thunderstorm, fog, dust haze and line squall that affect flight operation such as flight delays, diversion and cancellation. The study revealed that fog accounted for 13.2% of flight cancellation at the airport and line squall similarly accounted for 10.1% of delays, 8.4% of diversion and 20% of cancellation from 2000-2009 at the Murtala Mohammed International airport Lagos. Similarly, Enete et al (2015) examined only thunderstorm impact as the only hazard to flight operation. This study is a combination of weather hazards such as torrential rainfall, fog and thunderstorm impacting flight operation especially their implications for aviation safety at the Port Harcourt International airport. Previous studies however did not consider the incidence of torrential rainfall which is usually accompanied with a turbulent weather event of thunderstorms to flight operations. Similarly, the geographic locations of Port Harcourt and Lagos may exhibit different turbulent weather patterns which may influence aircraft operations. From the literature, there is dearth of empirical study of the influence of turbulent weather condition especially thunderstorm, fog and torrential rainfall on flight operations which is a daily occurrence in Port Harcourt International Airport in Nigeria. This is the gas which this study intends to fill in the literature. The recent Sosoliso air crash accident at the airport was attributable to turbulent weather condition. It therefore shows that for aviation safety to be guaranteed, a study such as this is very imperative and indispensable. This study therefore seeks to ascertain the influence of turbulent weather on air craft operations and its implications for aviation safety at the Port Harcourt International Airport.

In order to achieve this aim, the paper examined the various weather parameters that to a large extent, seem to affect aircraft operations at the airport; established the relationship between the

occurrences of these parameters and flight delay, cancellation and diversion; examined the nature, occurrence and variability of the weather phenomena in relation to its effects on air craft operations because of its implications for aviation safety.

The study Area

The area under study lies between latitude 4^{o} 72^{1}N and 4^{o} 91^{1}N and longitude 6^{o} 88^{1}E and 7^{o} 12^{1}E. Weather systems particularly rainfall in Nigeria are primarily as result of the interplay between two major pressure and wind systems. These are two dynamically generated sub-tropical high pressure cells entered over the Azores Achipelago (off the coast of North Africa) and St. Hellena Islands (off the coast of Namibia). These high pressure centers (or anticyclones) which are permanently generated and drive respectively the North-East trade wind and South-east trade wind of the South Atlantic Ocean. Both air streams blow over the air port at various seasons of the year. It is important to note that these air streams or masses follow the apparent movement of the sun which passes the region twice on its way to and from the tropic of cancer (Oyegun and Ologunorisa, 2002). These trade winds have been conditioned by the nature of their source regions having originated over the South Atlantic Ocean; the moist south-west wind transports its moisture to Nigeria. This air stream blows over the regions between the months of February and November. This is the period in which the region receives its rains. Conversely the north-east trade winds bring dry condition, having passed over in hot and dry Sahara desert to reach Nigeria from the north, this air stream blows over the study area.

METHODOLOGY

Data on turbulent weather conditions such as rainfall amount, thunderstorm and fog events from the year 2000 to 2012 were also collected from the Nigerian meteorological agency in the airport in Port Harcourt. Data on aircraft operations (such as flight diverts, delays and cancellations) were collected from the operators of Arik air, Dana air and Aero contractors for a period of twelve years (12yrs) (2000-2012). Multiple Regression (R) was used to examine which turbulent weather parameter that affects aircraft operations. Similarly the students t – statistic was used to determine the significant of the weather parameters on air craft operations at 95% probability level. The model equation of the stepwise multiple regression analysis is as follows:

$$Y = a + \beta_1 x_1 + \beta_2 x_2 + e \quad (1)$$

Where;

Y = aircraft operation
a = regression constant
β_1-β_2 = regression co-efficient
X_1= thunderstorm
X_2 = fog
X_3= rainfall amount
e = error term

The T-test was similarly used to examine the difference in the seasonal influences of turbulent weather conditions on aircraft operation.

RESULTS AND DISCUSSION OF FINDINGS

Yearly Turbulent Weather Characteristics of the Port Harcourt International Airport.

The figure 1 below shows a graphical representation of the spatial variation of mean monthly thunderstorm in the Port Harcourt international Airport for a period of twelve (12) years. It is observed that thunderstorm in the Airport varies from one month to the other and thunderstorm occurrence in the airport was high in october, followed by August and September respectively.

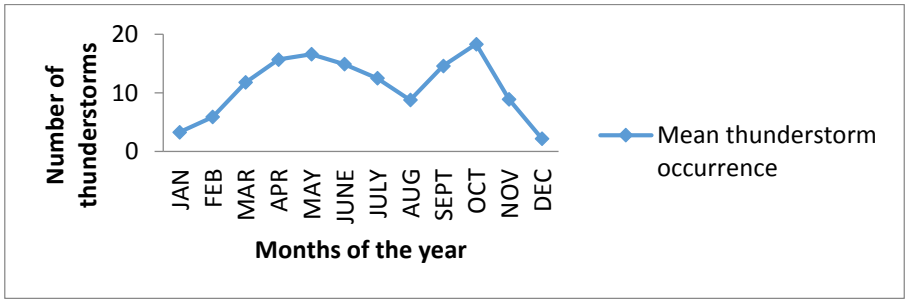

Fig 1: Mean monthly distribution of thunderstorm events (2000-2012)

The figure 2 below is a graphical representation of the variation of yearly thunderstorm event at the Port Harcourt international Airport for a period of twelve (12) years. .It is observed that thunderstorm occurrence in the Airport varies from year to year and thunderstorm occurrence in the airport was more in the year 2008, followed by 2007 and 2000 respectively.

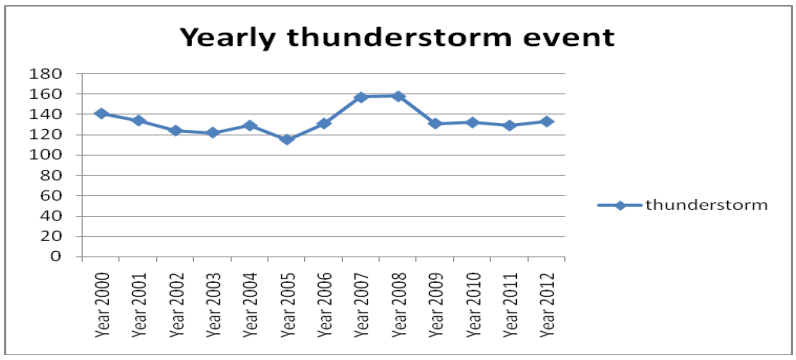

Fig 2: Yearly thunderstorm events (2000-2012)

The mean monthly fog event for 12 years indicates that there was a spatial variation of fog event at the Port Harcourt international Airport for the period. It is observed that fog occurrence in the Airport varies from from one month to another and that fog occurrence in the airport was more in the month of December, followed by January and November respectively, the dry season months (fig 3).

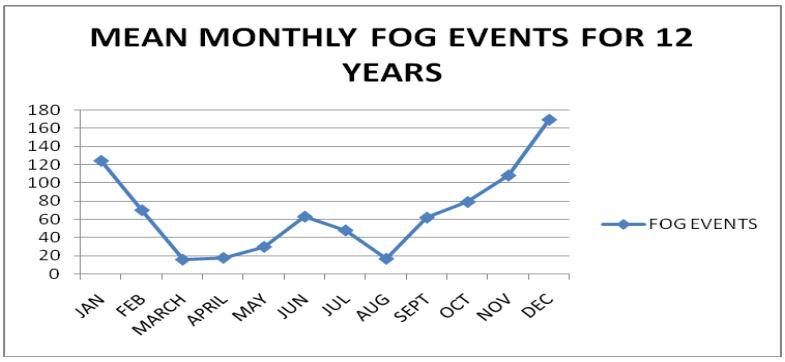

Fig 3: Mean monthly distribution of fog events (2000-2012)

The yearly fog event at the Port Harcourt international Airport showed that fog occurrence in the airport was more in the year 2004, followed by 2006 and 2002 respectively. The mean monthly rainfall event at the Airport also showed that rainfall occurrence in the Airport varies from one month to another and that rainfall occurrence in the airport was more in the month of July, followed by September and October respectively. However, the yearly distribution of rainfall in the airport showed that rainfall was more in the year 2006, followed by 2003 and 2001 respectively.

The Relationship between Turbulent Weather Events and Aircraft Operations

Turbulent weather conditions play very crucial role in aircraft operations and management. Therefore its activities and the extent to its effect on flight delay, cancellation and flight diversion was unraveled in this section. To achieve the objective of this paper, each of the fight operation was regressed with the extreme weather parameters. However, table 1 below is a correlation matrix table which identifies the relationship between flight delays and the independent variables (rainfall, thunderstorm and fog).

Table 1: Correlation Matrix for Flight delay on Rainfall, Thunderstorm and Fog.

	Delay	Rainfall	Thunderstorm	Fog
Delay	1.000			
Rainfall	0.754	1.000		
Thunderstorm	0.951*	0.728*	1.000	
Fog	-0.650	-0.541	-0.642	1.000

*Significant at 95%

Table 1, displays the relationship between the independent variable of rainfall and the dependent variable of flight delay in Port Harcourt International Airport. It is evident that the correlation co-efficient between rainfall and flight delay in Port Harcourt International Airport is positive (r = 0.754), it is statistically significant at 0.05 significance level with a calculated

t-statistic value of 3.81 and a table value of 2.20 at 11 degrees of freedom. In other words, there is a statistically significant relationship between flight delay and rainfall in Port Harcourt International Airport as shown by the analysis. Similarly, its co-efficient of determination (r^2) is 56.85%. This means that 56.85% variation in flight delay is by rainfall in Port Harcourt International Airport. It should also be noted that rainfall correlates positively with flight delay.

Table 1 shows that thunderstorm has a positive correlation of 0.951 with flight delay of Port Harcourt international Airport. Moreso, the calculated t-statistic is 10.2 which is greater than the table value of 2.20 at 0.05 significance level with at 11 degrees of freedom . In other words, there is a statistically significant relationship between flight delay and thunderstorm events . It should also be noted as earlier stated that the correlation co–efficient between flight delay and thunderstorm is +0.951. In essence this gives a co-efficient of determination (r^2) of 90.4%. This means that thunderstorm accounted for 90.4% variation in flight delay in the Port Harcourt international Airport.

The study showed that there was no relationship between fog and flight delays in Port Harcourt international airport. Findings further showed that flight delay is significantly correlated with rainfall and thunderstorm, no statistically significant relationship between fog and flight delay in the international airport.

Predicting flight delays from weather variables

In this section effort was made to develop a model to predict flight delays from the weather variables in line with the objective of the study.

Table 2: Summary of multiple regression of flight Delay and Weather parameters.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.951[a]	.904	.895	19.84428	.904	103.600	1	11	.000	2.328

Significant at 95%

Table 2, shows that only one variable thunderstorm entered the regression equation. It provided 90.4% explanation for variation in flight delay for the study airport. Conclusively, the study has revealed that thunderstorm is the predictor of flight delays in Port Harcourt international airport. It should also be noted that rainfall and fog are indirect predictors of flight delays Port Harcourt international airport, this is because it correlate positively with flight delay and also have positive correlation with thunderstorm which is the direct predictor.

Table 3: Standardized co-efficient model of aircraft diversion and thunderstorm occurrence.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-34.372	12.901		-2.664	.022	-62.766	-5.979
	Thunderstorm	.851	.084	.951	10.178	.000	.667	1.035

The stepwise multiple regression as shown in table 3 above revealed that thunderstorm explains the change in the flight operations. This is because it accounted for 95% change in flight delay.Thus, the model developed by this study is of the form,

$$Y = -34.372 + 0.951X_1 \quad - \quad - \quad - \quad -$$

Where,

Y = Flight Diversion
X_1 = thunderstorm

In order to determine the significance of this relationship, table 4 below was used.

Table 4: One way ANOVA for explanation of variation between Turbulent weather parameters and flight delay.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40797.327	1	40797.327	103.600	.000[b]
	Residual	4331.750	11	393.795		
	Total	45129.077	12			

Significance at 0.05 level.

From the table 4 above, the analysis of variance shows that the equation significantly explains variation in flight delay in Port Harcourt international airport. Given an F calculated value of 103.600 which is greater than the table value of 4.84, reveals that thunderstorm significantly influence flight diversion in Port Harcourt international airport. This therefore implies that flight delay is influenced by weather parameters.
Below is a correlation matrix (table 5) which identifies the relationship between flight cancellations and rainfall, thunderstorm and fog.

Flights Cancellation and Weather Parameters

Table 5, displays the relationship between the independent variable of rainfall and the flight cancellations in Port Harcourt International Airport. Result shows that the correlation co-efficient between rainfall and flight cancellations in Port Harcourt International Airport is

positive (0.745), this means that as rainfall amount increases flight cancellation increases. It is statistically significant at 0.05 significance level with a calculated t-statistic value of 3.708 and a table value of 2.20 at 11 degrees of freedom. In other words, there is a statistically significant relationship between flight cancellations and rainfall in Port Harcourt International Airport. Similarly, its co-efficient of determination (r^2) is 55.50% which mean that rainfall accounted for 55.5% of flight cancellation in Port Harcourt International Airport.

Table 5: Correlation matrix for Flights Cancellation on Rainfall, Thunderstorm and Fog.

	Cancellation	Rainfall	Thunderstorm	Fog
Cancellation	1.000*			
Rainfall	0.745*	1.000*		
Thunderstorm	0.947*	0.728*	1.000*	
Fog	-0.646	-0.541	-0.642	1.000*

Table 5 shows that thunderstorm has a positive correlation of +0.951 with flight delay of Port Harcourt international Airport. Moreso, the calculated t-statistic is 9.97 which is greater than the table value of 2.20 at 0.05 significance level with at 11 degrees of freedom. In other words, there is a statistically significant relationship between flight cancellation and thunderstorm events. It should also be noted as earlier stated that the correlation co–efficient between flight cancellation and thunderstorm is +0.947. In essence this gives a co-efficient of determination (r^2) of 89.68%. This means that thunderstorm accounted for 89.68% variation in flight cancellation in the Port Harcourt international Airport.

Table 6 Summary of Multiple Regression of flight cancellations and Weather parameters.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.951[a]	.904	.895	19.84428	.904	103.600	1	11	.000	2.328

Table 6 shows that no relationship exists between the independent variable of fog and the dependent variable of flight delays in Port Harcourt international airport. The student's't' statistic for this correlation is -0.389 which is less than the table value of 2.20 at 11degrees of freedom at 0.05 significance level. In other words, there is no statistically significant relationship between fog and flight cancellation in the international airport. Conclusively, the testing of various relationships as shown in the summary on table 5 within this section with the student "t" statistic at 0.05 significance level reveals that flight cancellations is significantly correlated with rainfall and thunderstorm; no statistically significant relationship between fog and flight cancellations in the international airport.

Predicting Flight Cancellations from Weather Variables

In this section effort was made to develop a model to predict flight delays from the weather variables.
Table 6, shows that only one variable thunderstorm entered the regression equation. It provided 89.69% explanation for variation in flight delay for the study airport. Hence the total explanation provided for the variation in flight cancellations by the independent variable of thunderstorm is 89.69%.The study has revealed that thunderstorm is the predictor variable of flight cancellation in Port Harcourt international airport. It should also be noted that rainfall correlated positively with flight cancellations and thunderstorm which is the direct predictor.

Turbulent Weather Events and Its Implications for Aviation Safety

Weather continues to play a significant role in a number of aviation accidents and incidents. While National Transportation Safety Board (NTSB) reports most commonly find human error to be the direct accident cause, weather is a primary contributing factor in 23 percent of all aviation accidents. The total weather impact is an estimated national cost of $3 billion for accident damage and injuries, delays, and unexpected operating costs. In addition to safety, convective weather poses a problem for the efficient operation of the National Air Space. Thunderstorms and related phenomena can close airports, degrade airport capacities for acceptance and departure, and hinder or stop ground operations. Convective hazards en route lead to rerouting and diversions that result in excess operating costs and lost passenger time. Lightning and hail damage can remove aircraft from operations and result in both lost revenues and excess maintenance cost. Non-convective turbulence is a major aviation hazard. All aircraft are vulnerable to turbulent motions. Non-convective turbulence can be present at any altitude and in a wide range of weather conditions, often occurring in relatively clear skies as clear-air turbulence. Any aircraft entering turbulent conditions is vulnerable to damage; smaller aircraft (both fixed- and rotary-wing) are susceptible at lower levels of turbulent intensity than are large aircraft. The effects of turbulence range from a jostling of the aircraft that is mildly discomforting for passengers and crews to sudden accelerations that can result in serious injury and temporary loss of aircraft control.

CONCLUSION

The study had shown that thunderstorm in the Airport varies from one month to the other and thunderstorm occurrence in the airport was high in october, followed by August and September respectively. This also coincides with the period of flight cancellation, delay and diversion. Similarly, the study revealed that there is a statistically significant relationship between flight cancellations and rainfall in the Airport. Thunderstorm is a predictor variable for flight cancellation, diversion and delays. However, no relationship existed between fog and flight delays in Port Harcourt international airport.

RECOMMENDATION

For safety to be assured, it is necessary to produce timelier and more accurate analyses and forecasts of turbulence, and develop user-friendly turbulence product. An algorithm designed to forecast turbulence models jet stream, mountain induced turbulence, and convective induced

turbulence. From this diagnostic data, and the addition of in-situ and remotely sensed data, an Integrated Turbulence Forecast Algorithm (ITFA)

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