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Mathematical Modeling of the Relationship between Wind Shear and Aircraft Operations at Murtala Mohammed and Port Harcourt International Airports, Nigeria

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Abstract
The demand for observation and forecast of wind shear and other troubling weather phenomena in the aviation industry has been on the increase in this period of climate change and its associated impacts. Nigeria and other countries in the tropical region greatly experience wind shear, hence the need for accurate wind shear forecast. The study mathematically modeled the relationship between wind shear and flight diversions, delays and cancellations at Murtala Mohammed and Port Harcourt International Airports, Nigeria. The annual time series secondary data used for this study were sourced from Nigerian Airspace Management Agency (NAMA) at Murtala Mohammed and Port Harcourt International Airports and Nigerian Meteorological Agency (NIMET). The data were compiled and presented in tables for easy understanding and further analysis. The statistical estimation (or analysis) techniques employed in achieving the research target was inferential statistics including Pearson's Product Moment Correlation (PPMC) and Regression. All inferential analyses were judged at 5% (0.05) level of significance. The correlation analysis conducted at Murtala Mohammed International Airport shows a weak (insignificant) positive relationship between wind shear measured at 20m above ground level and number of flight diversions, delays and cancellations. At Port Harcourt International Airport, an insignificant negative relationship between wind shear measured at 20m above ground level and number of flight cancellations was discovered, while an insignificant positive relationship was discovered between wind shear and number of flight diversions, and between wind shear and number of flight delays. From the mathematical or regressional relationships between wind shear at 20m above ground level and flight diversions, delays and cancellations at the two airports, the study discovered the best models for the relationships. The models discovered, reveal that, should in case the wind shear is known, the number of flight diversions, delays and cancellations can be predicted. The study therefore, based on its findings, recommends training and retraining of Meteorologists, Air Traffic Controllers and Engineers who are staff of Nigerian Meteorological Agency and Nigerian Airspace Management Agency, as well as the pilots for sufficient knowledge of wind shear.
Keywords: *Wind Shear; Mathematical Modeling; Aircraft Operations; Relationship; Aviation Industry.*

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I. Introduction

Despite the relatively conducive weather of Nigeria compared to other countries (such as Mauritania, 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 such as wind shear, thunderstorm, poor visibility, fog, dust haze and line squall (National Oceanic and Atmospheric Administration (NOAA), 2004; Sasse & Hauf, 2003; Jones, 2004; Knetch, 2008; Weli & Ifediba, 2014; Musa, 2014; Enete, Ajator, & Nwoko, 2015; Onwuadiochi, Ijioma, & Ozoemene, 2020).

The effects of wind shear on aircraft operations are countless and because of this, many researchers have defined it in various ways. For instance, Azad (2011) defined wind shear as a difference in wind speed and wind direction over a relatively short distance in the earth's atmosphere. In Aviation Meteorology, Wilson, Goodrich and Carson (2005) 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 aircraft.

While there could be a vertical and horizontal wind shear, the former is 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, 2011). Thus, low level wind shear can affect aircraft airspeed during takeoff 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. In general, the wind shear events that present the greatest risk to aircraft are those associated with convective activity, specifically gust fronts and microburst, and such events have resulted in several major accidents involving large transport aircraft internationally (National Research Council, 1983; Azad, 2011).

The impact of wind shear on aircraft is understood through the change in the aircraft's total energy, that is, the sum of its kinetic and potential energy (Wilson, Goodrich, & Carson, 2005). Changes in the kinetic energy are related to changes in airspeed, and changes in the potential energy are related to changes in altitude. The pilot and flight control systems can influence these allocations. When an aircraft is flying only slightly above the stall speed, a change in the wind velocity or direction can lead to a loss of lift. If the loss is of sufficient magnitude so that the response is inadequate to immediately correct the energy deficiency condition, it results in an excessive rate of descent. The altitude, at which the encounter occurs, the pilot's reaction time and the aircraft's response capability, determine whether the descent can be arrested in sufficient time to prevent an accident.

Despite the severity of wind shear in many parts of the world, especially the tropical region that experiences wind shear and thunderstorm than elsewhere on the globe, and the problems it has posed to the aviation industry, no much research have been conducted concerning this phenomenon. This paper therefore tries to model the association between wind shear and the aircraft operations with a view to avoiding the impending devastating impacts in the aviation industry.

II. Materials and Methods

Study area

The two study areas are Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State. Lagos State is located on the south-western part of Nigeria on the narrow coastal flood plain of the Bight of Benin. It lies approximately between latitude 6^0 22^1N and 6^0 42^1N of the equator and between longitude 2^0 42^1E and 3^0 22^1E of the Greenwich Meridian. It is bounded to the North and East by Ogun State of Nigeria, to the West by the Republic of Benin, and to the South by the Atlantic Ocean. Territorially, Lagos State encompasses an area of 358,862 hectares or 3,577 km^2 (Building Nigeria's Response to Climate Change Project (BNRCC), 2012).

The population of Lagos State by the 2006 National Census conducted by the National Population Commission was 17,552,942. Going by a population growth rate of 3.2 percent, the projected population for the State in 2015 is 23,305,971 (National Bureau of Statistics of Nigeria, 2013).

Fig. 2.1: Map of Nigeria showing Lagos State

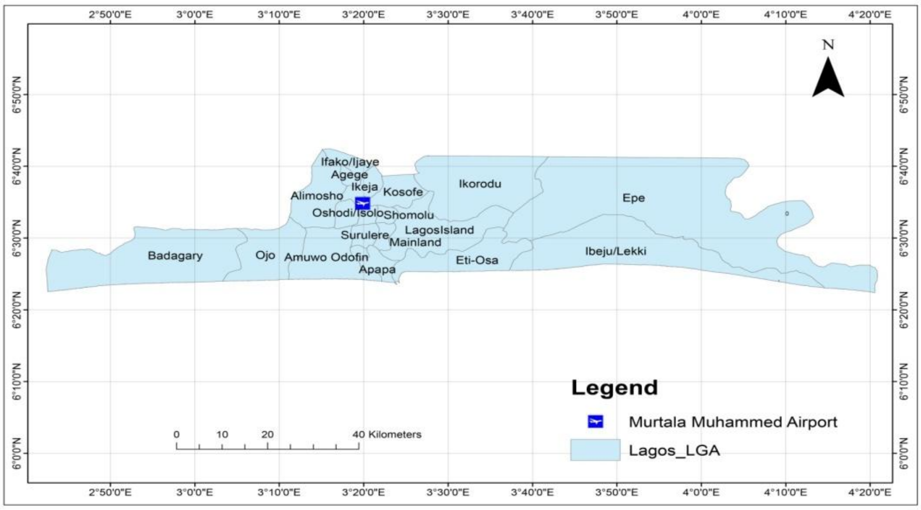

Fig. 2.2: Map of Lagos State showing Murtala Mohammed International Airport

Lagos State has a coastline of 180 km long (Oteri, 2013). Underlain by sedimentary rocks; it is on a coastal plain characterized by predominantly flat terrain, with an average elevation of less than 15m above sea level. The land slopes gently from the interior to the sea. Water bodies and wetlands cover over 40 percent of the total land area of the State with lagoons and creeks consisting 22 percent of its area. An additional 12 percent is subject to seasonal flooding (Building Nigeria's Response to Climate Change Project (BNRCC), 2012). Lagos has a tropical wet and dry climate. It experiences two rainy seasons, with the heaviest rains falling from April to July and a weaker rainy season from September to November (Oteri & Ayeni, 2016). There is a brief relatively dry spell in August and a longer dry season from December to March (Oteri & Ayeni, 2016). Rainfall varies from one location to the other in Lagos Megacity. With its high mean annual rainfall, Lagos Megacity has abundant water resources in the form of surface water (rivers, lagoons, lakes and creeks) and groundwater. The major rivers are Ogun, Yewa, Aye, Owo, Oworu and Osun (Oteri & Ayeni, 2016).

The dominant vegetation of the State is the tropical swamp forest consisting of fresh water and mangrove swamp forests both of which are influenced by the double rainfall pattern of the State, which makes the environment a wetland region, hence, the reference to Lagos as an environment of aquatic splendour. Its wetland environment is characterized by rich alluvial and terrallitic red-yellow soil, on which would be found dense luxuriant undergrowth, climbers, epiphytes and tropical hard woods (Oteri & Ayeni, 2016).

Murtala Mohammed International Airport (MMIA) (IATA: LOS, ICAO: DNMM) is an international airport located in Ikeja, Lagos State, Nigeria, and is the major airport serving the entire country. The airport was initially built during World War II. Originally known as Lagos International Airport, it was renamed in the mid 1970s, during construction of the new international terminal, after a former and fourth Nigerian military head of state, Murtala Mohammed.

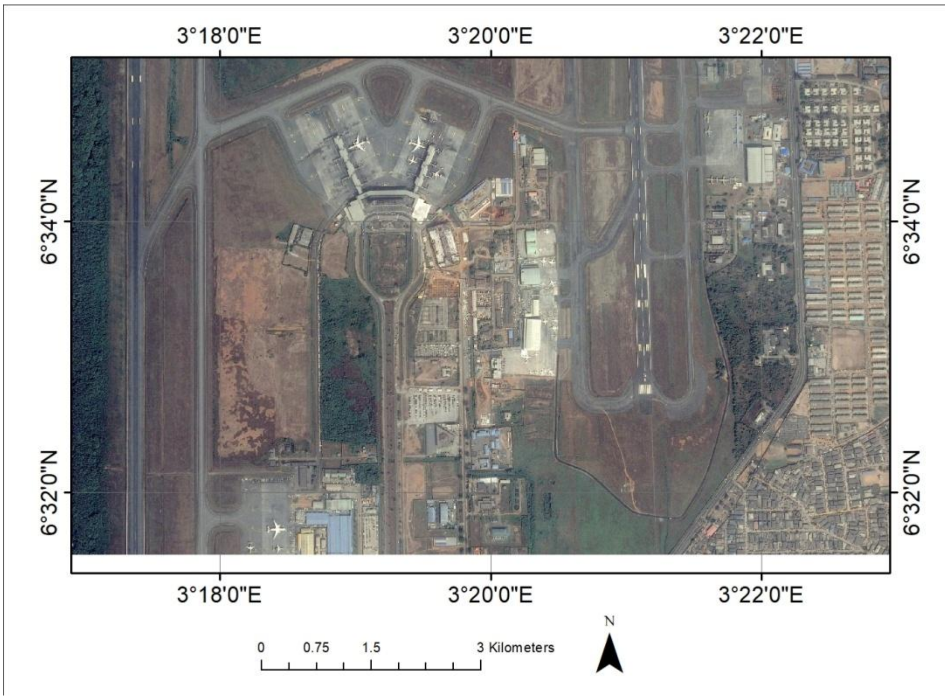

Fig. 2.3: Satellite Image of Murtala Mohammed International Airport

Port Harcourt is situated at the southernmost part of Nigeria and it is located between latitude $4^0 30^1$ and $4^0 47^1$ north of the Equator and longitude $7^0 00^1$ and $7^0 15^1$ east of the Greenwich Meridian (Ajie & Dienye, 2014). It is the largest city of Rivers State, Nigeria (The Tide News, 2013). It lies along the Bonny River and is located in Niger Delta (The Tide News, 2013). Port Harcourt is bounded to the Eastern and Western parts by meandering creeks and to the southern part by the first dockyard creek (Bonny River) and mangrove swamps. Towards the north where there is availability of land, it is bounded by Ikwerre Local Government Area (Ajie & Dienye, 2014).

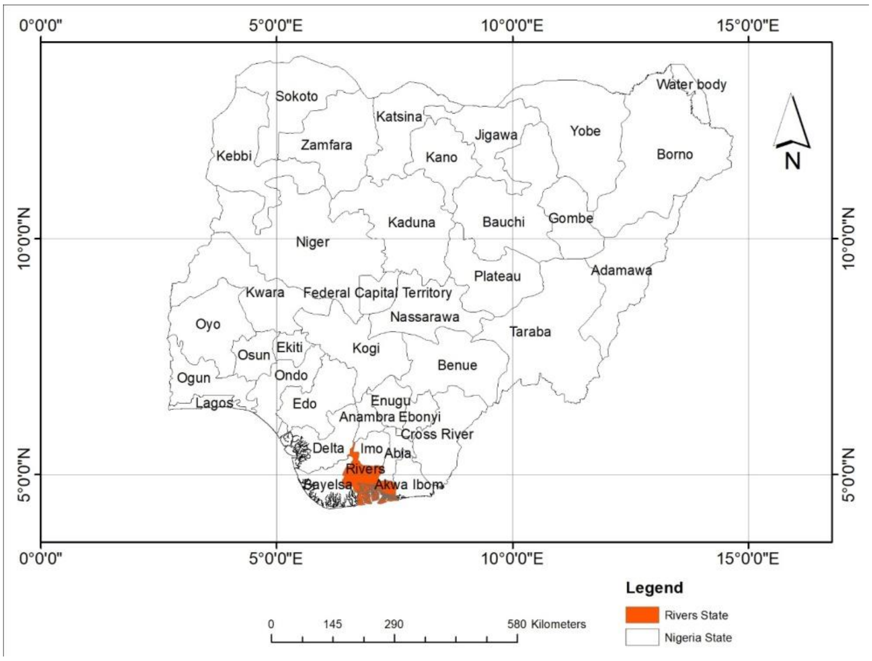

Fig. 2.4: Map of Nigeria showing Rivers State

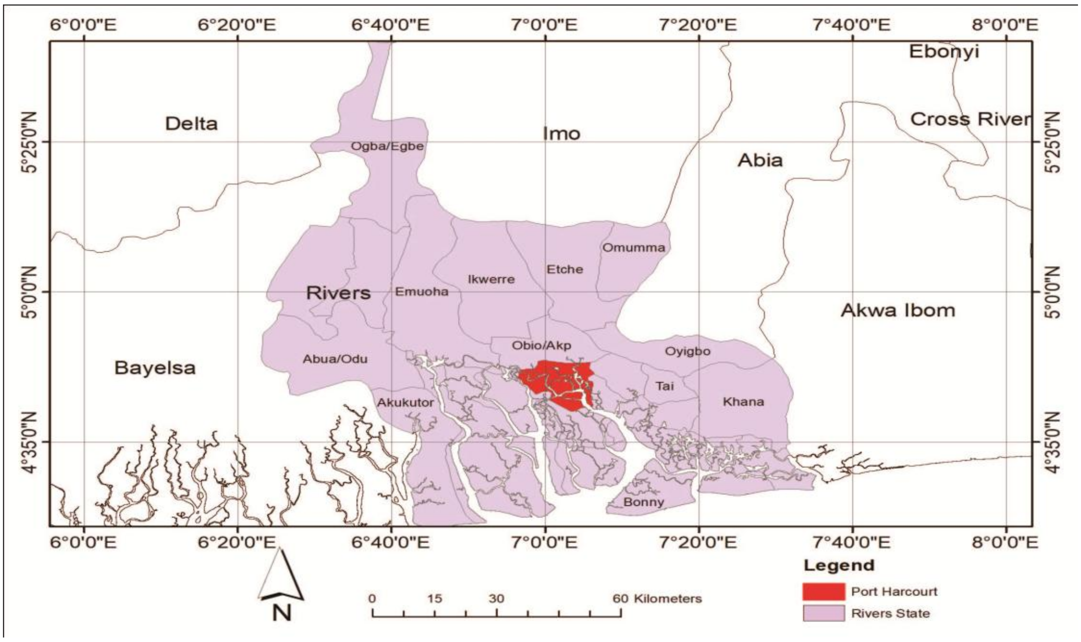

Fig. 2.5: Map of Rivers State showing Port Harcourt

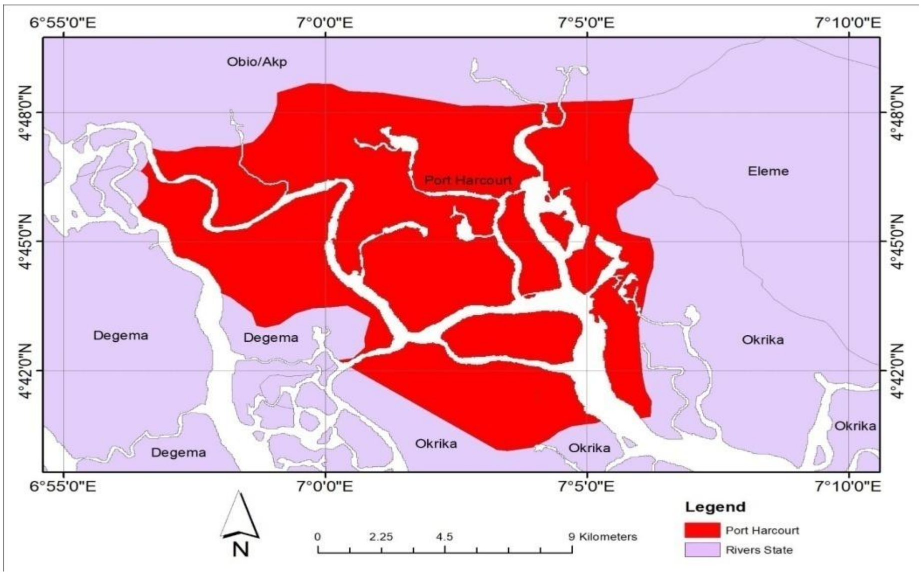

Fig. 2.6: Map of Port Harcourt

As of 2016, the Port Harcourt urban area has an estimated population of 1,865,000 inhabitants, up from 1,382,592 as of 2006 (Demographia, 2016). The ground surface of the area slopes from the north towards the Atlantic Ocean in the south (Nwankwoala & Walter, 2012). Geologically, Port Harcourt as well as the entire Rivers State, lies within the Niger Delta Sedimentary Basin (Nwankwoala, Abam, Ede, Teme, & Udom, 2008; Nwankwoala & Walter, 2012). Lithostratigraphically, these rocks are divided into the Oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene) (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970; Nwankwoala & Walter, 2012).

The Port Harcourt Airport features a tropical monsoon climate with lengthy and heavy rainy seasons and very short dry seasons (Enete et al., 2015; World Meteorological Organization (WMO), 2018; National Oceanic and Atmospheric Administration (NOAA), 2018). Only the months of December and January truly qualifies as dry season months in the city (WMO, 2018; NOAA, 2018). The harmattan, which climatically influences many cities in West Africa, is less pronounced in Port Harcourt. Port Harcourt's heaviest precipitation occurs during September with an average of 369 mm of rain (WMO, 2018). Rainfall is seasonal, variable and energetic (Enete et al., 2015). December on average is the driest month of the year; with an average rainfall of 20 mm dry seasons (Enete et al., 2015; WMO, 2018; NOAA, 2018). Temperatures throughout the year in the city are relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25 °C-28 °C in the city (Enete et al., 2015; WMO, 2018; NOAA, 2018).

The high rainfall and humidity promotes thick vegetation termed tropical rainforest (Iloeje, 1979). The area also has both mangrove swamp forest and fresh water swamp forest. Mangrove swamp forest is permanently occupied by salt and tidal waters whereas fresh water swamp forests are seen in areas where fresh water dominates (Ezenwaji & Chima, 2016).

The Port Harcourt International Airport lies between latitude 4^{o} 72^{1}N and 4^{o} 91^{1}N of the equator and longitude 6^{o} 88^{1}E and 7^{o} 12^{1}E of the Greenwich Meridian (Weli & Emenike, 2016).

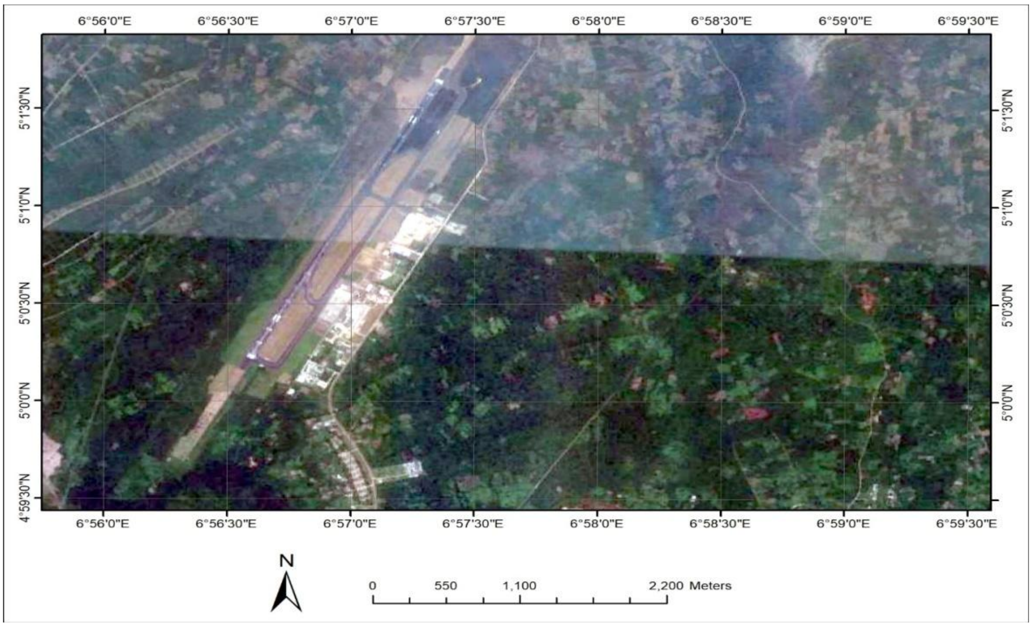

Fig. 2.7: Satellite Image of Port Harcourt International Airport

Port Harcourt International Airport (IATA:PHC,ICAO: DNPO) is an international airport located in Omagwa, a suburb of Port Harcourt city in Rivers State, Nigeria (Enete et al., 2015).

Data collection

The annual time series secondary data of flight operations and wind shear used for this study were sourced from Nigerian Airspace Management Agency (NAMA) at Murtala Mohammed and Port Harcourt International Airports and Nigerian Meteorological Agency (NIMET) respectively. The data were compiled and presented in tables for easy understanding and further analysis.

Data analysis

The statistical estimation (or analysis) techniques employed in achieving the research target are inferential statistics including Pearson's Product Moment Correlation (PPMC) and Regression. The Pearson Correlation technique was used to show if the relationship between the dependent (flight diversions, delays and cancellations) and independent (wind shear) variables are positive, negative, significant or insignificant whereas Regression technique was used to model, predict and show the nature of the functional or mathematical relationship. Analytical packages used were Microsoft Excel, Eviews and Statistical Package for Social Sciences (SPSS) version 25.0 for windows.

Pearson's correlation

The Pearson's correlation analytic technique was employed in validating the extent and relationship among the study variables without suppressing the other. This statistical estimation technique was considered appropriate as the data series of the variables under investigation were all converted to a continuous data through log-transformation. Geometrically, the Pearson's correlation coefficient is generally computed as:

$$r = \frac{Cov\,(M,N)}{\sqrt{(Var\,(M))(Var\,(N))}} = \frac{\sum_{i=1}^{T}[(M-\bar{M})(N-\bar{N})]}{\sqrt{\left[\sum_{i=1}^{T}(M-\bar{M})^{2}\right]\left[\sum_{i=1}^{T}(N-\bar{N})^{2}\right]}} \qquad (2.1)$$

Where,

r is the correlation coefficient,

$Cov\,(M,N) = \sum_{i=1}^{T}[(M-\bar{M})(N-\bar{N})]$ is the covariance of M and N series,

$Var\,(M) = \sum_{i=1}^{T}(M-\bar{M})^{2}$ is the variance of M series,

$Var\,(N) = \sum_{i=1}^{T}(N-\bar{N})^{2}$ is the variance of N series

T = Total number of observations,
$\bar{M}$ and $\bar{N}$ and mean values of series of M and N values,
M and N are variables of interest.

Regression analysis
The functional relationship among the selected variables was determined using the classical linear regression analysis technique. Geometrically, the relationship is represented as:

$$Number\ of\ Flight\ diversions, delays\ and\ cancellations = f(wind\ shear)$$

Such that:

$$LFDS, LFDL, LFCL = f(WS) \quad (2.2)$$

Where,

FDS = Number of flight diversions
FDL = Number of flight delays
FCL = Number of flight cancellations
L = Log-transformational operator
WS = Wind shear

III. Result and Discussion

Data presentation
The annual time series secondary data used for this study were sourced from Nigerian Airspace Management Agency (NAMA) at Murtala Mohammed and Port Harcourt International Airports and Nigerian Meteorological Agency (NIMET). The data were compiled and presented in tables for easy understanding and further analysis.

Table 1: Monthly distribution of Flight Diversions, Delays and Cancellation at Murtala Mohammed International Airport, Lagos (2008-2018)

Months	No. of Flight Diversions	No. of Flight Delays	No. of Flight Cancellations
Jan.	29	19	14
Feb.	22	28	21
Mar.	31	57	33
Apr	29	57	30
May	33	73	35
June	42	66	29
July	47	59	34
Aug.	38	37	26
Sept.	26	63	39
Oct.	17	77	38
Nov.	30	31	23
Dec.	23	17	18
SUM	**367**	**584**	**340**
AVE.±Std.	**30.58±8.54**	**48.67±21.12**	**28.33±8.03**

Source: Nigerian Airspace Management Agency (NAMA), Lagos

Table 2: Monthly distribution of Flight Diversions, Delays and Cancellation at Port Harcourt International Airport (2008-2018)

Months	No. of Flight Diversions	No. of Flight Delays	No. of Flight Cancellations
Jan.	22	21	11
Feb.	17	33	17
Mar.	32	52	21
Apr	25	55	33
May	38	74	29
June	39	61	28
July	44	57	31
Aug.	33	30	21
Sept.	21	59	37
Oct.	19	75	35
Nov.	22	29	20
Dec.	20	18	15
SUM	**332**	**564**	**298**
AVE.±Std.	**27.67±9.11**	**47±19.93**	**24.83±8.45**

Source: Nigerian Airspace Management Agency (NAMA), Port Harcourt

Table 3: Monthly distribution of wind shear measured at 20m above ground level at Murtala Mohammed International Airport, Lagos (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
JAN	7.2	4.4	3.0	2.7	3.5	3.6	4.7	4.2	3.0	4.0	3.9	4.0
FEB	8.7	8.7	3.0	4.4	3.8	5.0	4.0	4.3	3.0	3.8	4.0	4.8
MAR	8.4	9.0	4.4	4.7	3.7	4.6	5.0	4.0	3.6	4.2	4.3	5.1
APR	9.0	9.8	5.0	4.5	4.2	4.8	1.2	4.0	5.0	3.4	3.7	5.0
MAY	6.1	9.8	4.0	3.9	3.6	2.7	4.0	4.0	2.9	15.6	13.0	6.3
JUN	5.9	7.7	3.4	3.7	3.0	4.3	3.9	5.0	3.0	4.0	4.0	4.4
JUL	8.7	9.8	3.6	6.0	3.8	5.7	4.8	4.2	3.1	4.0	4.4	5.3
AUG	9.7	10.5	4.6	7.5	5.4	8.0	5.2	4.7	3.0	4.3	5.0	6.2
SEP	8.0	7.6	4.0	7.3	6.0	7.0	4.0	4.0	2.0	3.3	4.1	5.2
OCT	5.5	5.7	2.7	2.6	3.9	3.6	3.4	3.0	2.0	2.8	3.0	3.5
NOV	4.1	5.9	3.1	2.6	3.5	3.7	3.5	2.7	2.0	2.7	2.9	3.3
DEC	5.0	5.0	3.2	5.1	3.1	3.9	3.7	4.0	2.3	3.3	3.4	3.8
SUM	**86.3**	**93.9**	**44**	**55**	**47.5**	**56.9**	**47.4**	**48.1**	**34.9**	**55.4**	**55.7**	**56.9**
AVE.	**7.19**	**7.83**	**3.67**	**4.58**	**3.96**	**4.74**	**3.95**	**4.01**	**2.91**	**4.62**	**4.64**	**4.74**
Std.	**1.82**	**2.11**	**0.73**	**1.68**	**0.89**	**1.52**	**1.05**	**0.63**	**0.84**	**3.50**	**2.70**	**0.98**

Source: NIMET

Table 4: Monthly distribution of wind shear measured at 20m above ground level at Port Harcourt International Airport (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
JAN	3.3	5.3	4.0	3.8	2.4	2.4	2.4	3.0	2.4	2.1	2.0	3.0
FEB	3.8	2.3	4.0	2.8	2.4	2.5	3.2	3.1	3.2	2.4	3.0	3.0
MAR	3.2	2.3	4.0	2.9	2.5	2.5	2.7	2.4	2.7	2.7	2.1	2.7
APR	2.4	2.6	4.0	2.2	2.4	2.3	2.7	2.4	2.7	3.0	2.8	2.7
MAY	2.3	2.3	4.0	1.7	2.4	2.4	2.7	2.6	2.7	2.1	2.5	2.5
JUN	2.2	2.6	3.0	2.2	2.7	2.3	2.8	2.9	2.7	2.3	2.4	2.6
JUL	2.2	3.5	2.0	2.7	2.4	2.5	2.5	2.4	2.4	2.6	2.5	2.5
AUG	2.4	2.1	3.0	3.5	2.8	2.7	2.7	2.8	2.7	3.1	2.8	2.8
SEP	1.9	2.3	4.0	2.3	2.4	2.7	2.5	2.7	2.6	2.8	2.7	2.6
OCT	2.1	2.8	3.0	2.2	2.2	2.3	2.1	2.0	2.2	2.0	2.0	2.3
NOV	1.6	2.2	3.0	1.8	1.9	1.9	1.9	1.9	2.0	2.0	1.7	2.0
DEC	1.5	1.8	3.0	3.1	1.9	2.1	1.8	2.6	1.8	2.0	2.0	2.1
SUM	**28.9**	**32.1**	**41**	**31.2**	**28.4**	**28.6**	**30**	**30.8**	**30.1**	**29.1**	**28.5**	**30.8**
AVE.	**2.41**	**2.68**	**3.42**	**2.60**	**2.37**	**2.38**	**2.50**	**2.57**	**2.51**	**2.43**	**2.38**	**2.57**
Std.	**0.69**	**0.93**	**0.67**	**0.65**	**0.27**	**0.23**	**0.40**	**0.37**	**0.38**	**0.41**	**0.41**	**0.31**

Source: NIMET

Correlational analysis

Relationships between the wind shear measured at 20m above ground level and flight diversions, delays, and cancellations at Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State (2008-2018) were estimated. More so, the functional bonds (or relationships) between wind shear and flight diversions, delays, and cancellations were equally exposed. Since wind shear data is a continuous (measurement) data and which must be correlated and regressed with discrete (count) data of number of flight diversions, delays, and cancellations, the datasets must be log-transformed before analysis so as to keep them on the same level of measurement and ensuring that they do not lose their natural power.

Table 5: Correlation Matrix of the Relationship between wind shear measured at 20m above ground level and flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos
Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000 ----- -----			
LFDS	0.505668 1.853494 0.0935	1.000000 ----- -----		
LFDL	0.385092 1.319533 0.2164	0.197451 0.636935 0.5385	1.000000 ----- -----	
LFCL	0.397647 1.370481 0.2005	0.109155 0.347254 0.7356	0.946445 9.269925 0.0000	1.000000 ----- -----

Source: Author's Eviews Result
*** Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations.*

From the Pearson's correlation estimation as shown in table 5, there is an insignificant positive relationship between wind shear measured at 20m above ground level and number of flight diversions (r_p=0.506, p=0.0935>0.05); number of flight delays (r_p=0.385,p=0.2164>0.05), and number of flight cancellations (r_p=0.398, p=0.2005>0.05). Also, there is an insignificant positive relationship between number of flight diversions and delays (r_p=0.197, p=0.5385>0.05); number of flight diversions and number of flight cancellations (r_p = 0.109, p=0.7356>0.05) and a significant positive relationship between number of flight delays and cancellations at Murtala Mohammed International Airport, Lagos (r_p=0.946, p=0.000<0.05). The result therefore shows that, fluctuations in wind shear lead to increases in number of flight diversions, delays, and cancellations in the area. More so, increases in number of flight delays causes increases in number of flight diversions and cancellations.

The functional relationship between wind shear at 20m above ground level and number of flight diversions at Murtala Mohammed International Airport, Lagos is ***exponential*** in nature with the highest R-Square value among other estimated models **[See Appendix]**. The relationship is such that:

LFDS = $e^{0.208WS+2.449}$ - - - - - - (3.1)

The estimate above shows that should in case the wind shear at 20m above ground level is known, the number of flight diversions can be predicted. Evidently, if for instance, the wind shear at 20m above ground level is 4.0, the number of flight diversions can be obtained by appropriate substitution into the model (3.1) above as:

LFDS = $e^{0.208WS+2.449} = e^{0.208(4.0)} \times e^{2.449}$ = 2.2979 × 11.57676 = 26.62035 ≅ 27±1.641.

For flight delays and wind shear, the relationship is also ***exponential*** **[See Appendix]**, such that:

LFDL = $e^{0.281WS+2.427}$ - - - - - - (3.2)

In the case of equation (3.2) above, if the wind shear is known (for instance, 4.0), the number of flight delays can be obtained thus:

LFDL = $e^{0.281WS+2.427} = e^{0.281(4.0)} \times e^{2.427}$ = 3.0771 × 11.3249 = 34.8477 ≅ 35±6.023.

While, for number of flight cancellations and wind shear, the relationship is ***quadratic*** in nature **[See Appendix]**. The relationship is such that:

LFCL = 4.522 – 2.277WS + $0.949WS^2$ - - - (3.3)

The model in equation (3.3) above shows that, if for instance wind shear at 20m above ground level is known (e.g., 4.0), the number of flight cancellations can be estimated as:

LFCL = 4.522 – 2.277(4.0) + 0.949$(4.0)^2$ = 4.522 –9.108 + 15.184 = 10.598 ≅ 11±1.513.

Table 6: Correlation Matrix of the Relationships between wind shear measured at 20m above ground level and number of flight diversions, delays and cancellations at Port Harcourt International Airport

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000 ----- -----			
LFDS	0.101628 0.323050 0.7533	1.000000 ----- -----		
LFDL	0.052285 0.165568 0.8718	0.420754 1.466686 0.1732	1.000000 ----- -----	
LFCL	-0.162944 -0.522255 0.6129	0.316225 1.054082 0.3166	0.889905 6.169355 0.0001	1.000000 ----- -----

Source: Author's Eviews Result
***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDL = Flight delays; FCL = Flight cancellations; FDS = Flight diversions*

From the Pearson's correlation estimation as shown in table 6, there is an insignificant negative relationship between wind shear measured at 20m above ground level and number of flight cancellations ($r_p = -0.163$, p=0.6129>0.05), and insignificant positive relationship between wind shear and number of flight diversions (r_p=0.102, p=0.7533>0.05), and between wind shear measured at 20m above ground level and number of flight delays (r_p=0.052, p=0.8718>0.05) at Port Harcourt International Airport. However, the interactions between the number of flight diversions and delays (r_p=0.421, p=0.1732>0.05), and between number of flight diversions and cancellations (r_p=0.316, p=0.3166>0.05), are positive and insignificant, while there is a positive and significant relationship between the number of flight delays and cancellations (r_p=0.890, p=0.0001>0.05). The implication of the result therefore, is that increase in wind shear (at 20m above ground level) leads to higher number of flight delays and diversions, and reduction in number of flight cancellations at the area. Meanwhile, when flights are delayed, they are most likely to be cancelled.

The functional relationship between wind shear at 20m above ground level and number of flight diversions at Port Harcourt International Airport is ***cubic*** in nature with the highest R-Square value among other estimated models **[See Appendix]**. The relationship is such that:

LFDS = –3.301 + 11.054WS – 4.386WS^3 - - - - (3.4)

Based on the model as presented in (3.4), if the wind shear at 20m above ground level is increased by one unit, the number of flight diversions at Port Harcourt International Airport can be determined as:

LFDS = –3.301 + 11.054(1.0) – 4.386$(1.0)^3$= –3.301 + 11.054– 4.386 = 12.139 ≅ 12.

For the relationship between number of flight delays and wind shear, the best model is also a ***Cubic*** model **[See Appendix]**. Hence:

LFDL = –9.423 + 22.342WS – 8.995WS^3 - - - - (3.5)

Such that for a wind shear value of 1.2 at 20m above ground level in the Airport, the number of flight delays can be estimated as:

LFDL = –9.423 + 22.342(1.2)– 8.995$(1.2)^3$ = –9.423 + 26.8104 – 15.5434 = 1.844 ≅ 2.

However, for flight cancellations and wind shear at 20m above ground level, the relationship is ***cubic*** **[See Appendix]**. Hence;

$$LFCL = -1.532+18.530WS^2 - 13.743WS^3 \quad (3.6)$$

Such that for a wind shear value of 1.2 at 20m above ground level in the Airport, the number of flight cancellations can be estimated as:

$$LFCL = -1.532+18.530(1.2)^2-13.743(1.2)^3 = -1.532+26.6832-23.7479 = 1.403 \cong 1.$$

Table 7: Panel correlation matrix of the relationship between wind shear measured at 20m above ground level and flight diversions, delays and cancellations at Port Harcourt and Murtala Mohammed International Airport, Nigeria

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 24

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000 ----- -----			
LFDS	0.320575 1.587411 0.1267	1.000000 ----- -----		
LFDL	0.146148 0.692933 0.4956	0.309002 1.523925 0.1418	1.000000 ----- -----	
LFCL	0.264355 1.285669 0.2119	0.259414 1.259889 0.2209	0.892972 9.305242 0.0000	1.000000 ----- -----

Source: Author's Eviews Result

***. Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The panel correlation result as shown in table 7 indicates that wind shear measured at 20m above ground level interact positively and insignificantly with number of flight diversions, delays, and cancellations ($r_{WS.FDS}$ = 0.321, p=0.267>0.05; $r_{WS.FDL}$ = 0.146, p=0.4956>0.05; $r_{WS.FCL}$ = 0.264, p=0.2119>0.05). In the result also, it was shown that a positive but insignificant relationship exist between number of flight diversions and delays ($r_{FDS.FDL}$ = 0.309, p=0.1418>0.05), and between number of flight diversions and cancellations ($r_{FDS.FCL}$ = 0.259, p=0.2209>0.05). Meanwhile, the relationship between number of flight delays and cancellations is positive and significant ($r_{FDL.FCL}$ = 0.893, p=0.000<0.05). By implication, the result shows that increases in number of flight delays causes increase in number of flight diversion and cancellations, and vice versa; while increases in wind shear causes increase in flight diversions, delays and cancellations.

IV. Conclusion and Recommendations

The correlation analysis conducted at Murtala Mohammed International Airport shows a weak (insignificant) positive relationship between wind shear measured at 20m above ground level and number of flight diversions, delays and cancellations. Also, there is a weak (insignificant) positive relationship between number of flight diversions and delays; number of flight diversions and number of flight cancellations and a significant (strong) positive relationship between number of flight delays and cancellations at Murtala Mohammed International Airport, Lagos. The result therefore shows that, fluctuations in wind shear lead to increases in number of flight diversions, delays, and cancellations in the area.

At Port Harcourt International Airport, an insignificant negative relationship between wind shear measured at 20m above ground level and number of flight cancellations was discovered, while an insignificant positive relationship was discovered between wind shear and number of flight diversions, and between wind shear and number of flight delays. However, the interactions between the number of flight diversions and delays and between number of flight diversions and cancellations are positive and insignificant, while there is a positive and significant relationship between number of flight delays and cancellations. This implies that increase in wind shear (at 20m above ground level) leads to higher number of flight delays and diversions, and reduction in number of flight cancellations at the area. Meanwhile, when flights are delayed, they are most likely to be cancelled.

The study, based on the findings, proposed the following recommendations:

1. there should be training and retraining of Meteorologists, Air Traffic Controllers and Engineers who are staff of Nigerian Meteorological Agency and Nigerian Airspace Management Agency, so as to update their knowledge on the effects of wind shear in the aviation industry in the country. The same should also be done in the agencies involved in the observing, forecasting and dissemination of weather information in other countries.
2. pilots should always be well trained and retrained, so that they can have good knowledge of wind shear and other hazardous weather phenomena.

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APPENDIX I

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_1
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.256	3.435	1	10	.094	2.331	.685		
Logarithmic	.255	3.420	1	10	.094	2.953	1.025		
Quadratic	.256	1.547	2	9	.265	2.133	.952	-.088	
Cubic	.256	1.548	2	9	.264	2.158	.860	.000	-.025
Exponential	.263	3.561	1	10	.088	2.449	.208		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_2
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.148	1.741	1	10	.216	2.289	.966		
Logarithmic	.143	1.673	1	10	.225	3.175	1.423		
Quadratic	.152	.809	2	9	.475	4.164	-1.548	.828	
Cubic	.151	.801	2	9	.479	3.140	.000	.140	.078
Exponential	.159	1.892	1	10	.199	2.427	.281		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_3
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic

	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.158	1.878	1	10	.201	2.374	.603		
Logarithmic	.150	1.761	1	10	.214	2.931	.879		
Quadratic	.173	.940	2	9	.426	4.522	-2.277	.949	
Cubic	.169	.915	2	9	.435	3.602	-.635	.000	.177
Exponential	.162	1.927	1	10	.195	2.443	.193		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_4
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.010	.104	1	10	.753	3.032	.257		
Logarithmic	.020	.206	1	10	.659	3.296	.319		
Quadratic	.372	2.661	2	9	.124	-6.292	21.400	-11.749	
Cubic	.386	2.826	2	9	.112	-3.301	11.054	.000	-4.386
Exponential	.010	.100	1	10	.758	3.033	.076		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_5
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.003	.027	1	10	.872	3.562	.201		
Logarithmic	.012	.124	1	10	.733	3.780	.377		
Quadratic	.683	9.692	2	9	.006	-15.919	44.378	-24.549	
Cubic	.684	9.725	2	9	.006	-9.423	22.342	.000	-8.995
Exponential	.005	.052	1	10	.824	3.460	.077		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_6
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.027	.273	1	10	.613	3.605	-.485		
Logarithmic	.011	.112	1	10	.745	3.131	-.276		
Quadratic	.700	10.488	2	9	.004	-11.352	33.432	-18.848	
Cubic	.712	11.125	2	9	.004	-1.532	.000	18.530	-13.743
Exponential	.032	.326	1	10	.581	3.687	-.175		

The independent variable is Wind shear 20m.

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