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A Dynamic Model of Weaver Birds Flight Behaviour in Response to Electronically Generated Ultrasound using Bird-Flight Data

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Abstract
The weaver bird flight patterns in response to various ultrasound frequencies transmitted from independently assembled equipment were obtained from bird-flight data of a previous study which examined the pest and environmental specific application of ultrasound in weaver bird pest control. Statistical modelling was used to develop weekly model equations spanning for a period of seven consecutive weeks along with their respective model plots. Regression analysis was used as a statistical tool and significant value as the test for hypothesis. Result shows that the flight pattern for weeks one to four follows the cubic model with a physical significance of an effective system resulting to mass flight. Week's five to seven best fit the linear, inverse and quadratic models respectively with a physical significance of an ineffective system corresponding to partial and ineffective periods of ultrasound in weaver birds scaring resulting from habituation. A generalized model equation depicting the effective flight pattern was also obtained.

Keywords: weaver birds, bird-flight, ultrasound frequency, modelling, regression

Introduction
In previous works [1] and [2], it was put forward as part of the design consideration to guarantee the effectiveness of electronic pest control device against failure and habituation, that they should be pest specific, site/location specific and that comprehensive field studies be carried out. In the light of this, a weaver bird pest infested locality was identified [3] and [4] and a thorough field survey carried out to serve as feasibility studies in order to generate design parameters for the development of an ultrasonic brand of electronic pest control device in the locality [5].

Collection of Field Data
The study used independently assembled equipment comprising: a 12 volt car battery, 500 watt inverter, signal generator, power amplifier and five ultrasonic transducers. The transmission frequency spectrum ranges from the audible range into the ultrasonic in steps of 5 kHz to a maximum of 50 kHz while observing the effect on the weaver birds. It was observed that the repulsive effect of the ultrasound signal put the birds to flight and the numbers of bird involved was used to compute the Bird-flight data. The weekly average over the seven weeks duration of the ultrasound broadcast was worked out as presented in Table 1.

Table 1: Average Bird Flight Data Collected close to Bird Homes in Weeks One to Seven [6].

FREQUENCY	NUMBER OF BIRD-FLIGHT						
[kHz]	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7
5	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
15	0	0	0	0	0	1	0
20	3	2	4	0	1	0	0
25	10	11	9	1	0	1	0
30	15	14	16	3	0	1	1
35	26	27	25	5	1	0	1
40	8	7	9	5	1	0	0
45	3	4	2	4	0	0	0
50	1	0	2	1	1	1	0

Interpretation of Field Data

Analysis of the bird-flight data shows that week one to week three is the effective period when the bird's response to ultrasound frequency of 35 kHz was by a "quick flight and escape". Weeks four and five was the partially effective period associated with "reluctant flights" at the same frequency while week six to seven is the ineffective period where there is "little or no effect" of ultrasound on the birds [6]. The birds were said to commence habituation to the signal's scaring effect after three weeks. This result gave a clue of the effective duration within which to maximise the weaver birds chasing effect of ultrasonic brand of electronic pest control devices in the locality by timely deploying them during the peak pest period when the crops will be in their critical stages of vulnerability for an effective weaver bird cover.

In this current work, the weaver bird's behaviour in response to ultrasound was modelled statistically by using regression analysis as a statistical tool and Statistical Package for Social Sciences (S.P.S.S) as the statistical software. In statistics, regression analysis is a statistical process for estimating the relationships among variables. Especially, when the focus is on the relationship between a dependent variable and one or more independent variables, and to explore the forms of these relationships [7]. The dependent variable in this work is the number of bird-flight while the independent variable is the ultrasound frequency. Regression analysis is widely used for prediction and forecasting. To do this, a regression equation is obtained in which the dependent variable is expressed as a linear combination of unknown parameters (or coefficients) which are estimated from the data [8]. The aim of this work is to statistically predict the performance of a yet to be designed ultrasound weaver bird control device by modelling the weekly flight behaviour of the birds which will serve as a confirmatory testofthe outcome of the field survey's result of a satisfactory three weeks optimum performance period obtained via ultrasound testing using independently assembled equipment.

Materials and Method

For the purpose of this analysis, this work is broken into two composite systems: System A and B as shown in Figure 1.

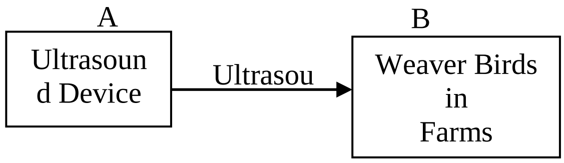


Fig 1: Device and Bird Flight Behaviour Relationship

System A comprises of the ultrasound generating equipment while system B comprises of the weaver bird pests in their feeding environment, that is, the farm. The output of system A, that is ultrasound serves as the input to system B. The behaviour of the weaver birds on the farm, whether they are effectively put to flight or not is a direct consequence of the output of the device. Modelling serves as a substitute for direct measurement and experimentation [9]. Therefore, a model obtained using a parameter each from both systems can be used to make an assertion for the flight behaviour of the birds in system B and by extension, the performance evaluation of its input (system A). For this reason, the flight behaviour of the weaver birds in response to ultrasound was modelled statistically using regression analysis.

The result of the regression analysis was presented in two forms: The model summary and parameter estimates and the model plots. The former is accessible on the left hand side of the model summary and parameter estimates table (Tables 2), while the parameter estimates are provided on the right hand side of the Table. The model summary explains the data, how well it fits a model in question. Of much interest is the R square column and the significance column. They both provide information on how much of the total variation in the dependent variable (number of bird-flight) can be explained by the independent variable (ultrasound frequency). The significance value comments on the degree of weakness or failure in satisfying a model in question by a particular data pattern [10]. Therefore, the lesser the significance value, the stronger the data satisfy the model or the lower the probability of committing errors. Lower significance values indicate a better fit, and higher values indicate a worse fit. While the R square (R^2) value gives a clue as to how many points on a set of data best fits a model in question [8]. The higher the R^2 value, the better the model fits the data. It gives more clarity when interpreted in percentage. In this work, strict adherence was made to the significance values as the sure test for hypothesis.

The model parameter estimates at the right hand side of the tables are values generated to help formulate the model equation. These parameters (coefficients) and constants when directly substituted into the regression equation (general model equation) will formulate a specific model equation for a set of data. The model plots on the other hand are graphical models to visualise the subject. They are made up of series of curves formulated using the inputted data. It analyses the variables (number of bird flight and frequency) in relationship with existing models to see how well the trend fits into the model. The best model was then selected and the model equation computed. To obtain the model for each week, the average bird-flight data for the week tabulated in their respective columns of Table 1 and ultrasound frequency were used as input data and a linear regression analysis was run for the set of data.

Results and Discussion

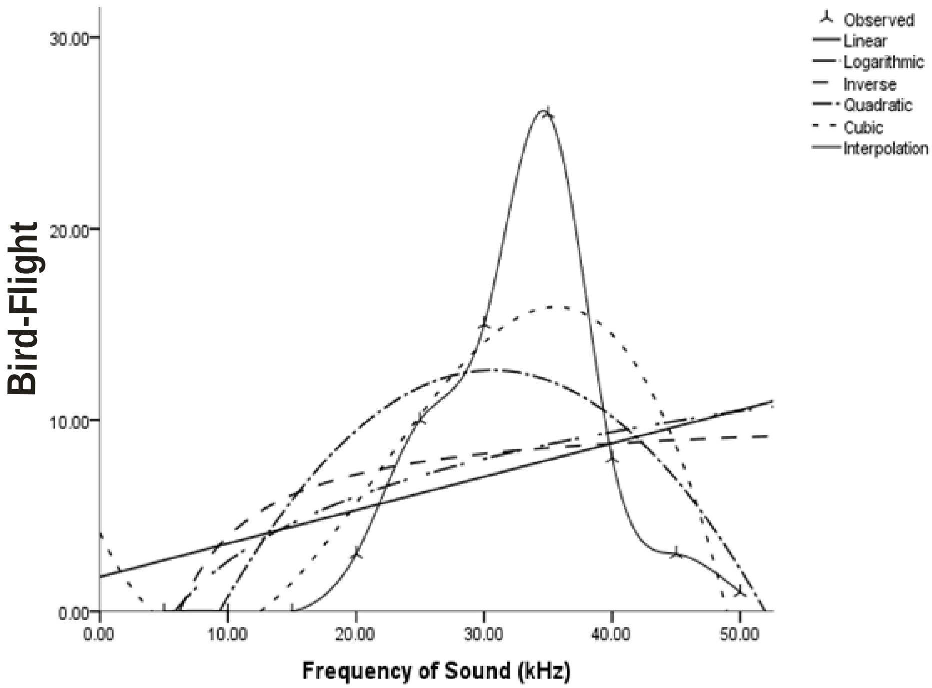
The average bird-flight data for week one to week seven tabulated in their respective columns of Table 1 were used as input data. The number of bird-flight for a week under consideration was selected as the dependent variable while the ultrasound frequency as the independent variable and a linear regression analysis was run for the set of data. The selected models highlighted to fit the data are linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential and the logistic models. The output known as the model summary and parameter estimates were computed and presented in Table 2.

Table 2: Model Summary and Parameter Estimates for Weeks one to seven

	Model	**Summary**		**Parameter**	**Estimates**		
Week	Equation	Significance	R Square	Constant (c)	b1	b2	b3
1	Linear	0.381	0.097	1.800	0.175		
	Logarithmic	0.226	0.177	-8.602	4.873		
	Inverse	0.225	0.178	10.382	-64.560		
	Quadratic	0.096	0.488	-13.450	1.700	-0.028	
	Cubic	0.058	0.687	4.100	-1.414	0.107	-0.002
2	Linear	0.408	0.087	1.800	0.171		
	Logarithmic	0.249	0.162	-8.511	4.811		
	Inverse	0.248	0.163	10.237	-63.800		
	Quadratic	0.112	0.465	-13.700	1.721	0.028	
	Cubic	0.066	0.674	4.833	-1.567	0.114	-0.002
3	Linear	0.359	0.106	1.800	0.178		
	Logarithmic	0.207	0.190	-8.694	4.934		
	Inverse	0.207	0.191	10.523	-65.320		
	Quadratic	0.087	0.503	-13.200	1.678	-0.027	
	Cubic	0.057	0.689	3.367	-1.261	0.100	-0.002
4	Linear	0.031	0.462	-0.733	0.096		
	Logarithmic	0.032	0.457	-4.232	1.965		
	Inverse	0.092	0.314	3.162	-21.545		
	Quadratic	0.060	0.552	-2.567	0.279	-0.003	-0.001
	Cubic	0.001	0.938	3.567	0.279	0.044	
5	Linear	0.143	0.247	-0.067	0.017		
	Logarithmic	0.150	0.241	-0.679	0.346		
	Inverse	0.215	0.185	0.634	-4.002		
	Quadratic	0.364	0.251	-0.150	-0.150	-0.00	
	Cubic	0.597	0.253	-0.267	0.046	-0.001	1.088E-5
6	Linear	0.695	0.020	0.267	0.005		
	Logarithmic	0.535	0.050	-0.091	0.157		
	Inverse	0.419	0.083	0.557	-2.685		
	Quadratic	0.840	0.049	0.017	0.030	0.000	
	Cubic	0.449	0.337	-1.267	0.257	-0.010	0.000
7	Linear	0.631	0.030	0.067	0.005		
	Logarithmic	0.472	0.066	-0.262	0.148		
	Inverse	0.464	0.069	0.317	-1.997		
	Quadratic	0.345	0.262	-0.517	0.063	-0.001	
	Cubic	0.353	0.397	0.200	-0.064	0.004	-6.682E-5

As observed from Table 2, the data does not fit into the compound, power, S, growth, exponential and the logistic models because both the bird-flight data and the ultrasound frequency data are non-negative and Log transform cannot be applied on them. For this reason, no entry was produced for them.

Table 2 displays the model summary and parameter estimates for the entire survey period. Inspecting week one, the significance column indicates that the least value of 0.058 was obtained for the cubic model. This means that the inputted data (bird-flight and ultrasound frequency data for week one) when analysed and compared with other selected models, the trend best fits that of the cubic model. Also, inspecting the R square column reveals that the highest value of 0.687 was also obtained for the cubic model. This means that 68% of the inputted data was captured and explained by the cubic model. The cubic model has the lowerest significance value and highest R-squared and therefore, the best model for the week. As earlier mentioned, a choice to stick to significance as the test for hypothesis has been made, but the corroboration of both the significance and the R square columns is an affirmation that the bird-flight pattern in response to ultrasound signal for week one strongly follows a cubic model. The plots for all the possible bird-flight models selected for week one are as shown in Figure 2. The best model for the week under consideration (cubic model) was isolated and presented in Figure 3.



Possible Bird-Flight Models for Week One

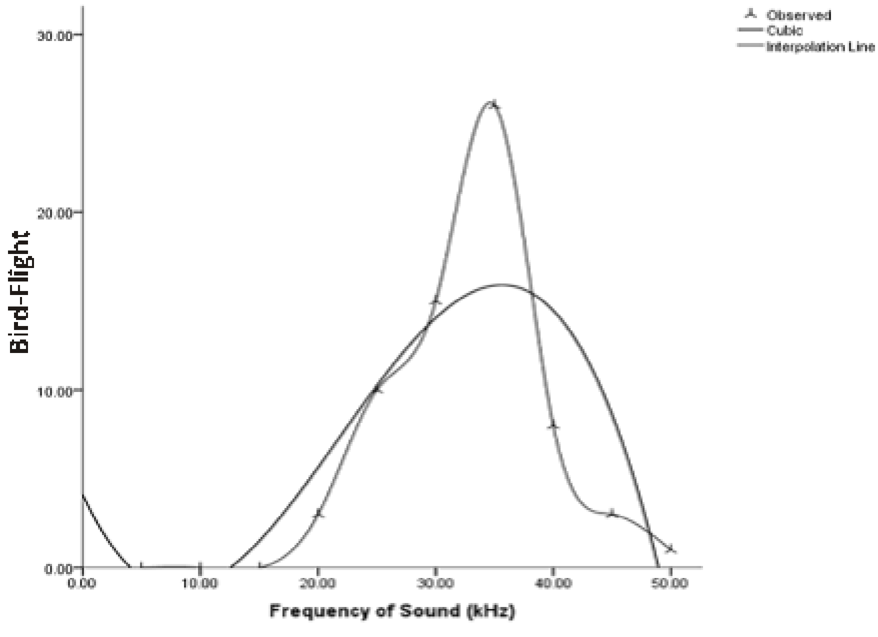


Figure 3: Bird-Flight (Cubic) Model for Week One to Week Four

The model equation describing a week's flight pattern can be obtained from the parameter estimates of Table 2. The general equation of a selected model is identified and the constants (parameters) are directly substituted from the parameter estimates side of the Table.

For week one which is cubic in nature, the general equation is given as

$$y = b3x^3 + b2x^2 + b1x + c \ (1)$$

Substituting the values of b1, b2, b3 and the constant c from Table 2 into equation (1) yields

$$y = (-0.002)x^3 + 0.107x^2 - 1.414\,x + 4.100 \ (2)$$

Equation (2) is the bird flight model equation describing the weaver birds-flight pattern for week one, where y is the dependent variable (bird-flight for week one) and x is the independent variable (ultrasound frequency).

It can also be seen from Table 2 by tracing the significance values for weeks two to week four that the best model is the cubic model as the case with week one. Their corresponding model plots are similar to the general cubic model pattern of Figure 3, while their model equation extracted from their respective parameter estimate columns are given by equation (3), (4) and (5):

$$y = (-0.002)x^3 + 0.114x^2 - 1.567\,x + 4.833 \quad (3)$$

$$y = (-0.002)x^3 + 0.100x^2 - 1.261\,x + 3.367 \quad (4)$$

$$y = (-0.001)\,x^3 + 0.044x^2 - 0.809\,x + 3.567 \quad (5)$$

Weeks five, six and seven witnessed a twist from those of week one to four by following the linear, inverse and quadratic models respectively. Their respective model equations are as shown in equation (6), (7) and (8):

$$y = (0.017)x - 0.067 \quad (6)$$

$$y = \frac{(-2.685) + 0.557}{x} \quad (7)$$

$$y = (-0.001)x^2 + 0.063x - 0.517 \quad (8)$$

Their respective model plots are shown in Figure 4, 5 and 6.

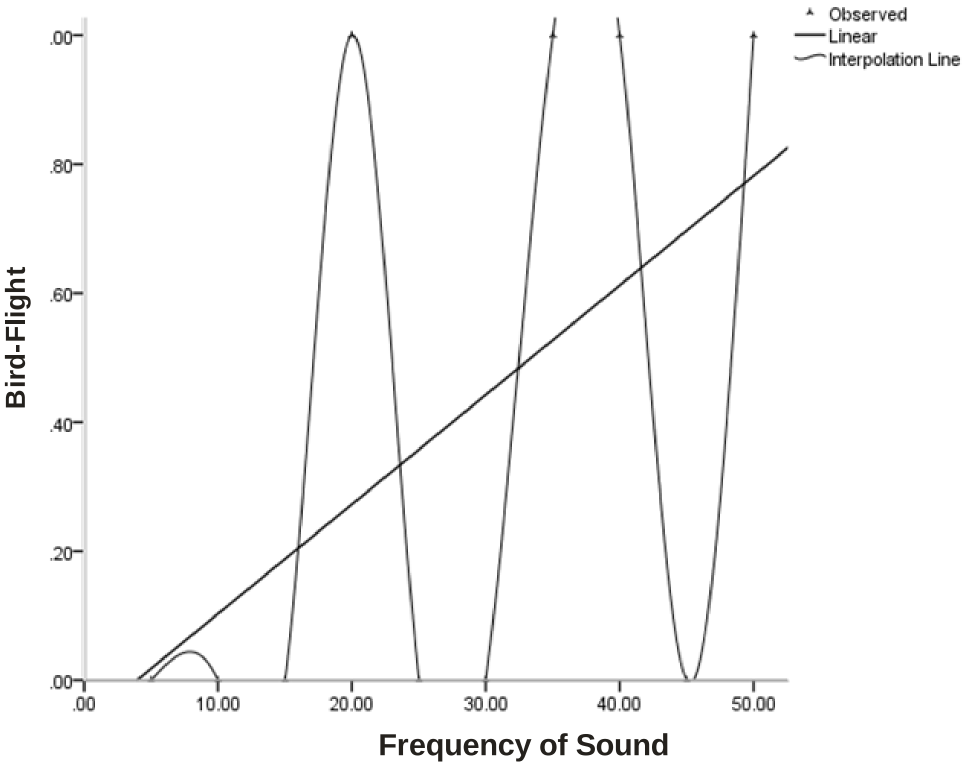


Figure 4: Bird-Flight (Linear) Model for Week Five

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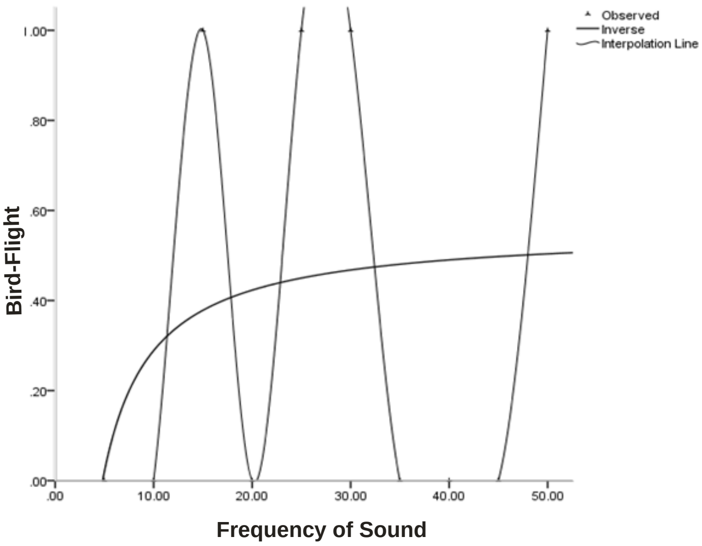

Figure 5: Bird-Flight (Inverse) Model for Week Six

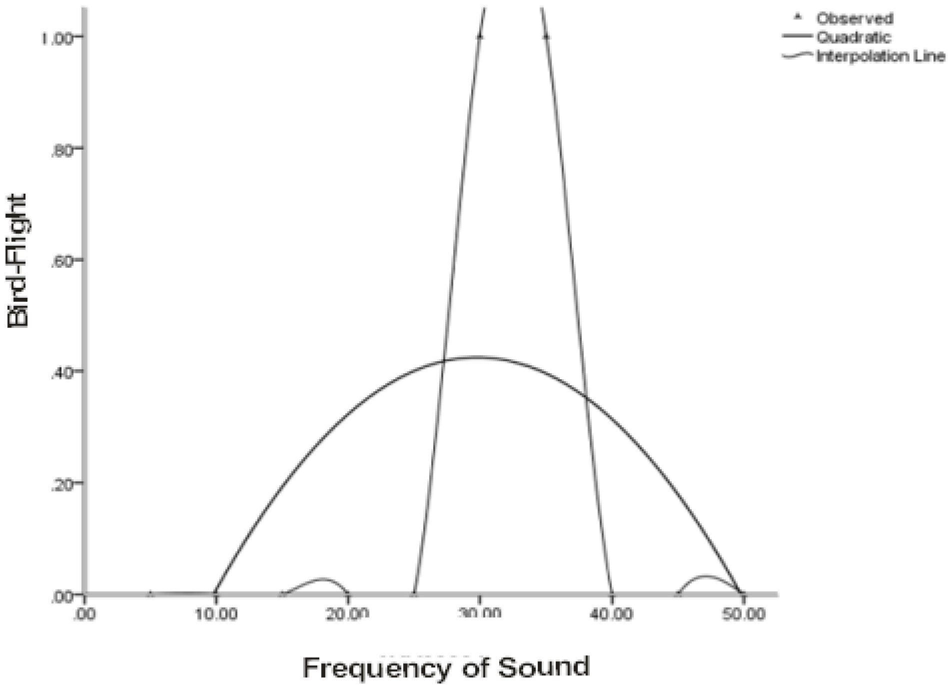

Figure 6: Bird-Flight (Quadratic) Model for Week Seven

In summary, the bird-flight pattern for weeks one to four follows the cubic model while those of weeks five to seven follow those of linear, inverse and quadratic models respectively. From observations made during field survey and field evaluation [6], weeks one to three correspond to the effective period of the device during which all activities of the birds ranging from flying, perching and nesting were completely deterred, while weeks four to five correspond to the partially effective period of the device associated with the gradual setting in of habituation, weeks six to seven correspond to the ineffective period of the device during which the weaver birds completely habituate. By this analysis, Week four which is the best of the partially effective weeks was recovered into the effective weeks while the worst of the partially effective weeks (week 5) was placed under the ineffective period.

If a choice to stick to the R square values as the test of hypothesis was made instead of the significant values, all the results from weeks one to seven would have pointed to the cubic model as the best flight model. As straight forward as this will be, it would have concealed some startling revelations. For instance, it will play down on the setting in of habituation. But the sudden twist in flight pattern from the cubic model after week four which also correspond to the partial and ineffective periods of the device gives credence to the choice of significance as the test of hypothesis.

Generally speaking, it can be said that the weaver bird-flight pattern due to ultrasound satisfies the cubic model. Even for weeks five to seven whose significance value does not support the cubic model, their cubic model R squared values ranked highest compare to those of linear, inverse and quadratic for those weeks. Hence, substantial portions of the bird-flight pattern for those weeks have the cubic components. Therefore, the overall general model equation which satisfies the weaver bird-flight pattern is that of equation (1) given as

$$y = b3\,x^3 + b2\,x^2 + b1\,x + c$$

where y is the bird-flight, *x* is the ultrasound frequency. b1, b2, and b3 are parameters while c is a constant. The values of b1, b2, b3 and c are provided by the model summary and parameter estimates tables.

A linear model or those of equation (6) to (8) depicts a trivial or less effective system. The reason for this is because it has one parameter and a constant to specify a system. Therefore, it tells less about the nature of something. Example of a system satisfying this model is a process on a queue where event take their turn one after another. By implication, that means at this point, the birds were flying one after the other from the farm which negates the intention of an effective system famous for initiating a mass flight (a simultaneous flight by a group of birds when the threshold sound bearing capacity of the birds is reached [6]). Same interpretation also holds for the inverse model with one parameter and a constant to specify a system.

The quadratic model is a slight improvement over the two. It attempts to explains a system but in the absence of a better model. That is to say that, this model describes the nature of bird-flight but not so effectively as another model can do it better.

A cubic model on the other hand, illustrates a multifaceted system. Such a model is used to illustrate an effective system with a winning strategy. The beauty of obtaining the cubic model as the best to explain or predict bird-flight behaviour is that:

i. Its equation has three parameters and a constant. Hence a system governed by it aids predictive analysis, as its four coefficients going into explaining the pattern of flight is a pointer that such a flight is likely to be a mass flight.
ii. A cubic equation has the independent variable raised to power of three, two and one respectively. This is responsible for the overwhelming effect on the

dependent variable, which is the number of birds put to flight. This flight behaviour is of interest in this work as it is a pointer to the required ultrasound frequency to be generated when designing an effective ultrasound pest control device.

iii. It's curve span through all the frequency values without extrapolation. Thus, naturally offering explanation for flight recorded at 0 kHz. That is, the possibility of flight in the absence of ultrasound. This also gives credence to the contribution of other non-ultrasound birds chasing parameters around the vicinity such as the predator cry section incorporated into an ultrasound pest control device [5].

Conclusion

A model for the weaver bird-flight behaviour was ascertained. By being cubic in nature, it tells of an effective flight behaviour. On site, this behaviour was observed during mass flights occurring at 25 and 35 kHz. The birds were constantly put to flight upon interaction with ultrasound from week one to week four after which its performance began to deteriorate due to habituation. Therefore, the change in trend from the cubic model to other forms gives credence to the setting in of habituation, a factor responsible for the inefficiency of ultrasound in weaver bird control beyond week four. By extension, obtaining this model implies that a device designed and configured after that of the independently assembled equipment transmitting the ultrasound signal will effectively initiate a mass flight on weaver birds in that environment at least for the first four weeks. This analysis is therefore a further confirmation of the result of previous studies [6] that an electronic device which is able to generate and transmit ultrasound at the determined frequencies (25 to 35 kHz) will effectively ensure maximum flight and minimum return of weaver birds to homes and farms in the test locality within three weeks of its deployment. As established by this study, the probability of extending such performance to four weeks is highly likely.

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