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Spectrum Diagnosis of Drone Structure Oscillation and Aerodynamic Forces

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Abstract

This paper includes an experimental study of the effect of irregular vibrations (random vibration) resulting from dynamic aerodynamic load or the turbulent winds of the unmanned aerial vehicle (UAV) wing, as well as finding aerodynamic forces affecting the wing. The objective of this study is to determine the concentration areas of the force in which the failure occurs and to know the behavior of random vibration and its effect on the wing structure. The wing was constructed and manufactured with suitable dimensions and then the wing was installed inside the wind tunnel of the test. The wing has been tested at five angles of attack (0º, 5º, 10º, 15º and 20º) and certain wind velocities. Through the sensors and associated signal analyzers, the relationship was obtained between acceleration and frequency acceleration of specific points on the wing surface and the forces of drag, lift and torque were calculated. The results show, it was found that the greatest value of the forces is concentrated in the area near the edge fixed at the wing root especially in the large attack angles. Also it was concluded that the drag and lift forces and torque torsional wing increases proportional to the increase in wind velocity and angle of attack.

Keywords: UAV, Deformation of Wing, Random Vibration, Drag and Lift forces, Lift Distribution.

1. Introduction

The great development of science and technology and prosperity of the industry throughout the world, all these things have increased the use of unmanned aerial vehicles (UAV's) or (Drone) in recent years, so it did not need the skill of a burden in the use and cost of a few manufactured and can be used in many applications such as imaging and load transfer in civil and military fields and control of agricultural crops and facilitate the work and conduct experiments in the field of study and design of the aircraft **[1] [2]**. Where the unmanned aerial vehicles are classified according to the type of tasks: Target and decoy, Reconnaissance, Combat, Research and development and Civil and Commercial UAVs **[3]**. In the past, the aluminum material is the basic material in the manufacture and construction of unmanned aerial vehicle structures and space craft's **[4]**. At present, modern design requirements such as light weight, structural rigidity and extreme thermal stability have surpassed traditional aluminum capacity **[5]**. Specialists in this field believe that composite materials with continuous fibers are the most appropriate option because of their characteristic properties, where light weight and high rigidity in endurance and cost relatively few and ease of formation and operation **[6]**. All these things are positively reflected with the use the composite materials in the manufacture and construction of unmanned aerial vehicle structures. In this paper will be study the vibrations that occur in the wing of unmanned aerial vehicle due to wind waves and areas of concentration of forces on the wing surface as well as study the effect of aerodynamic forces. The wind is a non-deterministic movement or irregular waves and therefore all waves and vibrations caused by them are random. This means that vibration behavior and future response to the structure of airplane will be absolutely unexpected **[7]**. The turbulent flow of wind passing around the wing is considered a forced function. Moreover, the turbulent pressure affecting the wing surface is randomized over time **[8]**. It seems that the turbulent wind waves around the wing will force him to vibrate randomly **[9]**. Plane fly according to the third law of Newton which states: for every action, there is a reaction equal and opposite. When the wind passes around the wing, it changes its direction to the bottom this is the act, the reaction is the force generated by the wind on the wing always, called lifting force **[10]**. Also, the movement of the plane forward by the drive of the engine will be offset by the disability shown by the structure of the aircraft against the wind, called the drag force **[11]**. The amount of lift and drag forces is controlled by changing the angle of the wing or the so-called angle of attack, which is the angle between the chord line of the wing and the relative wind.

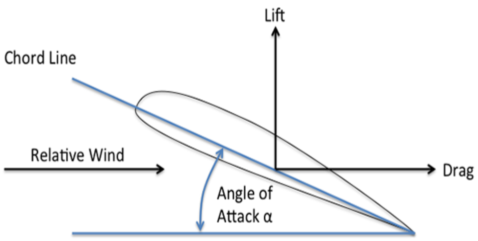


Fig.1 Aerodynamic parameters.

The aim of the study is to know the effect of wind waves (random waves) on the wing of a UAV. Also to know the distribution and analysis of forces and determine their areas of concentration, also the calculation of the lift and drag forces and affected the angle of attack on them.

2. Model Description

The model that was used in this work was the wing of unmanned aerial vehicle which was manufactured from the foam material covered by lamination plate. The basic parameter such as airfoil section, wing chord length C, wing span B, aspect ratio AR and thickness to chord ratio t/C should have been decided at early stages of the work. Table (1) shows the geometric parameters for the wing in this study, and figure (2) shows airfoil (NACA Clark y) of the wing selected in the present study.

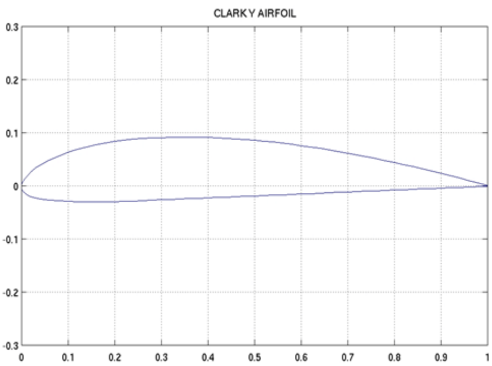


Fig.2 Clark y airfoil.

Table 1 Geometric parameters of the wing.

Airfoil section	NACA Clark y
Chord length (C)	16 cm
Wing span (B)	60 cm
Aspect ratio (AR)	3.75
Thickness to chord ratio (t/C)	0.125

The model was installed inside low velocity wind tunnel as shown in figure (3).

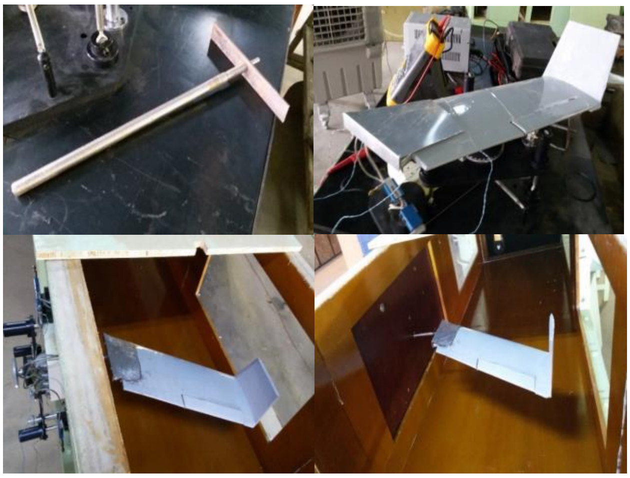


Fig.3 Method of installing the test model inside wind tunnel.

3. Measurement Tools

Measuring instruments were used in this test are: The flow meter is used to measure the velocity of the wind, the vibration measuring device of the type (Ni national instrument vibration system) for measurement and analysis of signals from sensors, sensors of type (peso electronic one dimension accelerometer) to record vibration values where four sensors were installed into specific locations on the wing surface, the first sensor (S_1) was installed in the middle of the fin at the end of the wing, while the remaining three sensors were glued to the upper surface of the wing in the center-line and at a distance of (52 cm, 35 cm and 18cm) for S_2, S_3 and S_4 respectively. An aerodynamic device of the type [Airfoil wind (Lift, Falt and Drag forces measurement)] was used to calculate the lift and drag forces and torque by three load cells.

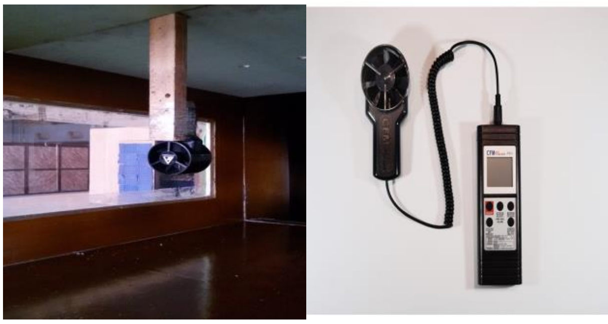


Fig.4 Flow meter.

Fig.5 Vibration measurement device.

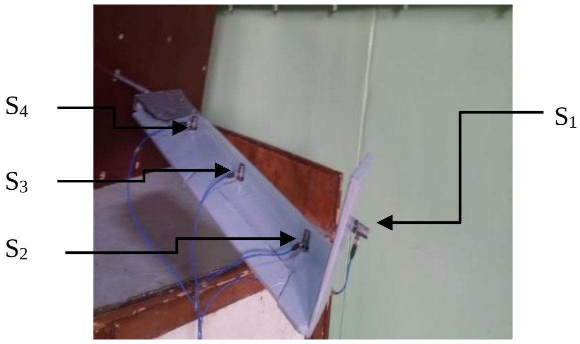


Fig.6 Sensors.

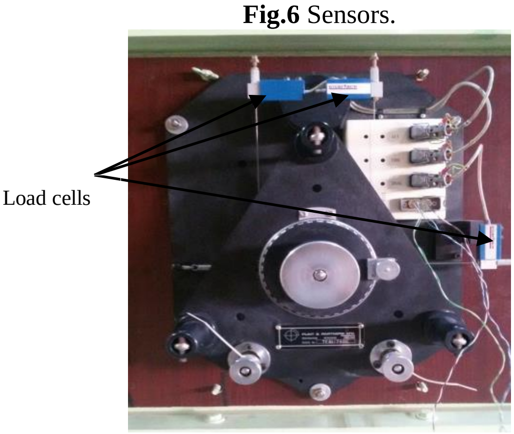


Fig.7 Aerodynamic measurement device.

Through this work the acceleration of vibration with time (real time) produced by the excitement of the wind waves was obtained when the wing was installed inside the wind tunnel were vibration acceleration and the aerodynamic variables were also calculated. Experiment was performed at variable wind velocities and different attack angles (0º, 5º, 10º, 15º and 20º).

4. Results and Discussions

4.1 Vibration Analysis

Turbulent or random wind movement is the cause of irregular vibrations. In this test wind waves are input or excitation units. The wing was installed inside the wind tunnel and after reaching the appropriate speed to conduct the experiment, the angle of wing attack was then changed and the readings are recorded via the sensors fixed to the wing surface. Through this process the variation between vibration acceleration over time was obtained. The (LAB VEIW) program is used and the Fast Fourier Transform (FFT) version (2014) method to obtain the relationship between vibration acceleration and frequency was obtained. Through this relationship it can be that the vibration concentration regains along the wing as well as using the aerodynamic device special aerodynamic variables were calculated.

The variation of vibration acceleration with frequency at wind velocity (22 m/s) and attack angle (0º) for all sensors is shown in figure (8). From this figure can be observed with increase wind velocity, the turbulence in the recorded vibration will be increasing. In this case the magnitude of acceleration was ranged between 0.01 m/s^2 and 0.095 m/s^2. Where, the maximum values was recorded at the period 100 Hz for S_1 and S_4 were 0.095 m/s^2 and 0.068 m/s^2, also S_2 and S_3 at same period 8 Hz were 0.066 m/s^2 and S_3 0.037 m/s^2 respectively.

Figure (9) describes the variation of acceleration with frequency at wind velocity (22 m/s) and attack angle (5º). It can be noted that the vibration in this case was increased, where the values for all sensors ranged between (0.01 m/s^2 to 0.085 m/s^2) during the different periods. The maximum values for S_1 and S_4 was recorded at period 100 Hz are (0.085 m/s^2 and 0.062 m/s^2) respectively, either S_2 is (0.058 m/s^2) at 11 Hz, the recorded value by S_3 was more oscillation, where it was the maximum value (0.041 m/s^2) at 50 Hz.

Figure (10) demonstrates the variation of acceleration with frequency at wind velocity (22 m/s) and attack angle (10º). It can be seen that the oscillation behavior and the magnitude of acceleration began to increase significantly with the change in the angle of attack. The recorded acceleration values for all sensors in this case ranged between (0.01 m/s^2 and 0.12 m/s^2) during the period (5 Hz and 5000 Hz). The maximum values recorded in this case for S_1 and S_4 at period 100 Hz (0.12 m/s^2 and 0.09 m/s^2) respectively, either S_2 and S_3 were recorded (0.061 m/s^2 at 11 Hz and 0.05 m/s^2 at 50 Hz) respectively.

Figure (11) shows the variation of acceleration with frequency at wind velocity (22 m/s) and attack angle (15º). It can be observed that the behavior of turbulence and vibration in this case, similar to the previous situation, where the value was ranged between (0.01 m/s^2 to 0.0119 m/s^2). The maximum value was recorded at 100 Hz for S_1, S_4 were 0.0119 m/s^2, 0.08 m/s^2 respectively, either S_2 was 0.055 m/s^2 at 10 Hz and S_3 0.062 m/s^2 at 50 Hz and 190 Hz.

Figure (12) observes the variation of acceleration with frequency at wind velocity (22 m/s) and attack angle (20º). It can be noted in this figure that the acceleration values are decrease in this case for all the sensors except S_3, it records the value of higher than the previous situation. The magnitude of acceleration of vibration in this case ranged between (0.01 m/s^2 to 0.12 m/s^2). The maximum acceleration value for S_1 0.125 m/s^2 at period 100 Hz, S_2 0.06 m/s^2 at 10 Hz, S_3 0.07 m/s^2 at 50 Hz and S_4 0.085 m/s^2 at 100 Hz.

That means the acceleration of the fin and fixation of the wing increased in the center frequency range while the acceleration of the other upper points of wing increasing at the fundament of excitation frequency. This means to avoid failure the designers must take into account the accurate design for this point. Also, when changing angle of attack observed acceleration of change for all sensors values for the fluctuation of this means offering the upper part of the wing to a more responsive.

4.2 Aerodynamic Analysis

Aerodynamics forces were obtained through the device to find the aerodynamic forces that effect on the wing of the plane, where the calculation of the forces of lift and drag and through the results it can be found the ratio of lift to drag. Experience was achieved by changing wind velocity (19 m/s, 21 m/s, 22 m/s and 23 m/s) and angle of attack (0º, 5º, 10º, 15º and 20º).

The variation of the lift and drag forces and torque with angle of attack at the wind velocity (19 m/s) is shown in figure (13). It can be shown that the lift force (L) and torque (T) is starting from zero, either the drag force (D) starting from (1.32 N), the reason is that the lift force and torque was generated from the result of changing angle of attack, either the effect of the drag force on the wing arising from the disability shown by the structure to resist wind waves. Aerodynamic parameters (lift and drag forces and torque) are proportional with the angle of attack in this case, where the maximum value reached (D_{max} = 15.226 N, L_{max} = 21.51 N and T_{max} = 2.15 N.m).

Figure (14) demonstrates the variation of the lift and drag forces and torque with angle of attack at the wind velocity (21 m/s). It can be seen that the increase in wind speed caused a clear increase in all values, as the drag force in this case started from (1.65 N). The maximum values for all variables in this case have become (D_{max} = 15.95 N, L_{max}=25.35N and T_{max} = 2.21 N.m).

Figure (15) shows the variation of the lift, drag forces and torque with angle of attack at wind speed (22 m / s). A gradual increase in the values of all the forces that affect the wing can be observed with increased wind velocity. The force of clouds in this case began from (1.72 N). Maximum values in this case reached to (D_{max} = 16 N, L_{max} = 28.42 N and T_{max} = 2.34 N.m).

Figure (16) shows the variation of the lift, drag forces and torque with the attack angle at wind speed (23 m / s). It is possible to observe that the behavior of the change and the amount of drag force is less than the lift force in all cases. This is because the angles of the attack have positive values. The wing is in the takeoff position, so the leverage effect is greater than the force of the drag while increasing the angle of attack of the pavilion. The drag force started in this case from (1.80 N), the maximum values recorded in this case were (D_{max} = 17.67 N, L_{max} = 30.73 N and T_{max} = 2.46 N.m).

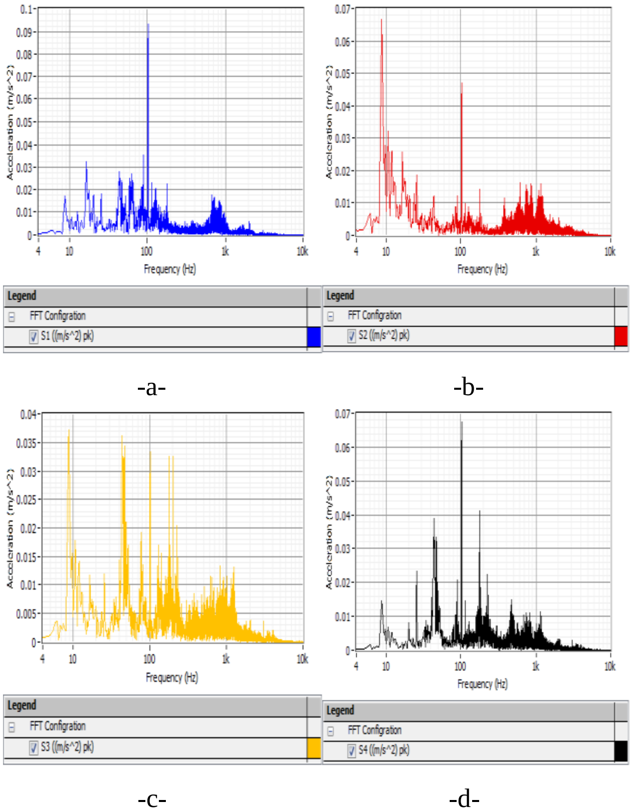


Fig.8 Relationship between the acceleration of vibration (the force per unit mass) and the frequency for all sensors at angle of attack (0º): a- First sensor (S_1). b- Second sensor (S_2). c- Third sensor (S_3). d- Fourth sensor (S_4).

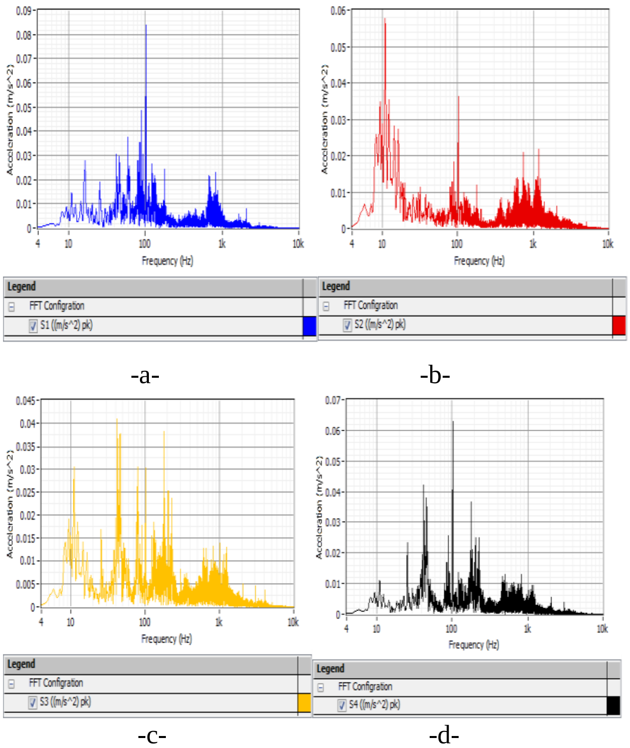
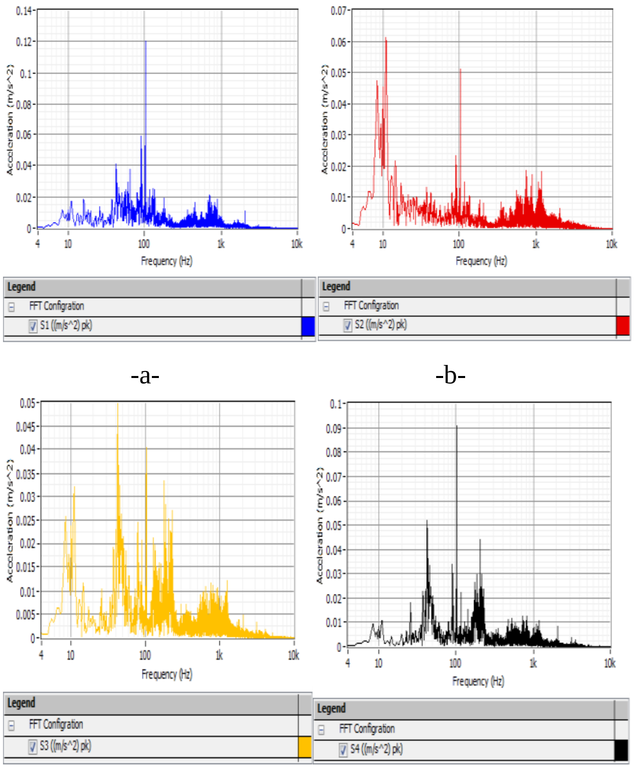


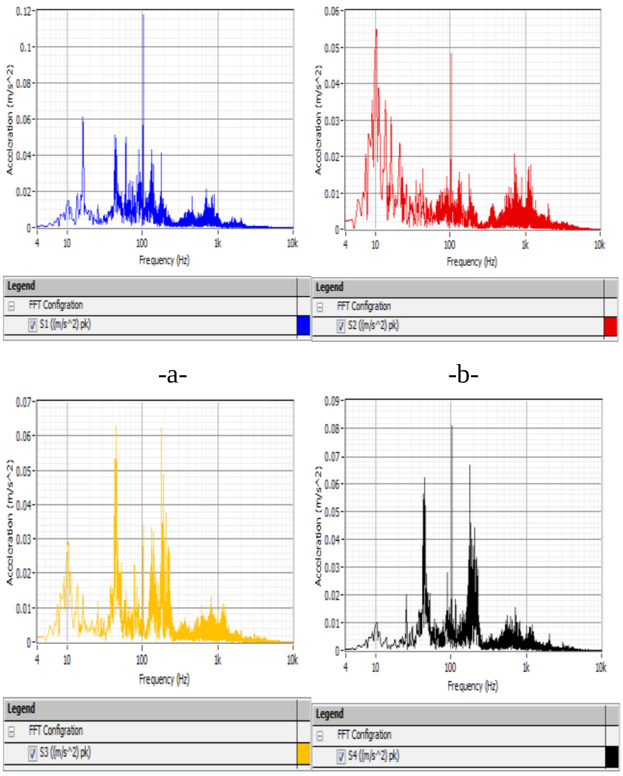
Fig.9 Relationship between the acceleration of vibration (the force per unit mass) and the frequency for all sensors at angle of attack (5º): a- First sensor (S_1). b- Second sensor (S_2). c- Third sensor (S_3). d- Fourth sensor (S_4).



-a- -b-

-c- -d-

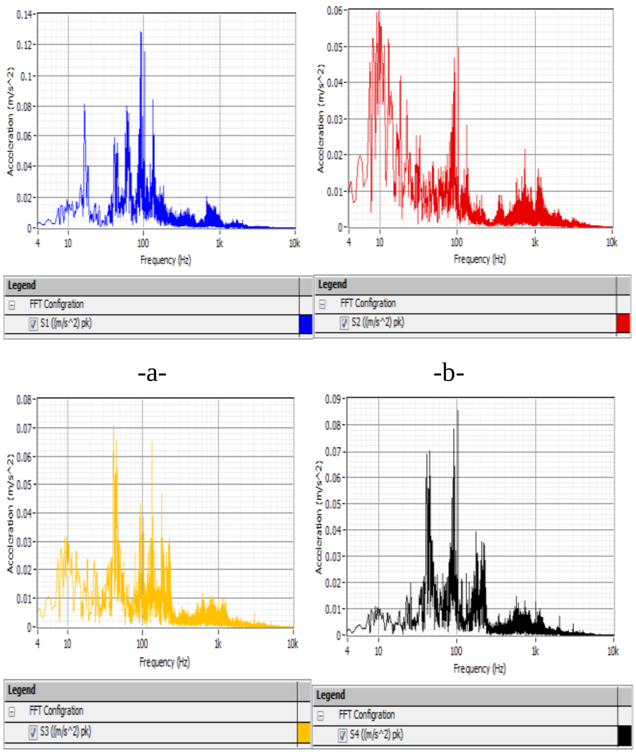
Fig.10 Relationship between the acceleration of vibration (the force per unit mass) and the frequency for all sensors at angle of attack (10º): a- First sensor (S_1). b- Second sensor (S_2). c- Third sensor (S_3). d- Fourth sensor (S_4).



-a- -b-

-c- -d-

Fig.11 Relationship between the acceleration of vibration (the force per unit mass) and the frequency for all sensors at angle of attack (15º): a- First sensor (S_1). b- Second sensor (S_2). c- Third sensor (S_3). d- Fourth sensor (S_4).



-a- -b-

-c- -d-

Fig. 12 Relationship between the acceleration of vibration (the force per unit mass) and the frequency for all sensors at angle of attack (20º): a- First sensor (S_1). b- Second sensor (S_2). c- Third sensor (S_3). d- Fourth sensor (S_4).

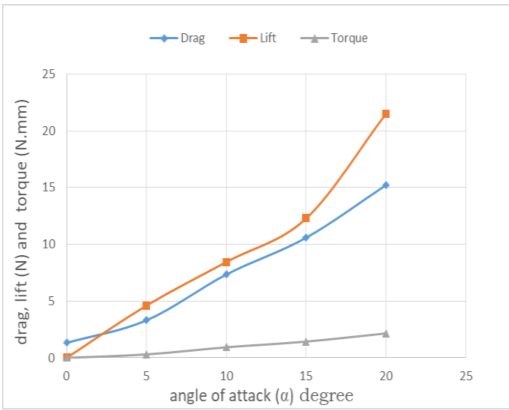


Fig.13 Relationship between the drag, lift forces and torque with variation the angle of attack at wind velocity (U=19 m/s).

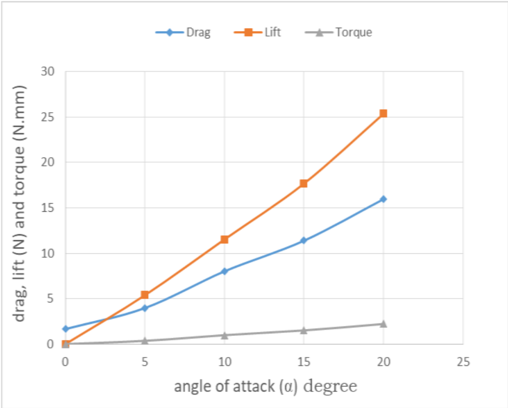


Fig.14 Relationship between the drag, lift forces and torque with variation the angle of attack at wind velocity (U=21 m/s).

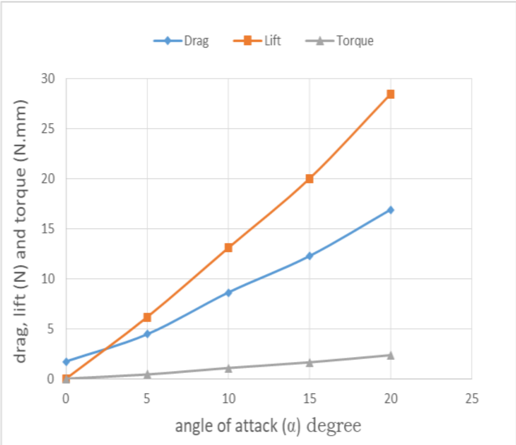


Fig.15 Relationship between the drag, lift forces and torque with variation the angle of attack at wind velocity (U=22 m/s).

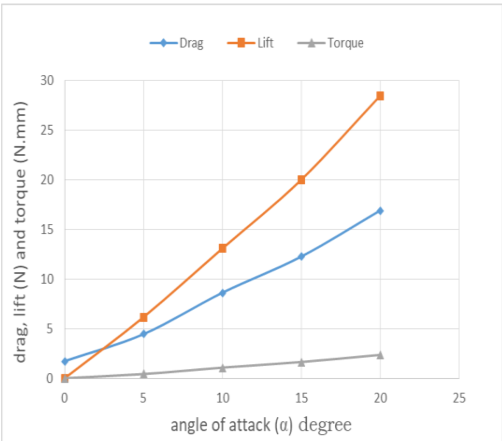


Fig.16 Relationship between the drag, lift forces and torque with variation the angle of attack at wind velocity (U=23 m/s).

Conclusions

The great development that is taking place in the field of the use of UAVs has made this field the focus of many concluded remarks. There have been many studies of design and calculation of force to affect the structures and wings of UAVs. This paper was concerned with the study of vibrations resulting from wind waves and to know its effect. Through analysis and study of the experimental results obtained, can be concluded several points:

1. Maximum amount of vibration acceleration occurs at the free end of the wing (fin).
2. The greatest value of the stresses and loads concentrated in the areas close to the fixed end of the wing, where these areas are more prone to failure or breakage.
3. Vibration behavior is similar in most cases to each sensor.
4. The maximum recorded value of the vibration acceleration at the angle of attack 15º and the lowest value recorded at the angle of attack 5º.
5. All aerodynamic parameters are increased with increased attack angle and wind velocity.
6. The drag force for all the selected velocity in the test starts from (1 N) or more.

Therefore designers should consider the above points and know how to deal with them to ensure the safety of aircraft wings of failure and crash during flight and avoid the danger caused by wind on the wing.

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