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The Design and Development of Ornithopter Test Rig

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Abstract—*There are various developments in science and technology in the field of aerospace where new design and model of flying vehicle are implemented. In this paper the aim is to design and develop a prototype of a versatile test rig such that to analyze the dynamic characterization of micro sized ornithopter which is less than 12 inches wing span. The developed test rig will have 0.0025N. The cost of the rig will be minimized by utilization of indigenous resources and new technologies. The test rig will be designed such that there is more compactibility with the micro aerial vehicle. The ability to measure the flapping frequency with the utilization of microphone and accelerometer sensors are implemented. The design of the test rig is carried out using PRO ENGINEER software and ANSYS from which finite element analysis will be done.*

1. INTRODUCTION

The Micro Aerial Vehicle (MAV) and Unmaned Aerial Vehicle(UAV)are one of the areas in which new thinking and new technology are implemented with new area of application. The development of mechanical flapping wing bird artificially and its significant name is termed to be known as “Ornithopter” where “ Orni” means bird and “pteron” means wing.These birds are now designed with very small size configuration also.This innovation in design lead to change of model. This change of model lead to change of application and which changes its reliability, controllability on that processed product.

One such development includes the ornithopter test rig There are various testing equipments developed from various parts of the world. The various types of testing machine for unmanned aerial vehicle with specialization of ornithopter type of system are discussed in the literature survey.

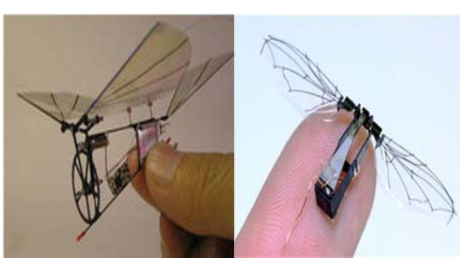

Fig. 1: Micro size ornithopter

2. LITERATURE SURVEY

R.J.Wood et.al, proposed the Following system. The actuator, wings, and transmission are assembled together onto an acrylic fixture. At the structure a custom build force sensor is embedded and the device is actuated at resonant frequency of 110Hz. The average lift is measured by averaging 50 wing beats after 50 wing beats are elapsed to allow stable periodic vortex formation. The average lift was collected from 10 trials giving an average of 1.14±0.23mN.

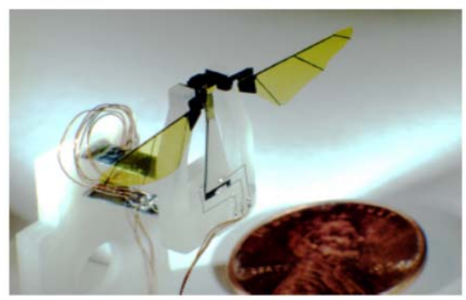

Fig. 2. Three DOF (degree of freedom) 3cm flapping wing MAV

Dae-Kwan Kim et.al, pp.423-431, 2008.The developed test rig consists of driving part, a test mount and a measurement part. The flapping motion is achieved with the help of DC motor and the flapping axis with respect to stream velocity can be changed by adjusting the test mount which supports the driving part. The lift and the thrust forcesare measured simultaneously by the horizontal and vertical load cells, respectively.

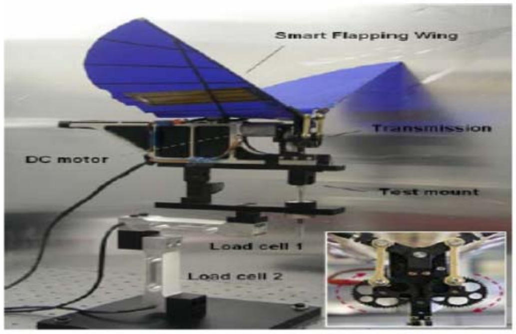

Fig. 3: Aerodynamic characteristics of a Biomimetic flapping wing with macro fiber composite

P. Daniel Kuang et.al. Simulate the various wing motions such as pitching, flapping and lead-lag. The eight degrees of freedom (DOF) test bed is having the following joints, three in each shoulder joint and two for the amplitude of flapping. Shoulder joints are also similar to human shoulder joints, able to move forward, backwards, up, down, and can twist in both directions. Using these DOF, lead-lag, flapping, and pitching are determined.

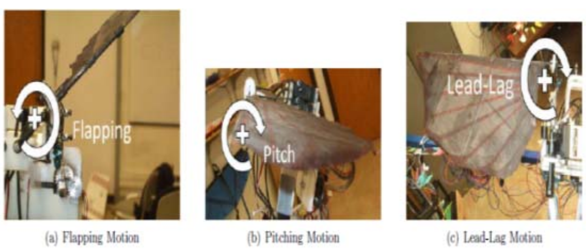

Fig. 4: The various motion of an ornithopter denoted with respect to the axis.

Robyn Lynn Harmon et.al. The test rig consists of aluminium base plate which is attached on top of reinforced PVC pipe be means of aluminium slugs. A strain gauge transducer with 6DOF is embedded between test stand and vice which was used to measure the vertical and horizontal forces during the flapping motion of an Ornithopter.

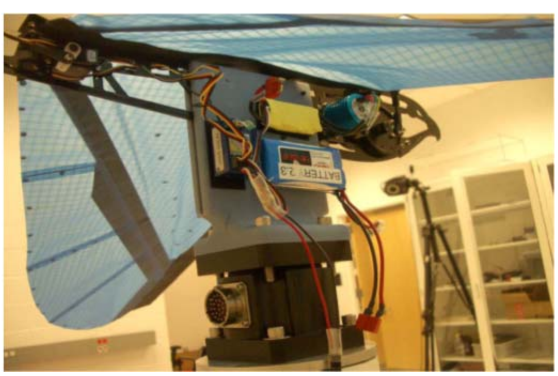

Fig. 5.Aerodynamic modeling of aflapping membrane wing using motion tracking experiments

3. TEST RIG DESIGN

From the literature survey it is evident that almost every research has been carried out on the basis of wind tunnel testing which makes the testing process completed for fixed wing UAV. However in the case of ornithopter which makes the testing in wind tunnel as complicated and not that accurate for measurement of dynamic analysis where thrust and lift are measured. In such cases the thrust and lift of an ornithopter are measured with he help of this test rig which simplifies the process for calculation of thrust and lift. The design ,construction, working of the test rig are as follows

- There is a horizontal member which has a degree of freedom that is oscillating about a horizontal axis by which lift force is transmitted through the probe to the load.
- There is a vertical member which has a degree of freedom that is revolving about the vertical axis in which the thrust is proportional to the angular velocity and this is measured with the help of gyro sensor.
- An assembled test rig model has been designed with the help of PROENGINEER software. An ornithopter will be attached to one end of the horizontal member.
- The selection of the material for transfer of load between the members is a very important criteria. The structural analysis should be carried out to determine the various parameters associated with it.
- An optimized model of the test rig has been modeled with the help of usage of alluminium A set of accelerometers and gyro are embedded on the vertical and horizontal member which will measure the lift and thrust.

A cantilever beam with a revolute joint about vertical axis is considered. The ornithopter and the accelerometer are mounted on the end of the beam. The fixed end of the beam is attached with a load cell. Thus the thrust exerted by the ornithopter can be measured with the help of accelerometer. Thereby the lift force is measured from the load cell.

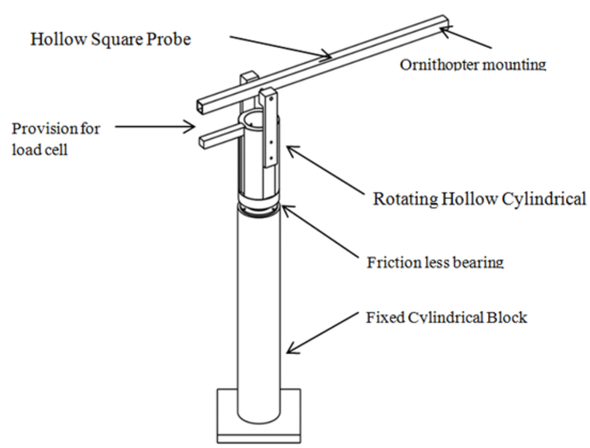

Fig. 6. Ornithopter test rig

The ornithopter in the Fig. 6 Denotes the various components of the test rig. The schematic diagram of the load cell and accelerometer position are represented with the axis of rotation in fig7.

In the Fig. 7 ,the three axis namely x,y,z are of a MEMS based 3 axis accelerometer sensor. Accelerometer sensor is a device which is used to measure the linear acceleration experienced on it. Here, this sensor is used to find the tangential acceleration of the horizontal member and also to determine the maximum vibration acting on it. Since the ornithopter is mounted on the end of the horizontal member the thrust force exerted by the flapping bird will be applied normal to the probe which is constrained with a revolute joint of a vertical axis. Hence the probe tends to rotate about vertical axis.

Therefore the accelerometer attached to the probe along with the flapping bird will sense the tangential acceleration from the rotation ; from measured acceleration data the thrust force exerted by the ornithopter can be calculated through various formulas

There are measured tangential force which is found as a result of cross product of mass and tangential acceleration. The tangential acceleration is found from the measured data. This tangential force exerted is proportional to the thrust force. There are various methods from which lift and thrust are measured.

The lift is measured with the help of two methods as Usage of load cell and Usage of accelerometer

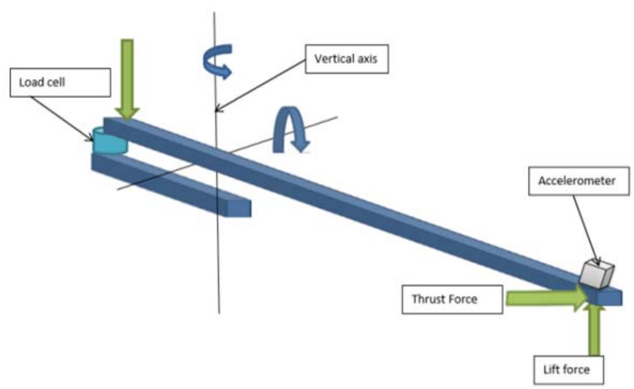

Fig. 7: Schematic representation of positioning of accelerometer and load cell

The calculation of this tangential force are given with the formulas as follows

FORMULAS ASSOCIATED

Tangential force = Mass * Tangential Acceleration

Tangential force ,($F_t = m * a_t$)

Thus tangential force proportional to thrust force

Considering the effect of friction,

Thrust Force = (1 + f) * Tangential Force

Where

a_t – tangential acceleration

m- mass moment of inertia of the rotar part

f - coefficient of friction of frictionless bearing

The lift force measurement is illustrated below

Fig. 8. Ornithopter with its remote control

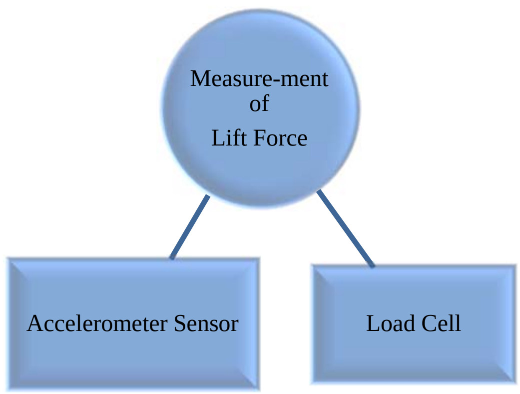

Fig. 9. Measurement of lift fore

4. MEASUREMENT OF LIFT FORCE

1. METHOD 1 :

The accelerometer attached to the end of the probe measures the acceleration data along three axis. This is illustrated in Fig. 9. The lift exerted by ornithopter makes the probe to vibrate vertically as the other end of the probe is fixed. The acceleration of vibration is measured by the accelerometer along the y axis. This acceleration data is then double integrated to get the displacement. On substitution of deflection value in the maximum deflection of the cantilever beam equation, the load acting on the beam can be calculated which is proportional to lift force.

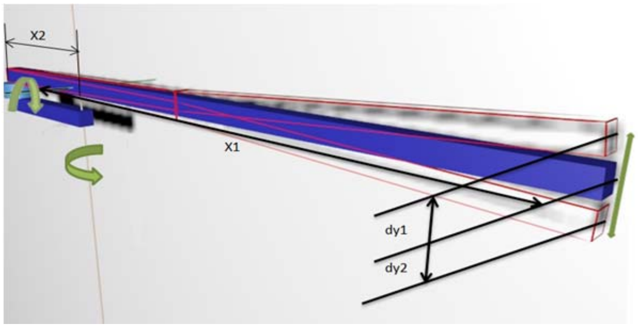

Fig. 9. Measurement of lift force (ACCELEROMETER)

2. METHOD 2

The lift force applied on one end is transferred through the probe and load cell on the other end measures the lift force applied. Therefore from formula the lift force can be calculated.

Measured Load cell Value * $X_2 = X_1$ * Lift Force

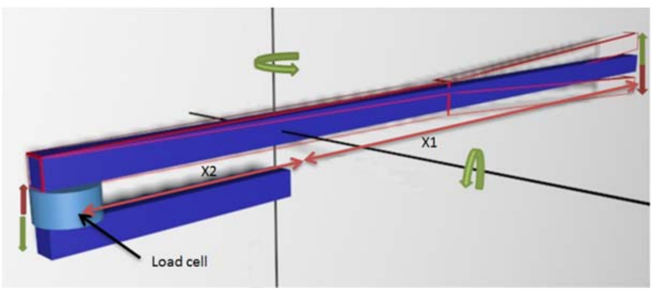

Fig. 10: Measurement of lift force (Load cell)

5. TEST RIG FABRICATION

The test rig consist of fixed block and a rotary block**.** The Fixed block act as the mounting stand for the rotor part of the test rig. Fixed cylindrical block is made of aluminium material and it is used for determining the friction less bearing and for determining the height of the test rig. The frictionless bearing is mounted between the fixed cylinder block and rotary block. Thus allows rotation motion in Y axis as a result one degree of freedom.

The rotary block consist of hollow cylinder block vertical member which acts as the central support and a load cell mount which is simply supported cantilever beam which is fixed parallel to probe. The load generated by the ornithopter on the probe is acted on the load cell which gives the lift force. A probe is the horizontal member and made up of aluminum. Ornithopter mount in which the ornithopter is mounted on it. In the Fig. 12 there is a fixed cylindrical block which is denoted by fix blk.

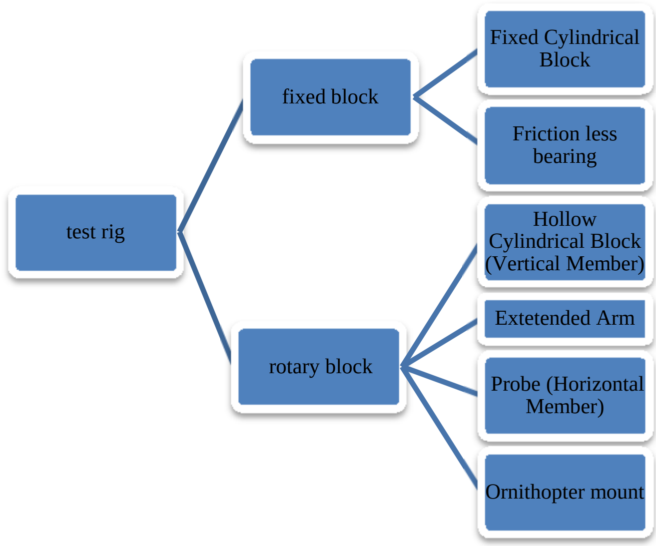

Fig. 11. Components of test rig

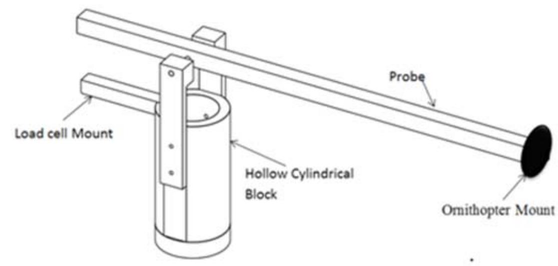

Fig. 12. CAD design of the rotary block

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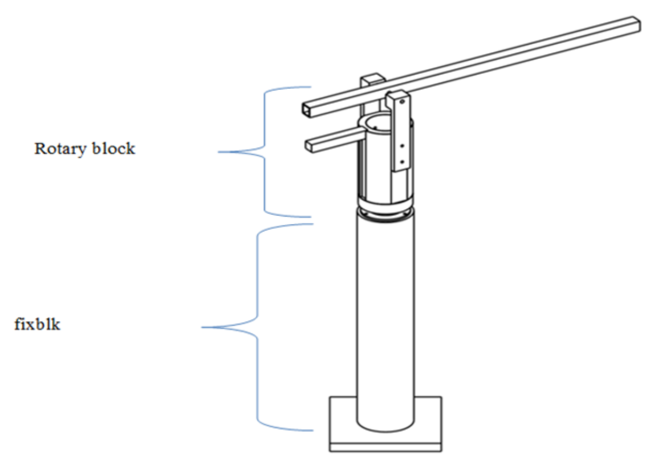

Fig. 13. CAD model of test rig

6. TESTING AND RESULTS

1. MEASUREMENT OF THRUST FORCE

The tangential acceleration data as mentioned above is used for thrust force.

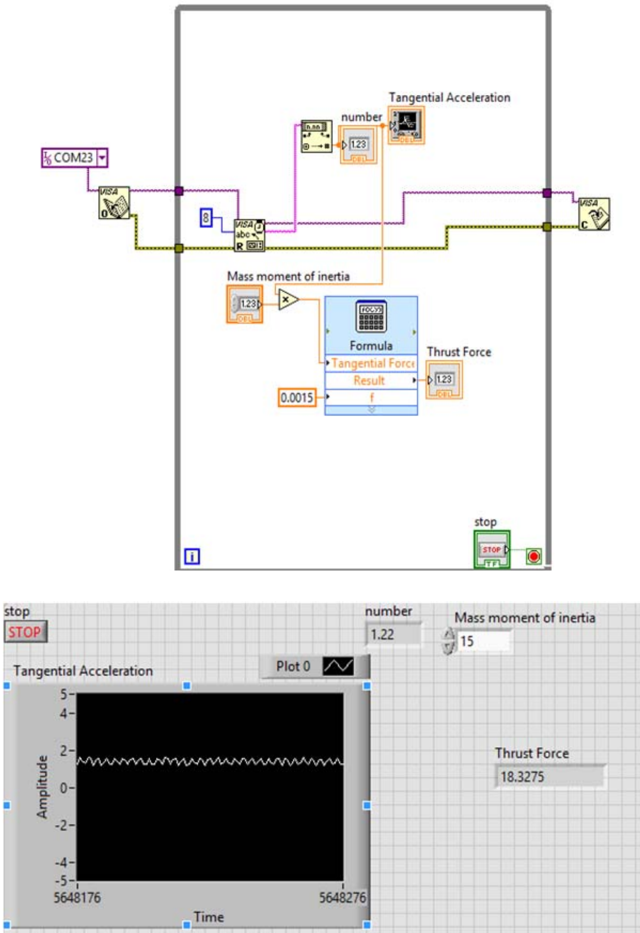

Fig. 14: Block diagram and result of thrust force measurement in lab view.

7. MEASUREMENT OF LIFT FORCE

7.1 MEASUREMENT OF LIFT FORCE USING LOAD CELL

The load applied on the probe will be acting on the other end of the probe mounted to the load cell. Thus the value of lift force generated by ornithopter is measured. A strain gauge is used. A wheatstone bridge is used to measure the change in resistance.

$$\frac{\delta l}{l} = K\frac{\delta R}{R} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, $\frac{\delta l}{l}$ = Mechanical strain

$\frac{\delta R}{R}$= Electrical Strain (ratio of change in resistance to original resistance)

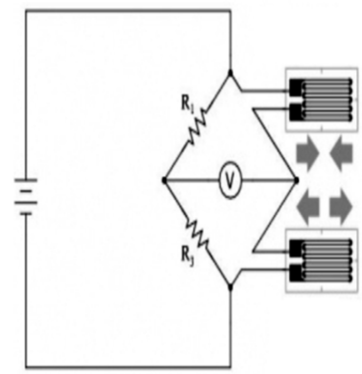

Fig. 15: Circuit diagram of load cell and its connection

Load cell value is obtained from the formula substitution.

Measured Load cell Value $X_2 = X_1$ * Lift Force.

The value of 250 corresponds to the value of X_1

The value of load cell is $95=X_2$

Therefore, Lift force = $\frac{Load\ cell\ value*X2}{X1}$

Lift force = $\frac{27.68*95}{250}$ = 10.5222 g

7.2 MEASUREMENT OF LIFT FORCE USING ACCELEROMETER

The load cell is mounted below the ornithopter and the accelerometer senses the acceleration of the vibration vertically when flapping occurs due to lift force and this vibration is due to probe fixed at other end.

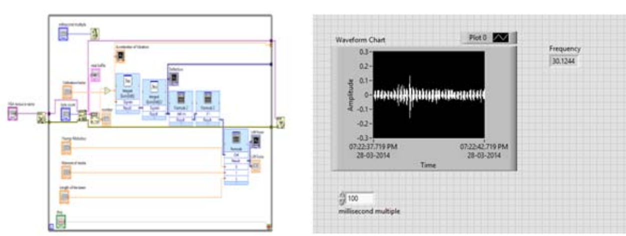

Fig. 16: Block diagram and result of lift force using accelerometer

7.3 MEASUREMENT OF FLAPPING FREQUENCY USING ACCELEROMETER

The flapping frequency is measured from accelerometer sensor on counting the number of cycles in the waveform generated in the lift force graph.

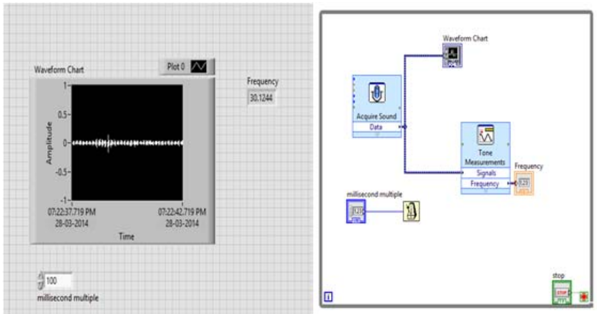

Fig. 16: Flappig frequency measurement

8. CONCLUSION

The characteristics of ornithopter such as lift, thrust and flapping frequency are measured using the developed test rig. There are accelerometer to measure the tangential acceleration, load cell from which lift force is obtained. All these parameters used are highly useful to create and design a test rig. A lab view based system is designed to measure all such parameters in real time.Some of the factors such as loss due to unbalance in mass which arise due to manufacturing problem ,friction are all neglected.

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