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ON TECHNIQUES FOR THE MEASUREMENT OF LIFT AND THRUST OF *TESSERATOMAJAVANICA*

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Abstract: Lift and thrust are important aerodynamic forces that a flier has to develop for its efficient flight.
A comparative study of these forces of *T. javanica* was done in the present investigation by designing and constructing three different techniques in the laboratory. The suspender technique modified Melde's technique and the flight balance technique yield results that are in good agreement with each other. These techniques besides being simple and inexpensive offers a ready means to measure aerodynamic forces such as lift and thrust.
Keywords: Flight, Lift, Thrust, Suspender, Flight balance.

1. Introduction

Osborne [1] discussed the characteristics of insect flight. Pringle [2,3,4] reviewed the aerodynamics and kinematics of insect wing motion. Sotavalta [5] in his monograph highlighted the problem of insect flight by studying the flight sound. Weis-Fogh and Jensen [6] analysed the flight performance of locust by studying the physical principles involved in the flight. Neville [7] studied the power requirement in insect flight. Vogel [8] studied the flight performance in *Drosophila.* Weis-Fogh [9] reported quick estimates of flight for hovering insects. AravindaBabuet.al [10] studied the aerodynamic parameters of *Chrysocorispurpureus.* Adeel Ahmad [11] did extensive work on aerodynamic parameters of different fliers and reported that a flier is conditioned by the basic aerodynamic problem. Cloupeall et.al [12] measured instantaneous lift produced in locust, flying in a wind tunnel by means of piezoelectric probe. Brodskii [13] analysed flight of may fly on the basis of wing kinematics data. Worthmann [14] measured lift and thrust of Locusta, fastened to a force transducer in front of a wind tunnel during tethered flight. Dickinsen Michael and Goetz [15] measured lift and drag of small insects on a two dimensional model with simultaneous flow visualization. Wells Dominic [16] examined the flight energetics of hovering humming birds on the basis of metabolic and kinematic data.

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2. Materials and Methods

The aerodynamic forces such as lift and thrust are important for the flier at different physiological and environmental condition. In view of this, three techniques, namely suspender technique, modified Melde's technique and flight balance technique were developed so as to study lift and thrust of *T.javanica.*

The soap-nut bug *Tesseratomajavanica* are available in and around Hyderabad on the soap-nut trees, which are collected freshly for the experiments.

2.1 Suspender Technique

To determine aerodynamic forces like lift and thrust of *T.javanica,* a simple technique is developed. This technique is called Suspender technique, because of the fact that an insect is suspended by means of a suspender and is free to move.

In this technique, the experimental part is the measurement of the angle (ϕ) made by the suspender with the vertical axis, when the insect is flying. The force acting on the insect, when it is suspended, is the gravitational force i.e. weight of the insect alone. When the insect is flying, lift and thrust are generated. Since the insect is flying in still air, the body drag called profile drag is negligible. From the free body diagram (Fig. 1.), lift (L) and thrust (T) are calculated as $L=W\cos\phi$, $T= W\sin\phi$, where $W=Mg$ = weight of the insect;

ϕ = angle made by the suspender with the vertical axis.

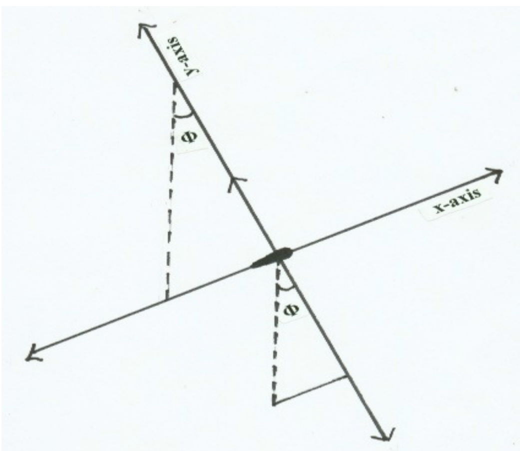

Fig. 1. Free body diagram of suspender technique

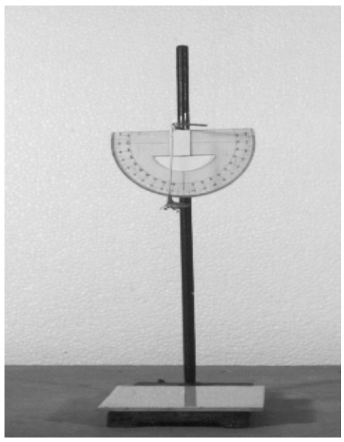

Fig.2. Experimental setup of suspender technique

Experimental

Fig.2 shows the experimental setup 'A' is a retort stand to which a peg is fixed so that a suspender can be hung to it. A circular scale marked in degrees (B) is attached to the retord stand such that the point of suspension (O) coincides with the centre of the circular scale. Here a broom stick of length 8 cm acts as a suspender. A small loop of thin wire is fixed to one end of the broom stick so that it can freely pass through the peg and the suspender (broom stick) can be rotated freely. As this suspender rotates in a vertical plane, the angle made by it with the vertical can be read easily from the circular scale. Let this angle be represented as ϕ. Another circular scale (c) is fixed to another retard stand such that the center of it coincides with the free end of the suspender. Now the insect *T. javanica* is fixed to free end of the suspender at its thorax using a small quantity of wax. The body axis of the insect makes an angle with the horizontal, which is read by the use of the circular scale (c). This body angle is referred as 'angle of attack' and represented by 'α'. The body angle (α) is measured using a cathetometer kept at a distance of 2 meters from the retord stand. The insect is stimulated to fly and as it flies the suspender makes an angle ϕ with the vertical. The mass of the insect is obtained using a sensitive digital balance whose least count is 0.1 mg. Experiments were performed on Φ samples of *T. Javanica*. Lift and thrust are calculated and data is tabulated as shown in Table 1.

2.2. Melde's Technique

Melde's experiment demonstrates the formation of stationery waves in a string and also measures the frequency of a vibrating rectangular metal bar or a tuning fork. Here this experiment is slightly modified. A bio-vibrator (flying insect) takes the place of a vibrating bar. Forces acting on the insects are gravitational force in the download direction and reacting force i.e. tension of the string due to the vibration of wings of the insects, which are shown in the free body diagram (Fig.3).

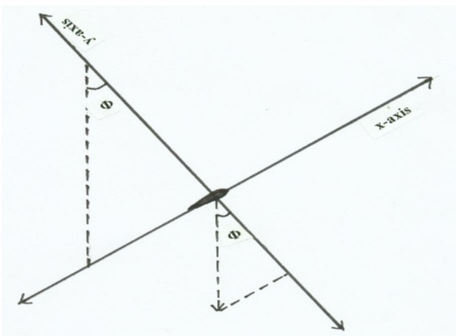

Fig. 3. Free body diagram of Modified Melde's technique

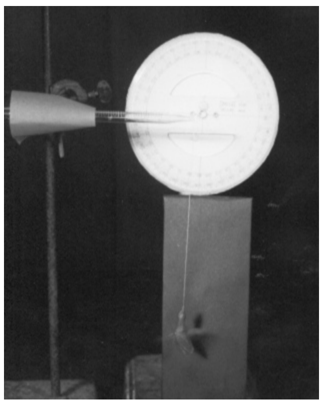

Fig. 4. Experimental setup of modified Melde'stechnique

The modified Melde's technique is definitely a useful tool, in the absence of expensive instrumentation, for the determination of aerodynamic forces like lift and thrust acting on an insect. This simple technique is used for the determination of aerodynamic forces of the insect *T.javanica.*

The experimental setup is as shown in Fig (4) below. In this technique, a glass tube of length 20 cm and bore diameter 2mm is clamped horizontally to a retort stand. A sewing thread is passed through the tube. To one end of thread the insect is attached by means of honey bee wax. The other end of the thread is free. When the insect flies, the thread makes an angle Φ with the vertical. In order to measure the angle, a circular scale is fixed to the retort stand in such a way that its center coincides with the end C of the glass tube as shown in fig. 4. This forms the experimental setup of Melde's technique.

Experimental

T. javanica was attached to one end I of the thread with small quantity of wax such that the wax does not touch the wings. The insect was then stimulated to fly and as it flies it moves in the forward direction and the thread attached to it makes an angle (Φ) with the vertical axis of the circular scale. The angle made by the thread was measured by looking through a cathetometer kept at a distance of 2 meters from the retard stand.

At the same time the length (l) of the thread between insect and glass tube was adjusted by pulling the thread on the other end f the capillary tube till a single loop was observed, formed by the thread while the insect was flying. The stationary wave formed in the string is due to the vibration of wings of the insect. The fundamental frequency of the stationary wave is equal to the frequency of wing beat. In this experiment the angle (Φ) and loop length (l) were noted.

The frequency of wing beat was measured using optical technique. The mass of the flier was measured using a digital balance whose least count is 0.1 mg. The experiment was repeated for 7 samples of *T. javanica*. Knowing mass (M) of the insect, loop length (l), angle(Φ) and the frequency of wing beat (υ), the vertical component of the reacting force, the lift (L) was calculated using the expression, $L = Mg \cos \Phi - \upsilon^2 l^2 \mu$.where μ is the linear density of the thread. Similarly, the horizontal component the reacting force, the thrust (T) was calculated as $T = Mg \sin \Phi$. The data was tabulated as shown in table 2.

2.3 Flight Balance Technique

In this technique, a flight balance is designed and constructed in the laboratory for the study of aerodynamic forces like lift and thrust acting on an insect in its tethered state of flight. This balance is used to study insect flight, hence is called flight balance.

In the flight balance torque is applied to counter balance the weight applied. This flight balance, developed in Biophysics laboratory of Nizam College, is very much useful to study aerodynamic forces such as lift and thrust. The flight balance is shown in the Fig.5.It consists of a horizontal beam AB. Above the center of the beam, there is a mirror (M), with a pointer, fixed to the end B of the beam, moving over the mirror which indicates the inclination of the beam.A steel wire ww^1 passes across and is fixed by means

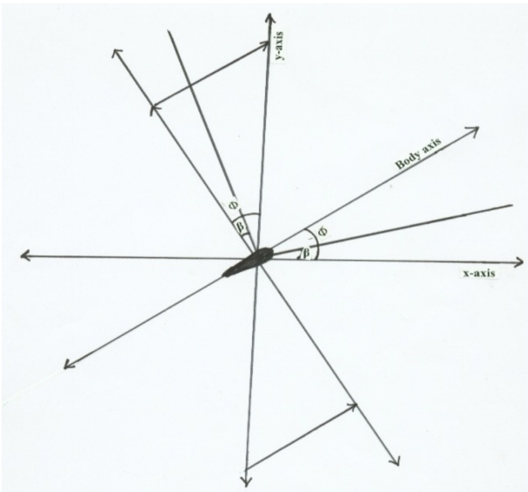

Fig. 6. Free body diagram of Flight Balance technique

Fig. 5. The Flight Balance

of a screw at the end B of the beam. The end w of the wire is linked to the center of a graduated circular tension gauge fixed to a pillar while the other end $w^/$ is rigidly fixed to another pillar. At the end 'A' of the beam a metallic strip of length 10 cm is suspended by means of a small peg which can move freely in the vertical plane. The whole set up can be moved up and down over two more pillars, rigidly fixed on heavy base. Fig 6 shows the free body diagram of the forces acting on the flying insect in order to calculate lift and thrust of the insect. When the insect is flying, suspender makes the angle Φ with the vertical. The reacting force acts along the direction of the suspender. The vertical component of the reacting force (R) i.e. R cosΦ gives lift, while the horizontal component of R i.e. R sin Φ gives thrust.

Calibration of flight balance

The flight balance was calibrated for different loads. A small paper pan was made with thread to hang on the peg of the flight balance. The initial reading of tension gauge with pan was noted. Then small weights ranging from 10mg to 1000mg were added in increasing order and the readings from the tension gauge of the flight balance were noted for respective loads. The difference between the readings with and without load applied (Φ) is obtained and tabulated.

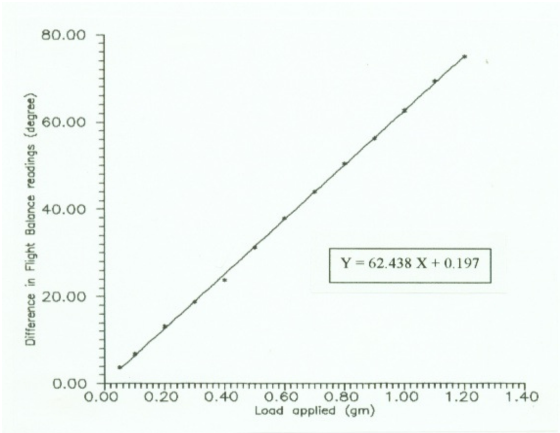

Fig.7. A plot between Load applied andDifference in flight balance reading

A graph was plotted between load applied M on x-axis and difference in readings of the tension gauge Φ on y-axis as shown in fig 7. The graph is linear passing through the origin. The equation of the straight line relates M and Φ, thus knowing Φ, M can be calculated. When M is multiplied by ‘g’, force is obtained.

Experimental

The insect was stuck to the suspender with a little quantity of wax on its thorax and the beam was made horizontal with the balancing screw of the tension gauge, which was calibrated for different loads. The suspender moves forward making an angle Φ with the vertical, when the insect was stimulated to fly. The beam gets tilted because of the lift. By adjusting the balancing screw the tilt is counter balanced and beam is restored back to the horizontal position and the pointer coincides with the reference mark on the mirror. The difference between the readings of the tension gauge before and after the flight gives the reacting force ‘R’ along the direction of the suspender, the vertical and horizontal components of which are lift and thrust respectively. The weight of the sticking wax does not change the value of lift, since the weight of the wax is counter balanced in the flight balance. Knowing the angle

Φ made by the suspender when the insect is flying, the aerodynamic forces such as lift (L) and thrust (T) are calculated using the relations, L=R cosΦ and T = R sinΦ, where 'R' is the reacting force, measured using tension gauge. Experiment was performed on 6 samples of T.javanica and data was tabulated in table 3.

3. Results and Discussion

Table 1,2& 3 presents the data on aerodynamic forces of *T. javanica* determined using Suspender technique, Modified Melde's technique and Flight balance technique. Table 4 gives a comparative data on aerodynamic forces of *T. javanica* in still air. It is observed that all the three techniques give approximately the same values of lift and thrust. In the absence of sophisticated techniques, these serve as the simplest and low cost techniques to determine the aerodynamic forces such as lift and thrust.

Table 1: Data on aerodynamic forces of *T. javanica* determined using suspender technique.

Sample code	*Mass of the flier, M (gm)*	*Angle (degree)*		*Lift, L (dyne)*	*Thrust, T (dyne)*
		α	*Φ*		
TJ1	0.761	13	27	665	339
		08	28	659	350
		19	32	633	395
TJ2	0.514	05	30	437	252
		10	27	449	229
		26	41	381	331
		29	36	408	296
TJ3	0.650	08	22	591	239
		15	25	577	269
		23	29	557	309
TJ4	0.535	12	35	430	301
		16	25	476	222
		29	36	424	308
TJ5	0.654	0	20	603	219
		06	24	586	261
			Mean :	525	288
			S.D. :	±95	±50

Table 2: Data on aerodynamic forces of *T.javanica* determined using modified Melde's technique

Sample Code	*Mass of the flier,M (gm)*	*Angle made by the thread, Φ (degree)*	*Length of the loop, l (cm)*	*Wing beat frequency,ν (Hz)*	*Lift, L (dyne)*	*Thrust T (dyne)*
TJ1	0.748	30	8.6	62	515	366
TJ2	0.752	34	8.3	65	486	411
TJ3	0.766	26	8.5	69	529	351
TJ4	0.805	28	8.9	67	544	362
TJ5	0.956	31	9.2	69	631	482
TJ6	0.626	31	7.2	72	411	315
TJ7	0.753	33	8.0	66	501	400
				Mean :	516	384
				S.D.:	±61	±49

Table 3: Data on aerodynamic forces of T. javanica using flight balance

Sample Code	*Mass of the flier, M(gm)*	*Angle (degree) α*	*Φ*	*Aerodynamic forces(dynes) R*	*L*	*T*
TJ1	0.700	7	23	485	446	189
TJ2	0.632	2	22	580	537	217
TJ3	0.724	9	33	296	248	161
TJ4	0.714	0	30	337	291	168
TJ5	0.991	0	27	366	326	166
TJ6	0.658	7	18	667	634	206
				Mean:	414	184
				S.D.:	±138	± 21

Table 4: Comparative data on aerodynamic forces of *T. javanica* in still air

S. No.	*Technique*	*Lift, L (dyne)*	*Thrust, T(dyne)*
1.	Suspender technique	525±95	288±50
2.	Flight balance technique	414±138	184±2
3.	Modified Melde'stechnique	516± 61	383±49

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