International Journal of Advanced Mechanical Engineering.
ISSN 2250-3234 Volume 4, Number 4 (2014), pp. 365-370
© Research India Publications
http://www.ripublication.com/ijame.htm

Numerical Analysis of Steady and Unsteady Flow for Dragonfly Wing Section in Gliding Mode

Husain Mehdi, Brajesh Kumar Lakhera and Anil Kamboj

Department of Mechanical Engineering, MIT, Meerut, (U.P) 250002, INDIA.

Abstract

A comprehensive numerical Analysis of Steady and Unsteady flow on the wing of Dragon fly Aeshna Cyanea has been performed at ultra low Reynolds numbers 100, 200, 500 ,and 1000 with angle of attack 0^0,5^0,10^0,12.5^0,15^0 corresponding to the gliding flight of these dragon flies. The simulations employ an unstructured triangular mesh based on finite volume discritization. A critical assessment of the computed results was performed. The results give a satisfactory measure of confidence in the fidelity of the simulation.

1. Introduction

There are two modes of flight in insects. First and the more dominating mode is the flapping mode while the second mode is the gliding flight. In a dragon fly, both modes are present. The dragon fly, for instance, *Pantala Flavescens*, can sustain 10-15s at a speed of about $15ms^{-1}$ (Hankin 1921). *Aeshna* genus dragon fly can glide up to 30s without any significant loss of altitude (Brodsky 1994). Wakeling and Ellington (1997) filmed a smaller dragon flies and found there gliding periods lasting 0.5s, covering a distance of approximately 1m and thus achieving gliding speed of $2.5ms^{-1}$. Thus the typical range of Reynolds number in gliding flight can vary from 10^2 to 10^4 as suggested by Wakeling and Ellington (1997). This regime of flow can be thus termed as an ultra low Reynolds number regime.Dragon flies have corrugated wings where the pleated configuration varies along the span-wise and chord-wise directions (Vargas and Mittal, 2006). They concluded that pleats have no aerodynamic significance. Rudolph (1977) argued that the pleated airfoils have delayed flow separation at higher angle of attack and thus a delayed stall is experienced. Neuman *et. al* (1977) concluded that microscopic hair like structures and serration on the leading edge are responsible for enhanced lift. Buckholz (1986) tested a pleated wing model at chord based Reynolds number of 1500 and concluded that pleats help in increasing lift.

Wakeling and Ellington (1997) also had same conclusion after filming free gliding dragonflies and conducted their wind tunnel experiments at a Reynolds number range of 700 to 2400. Maximum coefficient of lift was recorded between 0.93 to 1.07. They further concluded that enhanced lift is neither due to Reynolds number or its aspect ratio but to the presence of pleats. Okamato et al (1996) conducted experiments for determining aerodynamic characteristics of dragonfly wings and model wings in the Reynolds number range of 11000 to 15000. Their experimental results focussed on the effect of thickness, camber, pleats and leading edge sharpness.

Kesel (2000) compared aerodynamic performance of cross-sections at different positions along the span of a wing of an *Aeschna cyanea* to develop the pleated models and its corresponding profiled airfoil at a chord Reynolds number of 10 000, and the results showed that the pleated airfoils generated higher lift than the profiled airfoils. However, Okamoto et al (1996), Kesel (2000) revealed that the orientation of the leading edge does not have an effect in enhancing the lift production. As with the early flow visualization experiments, Kesel (2000) noticed trapped vortices present in the folds that serve to change the effective profile of the airfoil. Further

Vergas and Mittal (2006) also studied the aerodynamic performance of a pleated wing section based on the wing of *Aeshna cyanea* has been performed at ultra-low Reynolds numbers (5000-10000) corresponding to the gliding flight of these dragonflies in two dimension using computational fluid dynamics. The simulations demonstrate that the pleated airfoil produces comparable and at times higher lift than the profiled airfoil, with a drag comparable to that of its profiled counterpart.

In this work, we investigate analysis of steady and unsteady flow for spatio-temporal dynamics of a cut section of Aeshna Cyanea's wing at ultra low Reynolds numbers (100 to 1000) at different angle of attacks ranging from 0^o to 15^o. To the best of author’s knowledge, the aerodynamic characteristic at such Reynolds number is not studied. These parameter ranges are relevant for both dragonflies and micro-aerial vehicles. Past experimental studies (Buckholz, 1986, Okamoto *et al* 1996, Kesel, 2000) have found no intrinsic three-dimensional effects at these low Reynolds numbers. Thus, 2D simulations are implemented in this study to encompass a relatively wide range of the parameter space necessary to draw some general conclusions regarding pleated airfoils. The pleated airfoil implemented in the numerical simulation corresponds to a cross-section located at the mid-section of the forewing of a dragonfly (*Aeshna cyanea*). The specific profile chosen for the numerical simulations corresponds to ‘Profile 2’, which was digitally extracted from the paper of Vargas *et al* (2008) (which is the same as Profile 2 from Kesel (2000)). From the three pleated geometries to select from the paper of Kesel (2000), ‘Profile 2’ was chosen due to its horizontal leading edge, thus eliminating the issue that the orientation of the leading edge has an influence on the aerodynamic performance (Okamoto *et al* 1996) (Fig 1). For the purposes of reducing the resolution requirements in the simulation, the sharp edges of the pleats were rounded out slightly without affecting the basic geometry of the pleats and the overall shape of the airfoil as shown in Fig 2.

(a)Profile 1 (b) Profile 2 (c) Profile 3

Fig. 1: An Illustration of different cut section profiles used by Kessel (2006) and Vargas et al (2008)

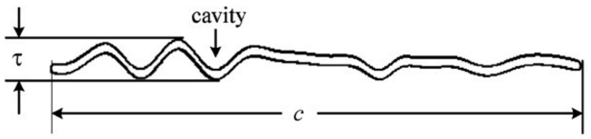


Fig. 2: The two-dimensional airfoils used in the numerical simulation. Pleated airfoil representing a cross-section of the forewing of a dragonfly (Aeshna cyanea) having τ /c = 7.531%,

2. Governing Equations and Numerical Method

2.1 Governing Equations

The equations governing the flow in the numerical solver are the time-dependent, viscous incompressible Navier–Stokes equations. The non-dimensional momentum and continuity equations are as follows:

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j \partial x_j}$$

The equations are non-dimensionalized with the appropriate length and velocity scales, in this case the airfoil chord and free stream velocity. Here *Re* corresponds to the Reynolds number which is defined as below:

$$Re = \frac{\rho u_\infty c}{\mu}$$

Using the same flow parameters and geometrical dimensions as Kesel (2000), this allowed for validation and a critical analysis of the numerical results. The key quantities examined are the lift and drag coefficients which are defined as

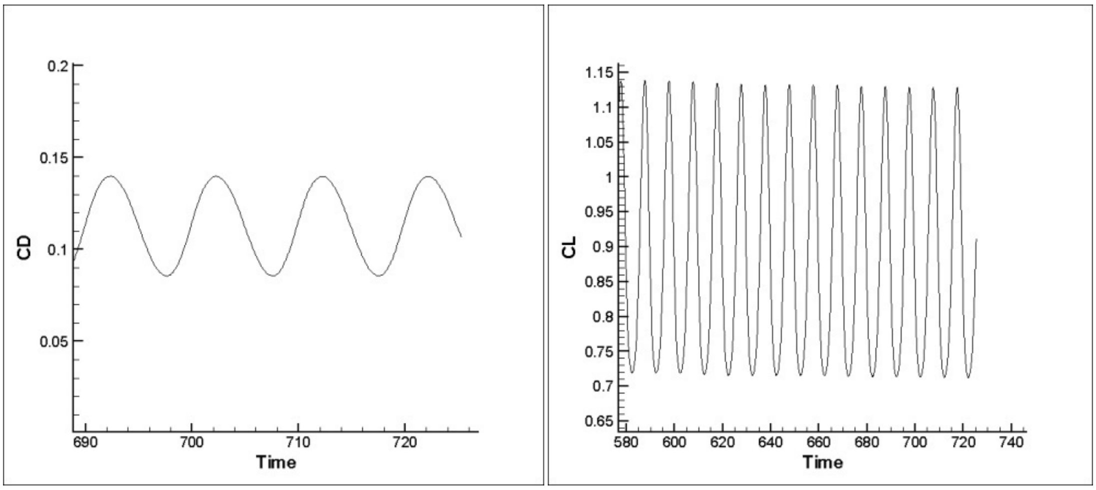
$$C_L = \frac{F_L}{\frac{1}{2}\rho u_\infty^2 c}, \; C_D = \frac{F_D}{\frac{1}{2}\rho u_\infty^2 c}, \text{ and Gliding Ratio} = \frac{C_L}{C_D}$$

2.2 Numerical Methodology

Ansys Fluent 14.0 is used to solve the above equations. The solver used is based on collocated methodology and finite volume discretization technique is used. The gradients are calculated using Green-Gauss Cell-Based methodology proposed by Holmes and Connel (1989) and Rauch *et al.*(1991). Convection terms in the momentum equation are discretized using the second order upwind methodology given by In the second order upwind, quantities at cell faces are computed using a multidimensional linear reconstruction approach (Barth and Jespersen , 1989).

3. Result and Discussion

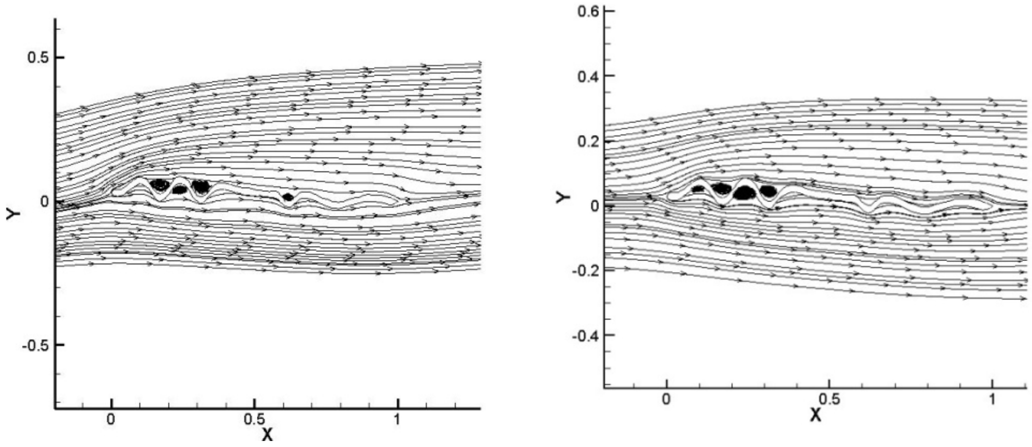
It was found that for all the simulations performed flow always remained steady at Re 100 and 200 with all angle of attack ranges from 0^0 to 15^0. First unsteady flow was obtained at Re 500 of AOA 10^o. But flow always remained steady at AOA 0^o and 5^o for all the Reynolds numbers.



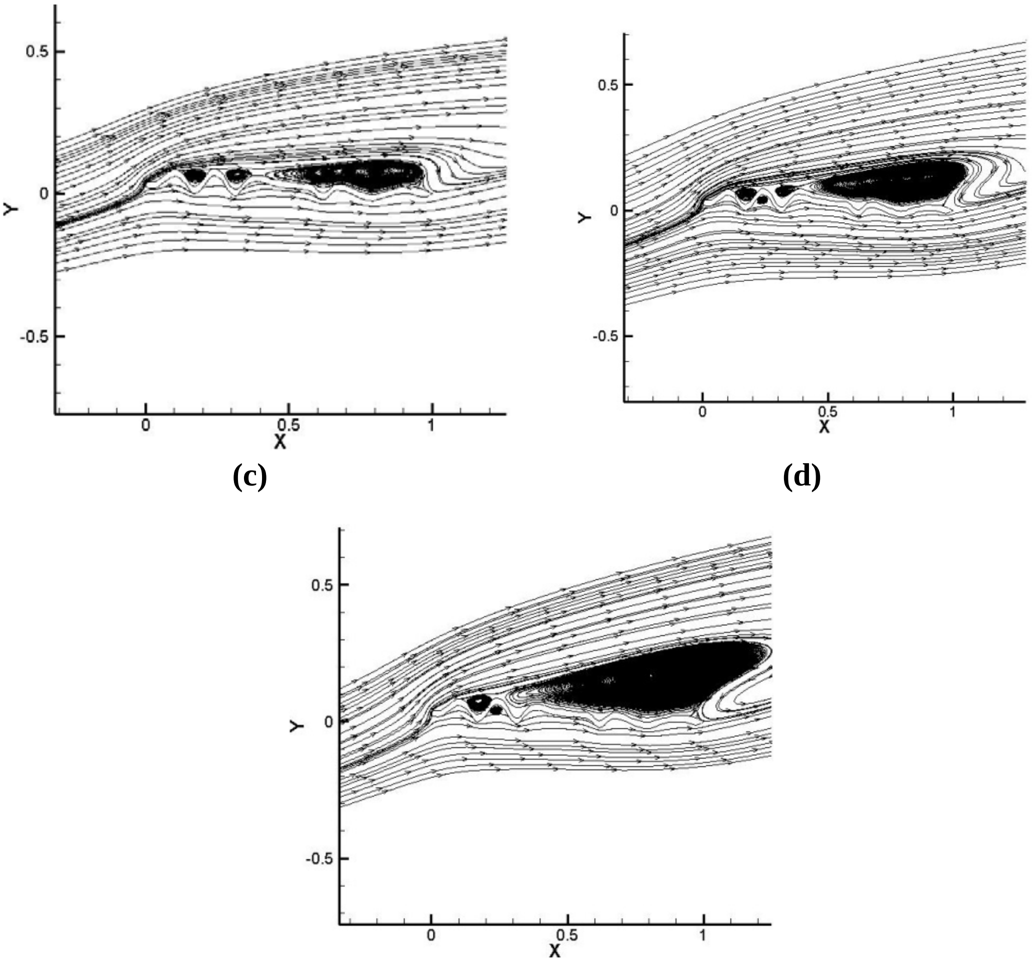
(a) **(b)**

Fig. 3: Time variation coefficient of (a) Drag (b) Lift at Re-1000 at AOA12.5^0

In steady flow the graph of the C_D and C_L shows the constant line where as in unsteady flow there is some variation of C_D and C_L graph with respect to time as shown in Fig. 3. The pleated airfoil reaches a maximum C_L = 1.048 at Re-1000 with angle of attack 15^0 and minimum C_L=0.1715 at Re-100 with angle of attack 0^0. Whereas the maximum value of C_D =0.4 at Re-100 with angle of attack 0^0 and the minimum value of C_D= 0.0873 at Re-1000 with angle of attack 15^0.



(a) **(b)**



(c) **(d)**

(e)

Fig. 4: Stream-traces at Re = 200 for (a) $\alpha= 0^0$, (b) $\alpha= 5^0$, (c) $\alpha= 10^0$, (d) $\alpha=12.\ 5^0$ and, (e) $\alpha=15^0$

As the angle of attack increases, drag force continue to decrease while lift force continuously increases. This is due to a larger attached vortex on the upper surface of the airfoil. The decrease in drag is due to lower shear drag as the strength of the trapped vortex in the pleats of the airfoil. Thus the pressure is larger at the lower side of the pleated airfoil is larger and hence an increase in lift is obtained. When we increase the angle of attack with same Reynolds Number then the vortex is increased in pleats of the airfoil, and continuously going to large as shown in Fig. 4. So we found large attached vortex in angle of attack 15^0 that's why got the maximum lift at angle of attack 15^0 at Re-1000.

4. Conclusions

In this work, we investigated the steady and unsteady flow for spatio-temporal dynamics of a cut section of *Aeshna Cyanea's wing*. Numerical simulations were performed at ultra low Reynolds numbers (100 to 1000) at different angle of attacks ranging from 0^0 to 15^0. The results give a satisfactory measure of confidence in the fidelity of the simulation. It was found that for all the simulations performed flow always remained steady at Re 100 and 200 at all angle of attack (0^0 to 15^0). First unsteady flow was obtained at Re 500 and AOA 10^o. But flow always remained steady at AOA 0^o and 5^o for all the Reynolds numbers.

References

[1] Brodsky, A K. The aerodynamics of insect flight: The Evolution of Insect flight. New York: Oxford University Press, 1994.

[2] Buckholz, H. "The functional role of wing corrugations in living systems." J of Fluid Engg 108 (1986): 93-97.

[3] Hankin, A M. "The Soaring Heights of dragon fly." Proc. Camb. Phil. Soc. 20 (1921): 460-465.

[4] Kesel, A B. "Aerodynamic characteristics of dragonfly wing sections compared with technical aerofoil." J of Exp. Biology 203 (2000): 3125-3135.

[5] Newman, B G, S B Savage, and D Schouella. "Model test on a wing section of a Aeschna dragonfly." In Scale Effects in Animal Locomotion, by T J Pedley, 445-477. london: Academic, 1977.

[6] Okamoto, M, K Yasuda, and A Azuma. "Aerodynamic characteristics of the wings and body of a dragonfly." J. of Experimental Biology, 1996: 281-294.

[7] R, Rudolph. "Aerodynamic properties of Libellula Aerodynamic properties of Libellula around smooth and corrugated wing section models during Gliding Flight." Odonatologica 7 (1977): 49-58.

[8] Rees, C J C. "Aerodynamic properties of an insect wing section and a smooth aerofoil compared ." Nature, 1975: 141-142.

[9] Vargas, Abel, Rajat Mittal, and Haibo Dong. "A computational study of the aerodynamic performance of a dragonfly wing section in gliding flight." Bioinsp. Biomim., 2008: 1-13.

[10] Wakeling, J M, and C P Ellington. "Dragonfly flight: I. Gliding flight and steady state aerodynamics forces." J of Experimental Biology, 1997: 543-556.

[11] Wotton, R J. "The functional morphology of the insect wings of Odanato." Adv. Odanatol 5 (1991): 153-169.