CFD Analysis of Butterfly Type Ornithopter

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Abstract - *Since ages butterflies have fascinated scientists and philosophers. These creatures have their unique way of flying. The present study is devoted to study the implementation of their flight to Butterfly Type Ornithopter (BTO) using CFD. We have tried to approximate the movement of the wing obtained from the PIV data and implement it using trigonometric functions. This movement is then implemented in the CFD analysis using dynamic meshing of a possible ornithopter that can be built. But the deformation of the body of the butterfly is not considered, as we are interested to implement it in a BTO. We have found that the Cl curve for the motion approximated using trigonometric functions and the actual Cl curve for a butterfly are in close agreement. Also the Cd produced due to the body movement alone is negative.*

Key Words: **Butterfly Type Ornithopter, CFD, Dynamic Meshing, Flapping wing, Cl (Coefficient of lift), Cd (Coefficient of drag)**

1. INTRODUCTION

In this study, we have analyzed the flight of the Butterfly Type Onithopter (BTO) in 2D using dynamic mesh methods. The BTO has potential application in the defense industry for spying purposes. These MAV can virtually go to any territory for the reconnaissance purpose, giving the information about the enemy territories. BTO has potential application in rescue operations. The most compelling reason for choosing BTO over other type of the ornithopter is that, they can be produced cheaply and hence we can have hundreds of them instead of just handful of them. Moreover, as they are expected to be very cheap. Simply this can be used to out number the enemies and to cover more area in a way which is not possible earlier for the rescue and recovery operations. CFD data obtained in this study can be used to implement in the development of BTO.

2. LITERATURE REVIEW

K. Senda , M. Sawamoto , T. Shibahara and M. Kitamura have obtained PIV data of the motion of the wings of an actual butterfly and also they had studied the butterfly flight using the panel method [1]. M. Fuchiwaki, T. Imura and K. Tanaka have built a Micro Aerial Vehicle (MAV) to study the flight of the Cynthia cardui, they are able to achieve a stable flight for 12 minutes [2].

3. SETUP

This is a case of a very typical low speed aerodynamics. So, we will be using the one equation Spalart–Allmaras model to take the turbulence into our account. The flight of the Butterfly Type Onithopter (BTO) is studied using dynamic meshing methods in ANSYS fluent.

In this study the motion of the wings of the BTO is being adopted from the PIV data of ref [1]. It is approximated using trigonometric functions. We have chosen the time period of the whole motion of 1 flap as 0.09sec, while the typical values for a typical butterfly lies between 0.2sec (5Hz) to 0.06666sec (15Hz) ref [2]. Here the maximum upstroke angle is 75 deg while that of the downstroke is 45 deg for the BTO. We have used a hybrid mesh to model the flapping of the wings. Only half of the wing is being analysed to reduce the computational cost and moreover there is symmetry. Also the changes in the shape of the body of the butterfly are neglected just the part of the wing attached to the body of the butterfly is deforming. Also the wing along with the inflation layer is set as rigid body, i.e. we are neglecting the fluttering of the butterfly wings, which do have a significant impact of its motion if the wings are relatively large. But in our case we have assumed the wingspan to be 4.5 cm which is not so large.

4. FORMULATION

The flapping angle of BTO is approximated as follows:

Downstroke angle:(t = 0s to 0.05s)

omega_d = (pi/0.05)

(pi = 3.1415926)

Flapping Angle = (15*(pi/180)) + (60*(pi/180)*cos(w_d*t))

Upstroke angle:(t = 0.05s to 0.09s)

omega_u = (pi/0.04);

Flapping Angle = (15*(pi/180)) - (60*(pi/180)*cos(w_u*(t-0.05)));

as shown in the fig.1.

The flapping speed is approximated just by differentiating this function as follows:

Downstroke speed:(t = 0s to 0.05s)

Flapping Angle Speed = -w_d*(60*(pi/180)*sin(w_d*t));

Upstroke speed:(t = 0.05s to 0.09s)

Flapping Angle Speed = w_u*(60*(pi/180)*sin(w_u*(t-0.05)));

The body angle is approximated as follows:

tau = 0.09;

tau_d = 0.05;

tau_u = 0.04;

tau1 = ((tau_d+tau_u)/2)/(1-((arccos(2/3))/pi));

P = tau_d + (tau_u/2) - tau1;

tau2 = tau - tau1;

1^{st} segment angle: (t = 0s to 0.03s)

Lateral Angle = 20 - (30*cos(pi*(t-(P))/(tau2)));

2^{nd} segment angle: (t = 0.03s to 0.075s)

Lateral Angle = 20 - (30*cos(pi*(t-P)/(tau1)));

3^{rd} segment angle: (t = 0.075s to 0.09s)

Lateral Angle = 20 + (30*cos(pi*(t-(P+tau1))/(tau2)));

The body rotation speed is approximated just by differentiating this function as follows:

1^{st} segment speed:(t = 0s to 0.03s)

Lateral Speed = -(30*w_d*cos((w_d*t) - 15));

2^{nd} segment speed: (t = 0.03s to 0.075s)

w_av = (180/0.045);

Lateral Speed = -(30*w_av*cos((w_av*(t-0.025)) + (75)));

3^{rd} segment speed: (t = 0.075s to 0.09s)

Lateral Speed = (30*w_u*cos((w_u*(t-0.05)) – 15));

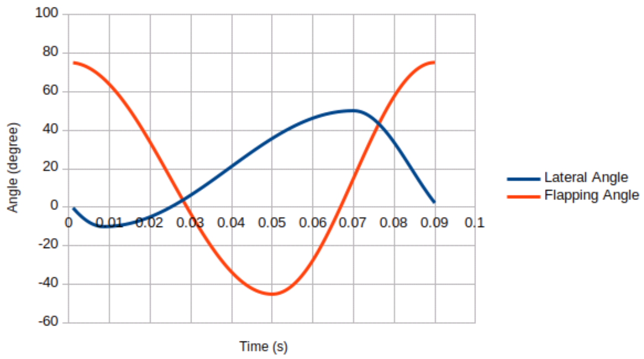

Fig -1: Variation of the lateral angle (Body movement angle) and flapping angles

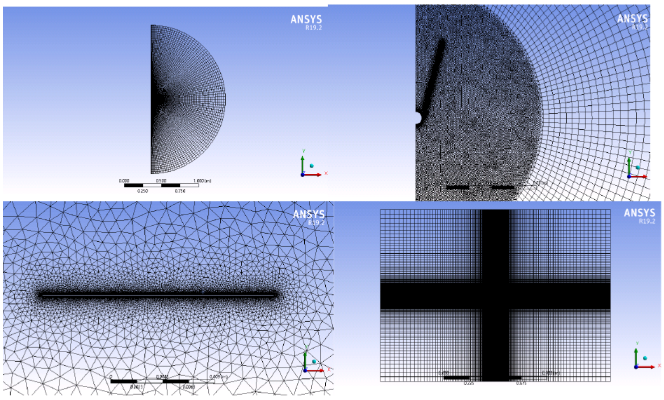

Fig -2: Initial Mesh used for this study

The mechanism of the flapping along with the pressure contour plots is shown in the fig. 3 and 4.

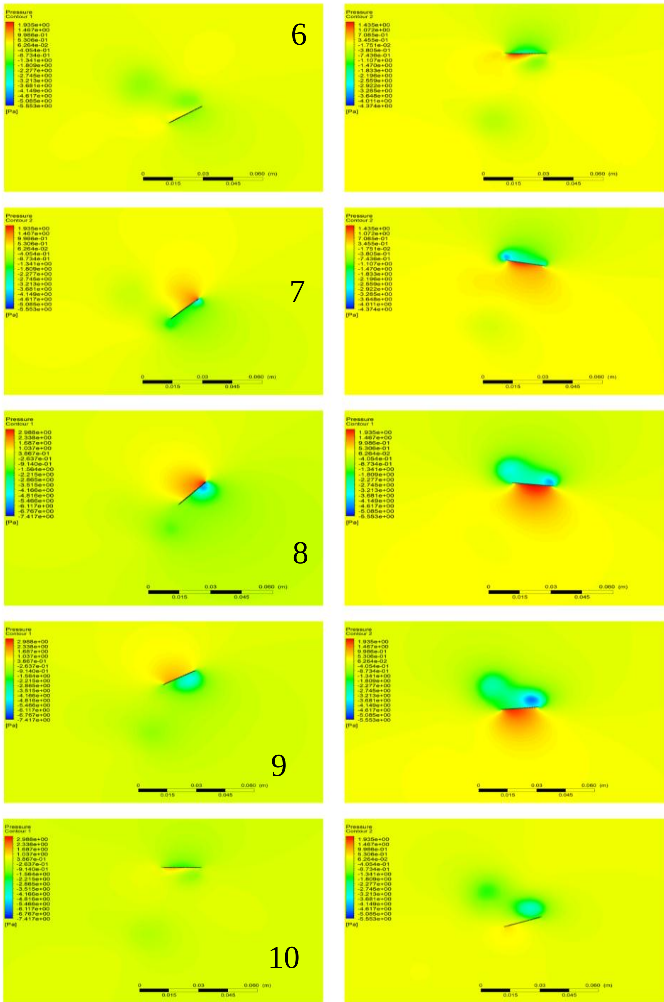

Fig -3: Pressure contour of the motion due to body movement

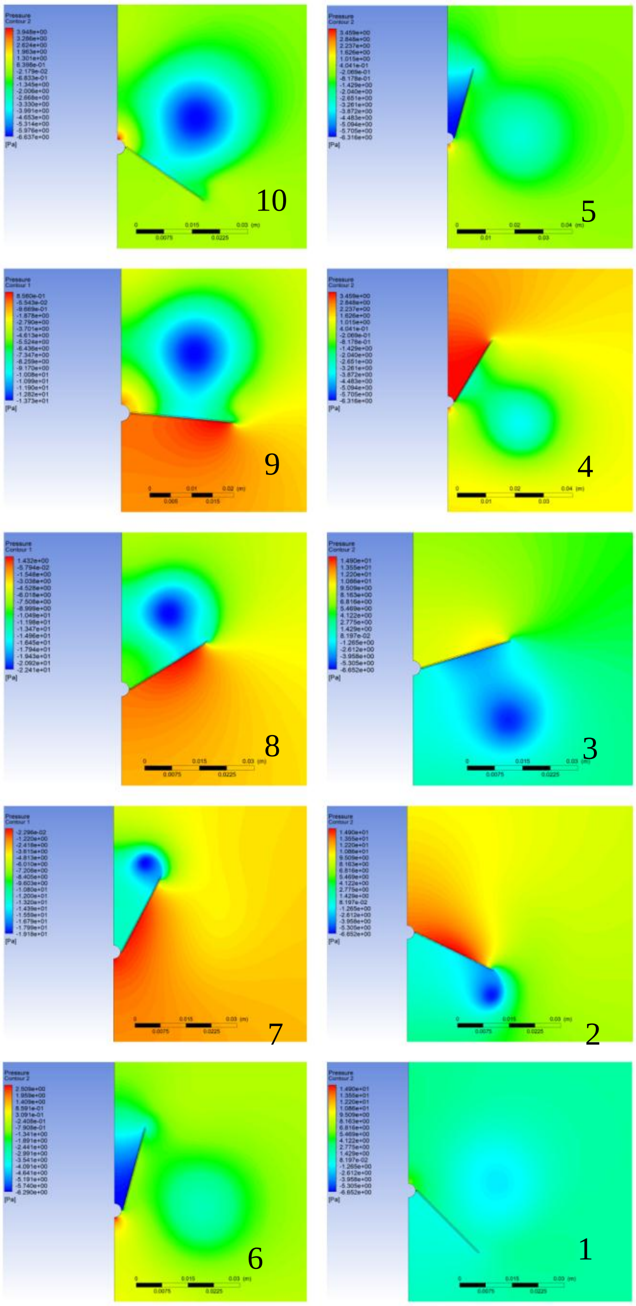

Fig -4: Pressure contour of the motion due to flapping of the wing

5. RESULTS

The flapping of the butterfly generates lift in one of the most unique ways. If the body of the butterfly remains horizontal in the gravitation field, they will never fly, this can be seen from fig.5. The movement of their bodies makes all the difference, this can be seen from fig.6. Giving them the way to overcome the lift produced downwards during upstroke. Infact, this lift is more than what is produced during the downstroke.

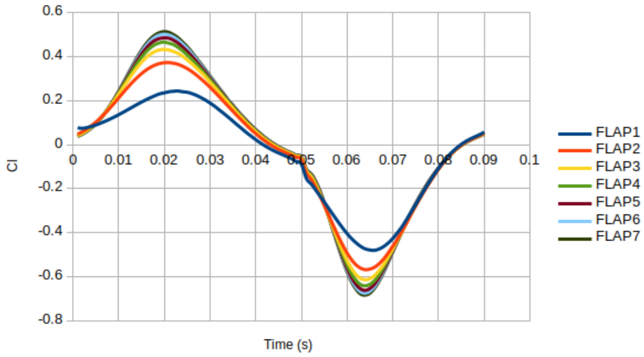

Fig -5: Actual Cl variation with time

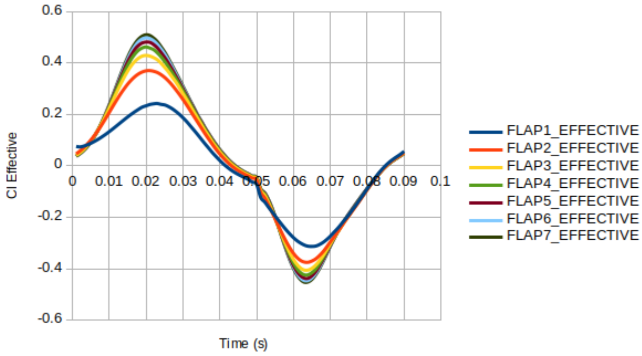

Fig -6: Effective Cl variation with time

The Cl produced without the movement of the body is shown in the fig.7. While that coupled with the body movement is shown in the fig.6. Their body movement changes the total lift they experienced which is approximated as a trigonometric expression to approximate what is obtained from the PIV data of ref [1]. One of the striking feature of the Cl produced by the body movement is that, it seems that the Cl produced in the downward direction is very selectively reduced making the overall average a positive quantity as shown in the table 1.

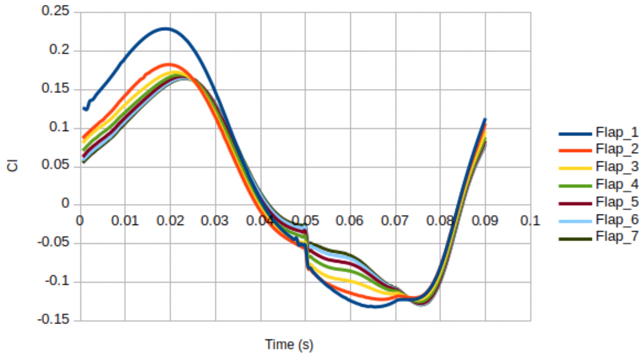

Fig -7: Cl variation with time due to movement of the body of the BTO

Table -1: Average value of force coefficients

Force coefficients	Average value of force coefficients
Cl due to flapping (Not Considering the body movement)	-0.0182242
Cl due to flapping (Considering the body movement)	0.0208999
Cl due to body movement	0.0187714
Cd due to body movement	-0.0383801

Moreover, if we design a BTO (Butterfly Type Ornithopter) and make the whole BTO move according to the body movement of the butterfly. It will generate a significant amount of lift which is approximately equal to the lift produced by flapping coupled with the body movement. But something very unusual is noticed when we take a closer look at the Cd plot of the mechanism due to the body movement of the BTO fig.8. The Cd is is negative i.e. drag produced due to the body movement alone is basically pushing the BTO forward, this can be of some serious impact on propulsion aspect of BTO.

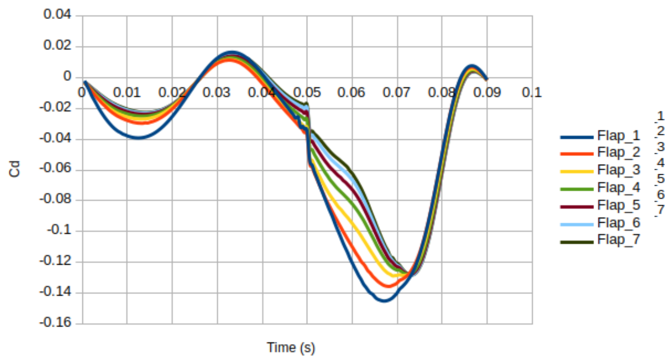

Fig -8: Cd variation with time due to movement of the body of the BTO

6. CONCLUSIONS

Cl produced in the downward direction is very selectively reduced due to the body movement making the overall average a positive quantity.

Significant amount of lift is produced due to the body movement alone, which is approximately equal to the lift produced by flapping coupled with the body movement.

Cd produced due to the body movement alone is negative, this can be exploited to get some advantage in propulsion of BTO.

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