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« Motion Study of Flapping Wings Vehicles »

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Abstract *– Micro aerial vehicles design, due to their low Reynolds number aerodynamics, motivated the aerospace engineering community a lot the last year, and especially the flapping wing operated MAVs.*

The simulation of the mechanical equations of motion for a flapping wing MAV is presented in this work to have an approximate the behavior and the condition of flight of the vehicle and to present a control model that can be implemented to auto control the vehicle.

The spherical coordinates system is used to develop the equations in this work , and Mathcad software is mainly used for the solution ,simulation and graphing of the results, constants related to the size of the vehicle are changed to match different a range of existing flying insects or birds.

Upstroke and down stroke of the flapping wing were modeled using two different drag coefficient.

The study resulted in excluding the smaller sizes and higher flapping frequency from use of this model without any rectifications that account for the accentuated mow Reynolds unsteady effect, but bigger vehicles (bird sized) were modeled with a good accuracy and the model can be used as well for auto-control by predefined flying path.

Keywords: Aerodynamic, control, equation of motion, feather, flapping, MAV, wings.

Introduction

Birds, insect and bats was a subject of fascination to the human since the dawn of humanity, and he did not just content by envying their ability, but he invested his energy and intellect in order to mimic them and conquer the sky using the ability of those great flyers.

However it was only recently with the advent of simulation, analysis and high-speed videography that we could decipher some of their complex mechanisms that make them that good.

Such a way of generating lift and thrust was examined closely from pioneers from *Abbas Ibn Firnas to Leonardo di Vinci;* however lately researchers are more and more attracted by this kind of propulsion for the application on small scale flapping wings vehicles, because of the need for a smaller, maneuverable aerial vehicle.

1. State of art in micro aerial vehicle design

Flapping wings:

Nature makes it clear that this propulsion mechanism is very efficient and effective in an aerodynamics view at a low Reynolds number and in the same time allows high degrees of maneuverability, humming birds are the best example, while despite requiring a lift coefficient, in the quasi-steady sense, over twice that of any aircraft. Bumblebees are able to fly

However, a distinction should be made when focusing on this class of vehicles between bird-like vehicles called Ornithopter and Insect-like vehicles called Entemopters [1].

The last ones suits more MAV tasks because hovering and this class provides maneuver in tight spaces.

The advantages offered by flapping wing vehicles seduced the engineers to pursue in this direction come up with an efficient and effective vehicle, but the MAV are quite tiny compared to the challenges.

Despite the enormous challenges, last years experienced advance in the MAV field where several promising MAVs, like the one developed by Festo Company revealed, the SmartBird and BionicOpter.

I. Numerical investigation with Mathcad
Theoretical investigation:

the flight of the vehicle is well described my Newtonian mechanics , the equations of equilibrium which result from Newton's second law are used to describe the flapping wing vehicle, and other systems of coordinates than the rectangular is used because it describes better this motion in space [9].

The resultant of all the forces acting on a particle is proportional to the acceleration of the particle:

$$\sum F = ma \tag{1}$$

By applying this basic principal to a body in motion in a plan, the equations in a rectangular basis would be:

$$\sum F_x = ma_x$$
$$\sum F_y = ma_y$$

II. Application on a real case:

Despite their simplicity the previous equations of motion as can be used in order to simulate the flight of a flapping wing MAV; Mathcad was used with an increment in time in order to simulate the flight.

However, we need to define the forces acting on the MAV.

1. Lift force:

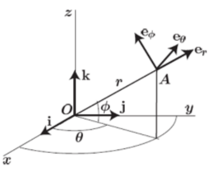


Fig.1: spherical Coordinate

The original idea of this work [9], is the use of two drag coefficient in the expression of the resultant force ; as we deduct from nature ,when a wing is in the upstroke the muscle is used to alter the shape of the wing to cause less drag therefore a smaller drag coefficient C_{d1} in contrast in the down stroke the shape of the wing is optimal for a large lift force which is the opposite of the drag force, if we change the direction of the axis , therefore a biggest drag coefficient C_{d2} .

With the introduction of this two-drag coefficient approach, we will have two forces and knowing that the lift force expression is:

$$F_1 = \frac{1}{2}\rho C_L A V^2 \quad (2)$$

Where:

ρ: density of the air.

V: the velocity.

S: the lifting area (both wings).

C_L : lift coefficient

By introducing both drags coefficients:

$$F_1 = \frac{1}{2}\rho C_{d1} A V^2 \quad (3)$$

And:

$$F_2 = \frac{1}{2}\rho C_{d2} A V^2 \quad (4)$$

The switch between the two different drag coefficients in the upstroke and the down stroke is done by the introduction of a formulate that uses the direction (therefore sign) of the velocity the deactivate one or the other coefficient such as:

$0.5 - 0.5sign(\cos(\omega t)), 0.5 + 0.5(\cos(\omega t))$

The velocity approximated from the sinusoidal motion of the wing, the path would be A. sin (ω) therefore the velocity can be expressed as the first derivative: $A.\omega.\cos(\omega t)$ another sign related expression is needed so the expression of the velocity is:

$$V^2 = (A\omega\cos(\omega t))^2 sign(\cos(\omega t)) \quad (5)$$

Where:

ω: Angular frequency.

A: Amplitude.

A projection of all those expressions on their respective axis is performed the find the 3D equations, the gives the explanation of the forces acting on the center of gravity of the MAV and the angles between the projections.

The accelerations equations for each axis are:

For The radial, coordinate axis:

$$\ddot{r} = \frac{1}{m}(-mg\sin\varphi + mr\dot{\theta}^2\cos^2\varphi + mr\varphi^2 +$$
$$[\frac{1}{2}((0.5 - 0.5sign(\cos(\omega t))C_{d1} + 0.5 + 0.5sign(\cos(\omega t))C_{d2}). \quad (6)$$
$$S.\rho.(A\omega\cos(\omega t))^2 sign(\cos(\omega t))].\cos\beta\cos(\varphi - \alpha) - b.\frac{dr}{dt})$$

For The polar axis:

$$\ddot{\theta} = \frac{1}{m.r.\cos\varphi}(-2m\dot{r}\theta\cos\dot{\varphi} + 2m\dot{\theta}\dot{\varphi}\sin\varphi) +$$
$$[\frac{1}{2}((0.5 - 0.5sign(\cos(\omega t))C_{d1} + 0.5 + 0.5sign(\cos(\omega t))C_{d2}).$$
$$S.\rho.(A\omega\cos(\omega t))^2 sign(\cos(\omega t))].\cos\beta\sin(\frac{\pi}{2} + \varphi - \alpha)$$
$$- b.r.\cos(\varphi)\frac{d\theta}{dt})$$

(7)

The Azimuth coordinate axis:

$$\ddot{\varphi} = \frac{1}{m}(-mg.\cos\varphi - 2m\dot{r}\dot{\varphi} - mr\dot{\varphi}^2\sin\varphi\cos\varphi +$$
$$[\frac{1}{2}((0.5 - 0.5sign(\cos(\omega t))C_{d1} + 0.5 + \quad (8)$$
$$0.5sign(\cos(\omega t))C_{d2}).S.\rho.(A\omega\cos(\omega t))^2].\sin(\beta) - b.r.\frac{d\varphi}{dt}$$

A certain criteria was added the last equation in order to control the altitude of the MAV, [9]:

$$(0.5 - 0.5.sign(\cos(r\cos\varphi - H_m)) \quad (9)$$

Where H_m is the maximum height that the MAV is supposed to reach.

2. Mathcad implementation:

We had a set of parameter, some of them remained constant, and others were modified.

two different range of dimension were used , the bird –like and insect-like, in the literature we found the parameters needed and a formula developed by PENNYCUICK, that link the flapping frequency of the birds wing to the other parameter (m, S, ρ, g, b (wing span)) [6] was uses , which is written as:

$$f = m^{3/8} g^{1/2} b^{-23/24} S^{-1/3} \rho^{-3/8} \quad (10)$$

For the bird-like configuration two different sizes were used, the first ones from DARPA [9] definition the second one from an actual bird which is the Dove prion.

For the insect-like configuration, dimensions of a dragonfly were used.

Drag coefficient:

it is mentioned in the literature that the lift to drag ratio is between 3 and 17 which gives a drag coefficient for birds between 0.8 and 1.2 however the motion of the wing affect significantly the coefficient therefore a set of drag coefficient around the real value were used .

For insect like MAVs insects wing have very small drag coefficient around 0.06, so we used numbers around it.

3. Mathcad manipulations:

The Cartesian coordinates where obtained by the transformations:

$$x = r\cos\varphi\sin\theta$$
$$y = r\sin\phi\sin\theta \qquad (11)$$
$$z = r\cos\theta$$

We found out that the MAV goes very high up to 40m, which means that the force is very strong; therefore, changes in the damping coefficient were done for the radial coordinates, by steps of 0.05. [1]
We performed more manipulations on different parameters [7] the results are illustrated in graphs (1), (2), (3)

It was obvious the instability occurred in the z-axis so the damping coefficient was changed from b to b1 and the later was varied. the increase of the damping coefficient (b1=0.1 and 0.15) the results were close but far more stable, as it's illustrated in the graphs (4) where we can see the path of flying in the (r,ϕ) .

3.1. Steering:

We steered the MAV by directly implementing and fixing the angles α and β or by making one or both of the angles time dependent.

We used as an example [7], the change in the angles value by a time depending functions:

This do not affect the vertical coordinates; however, we can see the change of path in the other plans

$$\alpha = \frac{\pi}{2.5}.(e^{-0.01t})$$
$$\beta = 1.5.\frac{\pi}{2}(e^{-0.01t}) \qquad (12)$$

In the Graph 5 we see that after the stabilization the MAV stop turning in circles and take a fixed direction.

3.2. Dimensions of an insect:

We tried the characteristics of a dragonfly, we did some manipulation in all the parameter but the MAV only flies for very high frequency, amplitude, or drag, so this model does not work for very small dimensions.

4. Results:

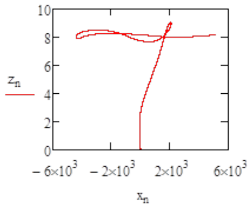
We can summarize the results in the next points:

1. The major parameter that influences the MAV flying is the damping coefficients.

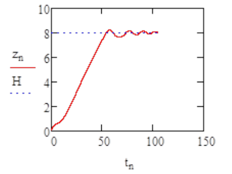
2. The flapping frequencies have to be defined and limited under certain value to keep up with the reality, and the available force for flapping.

3. The difference between the two drags coefficients plays a central role in making the MAV fly.

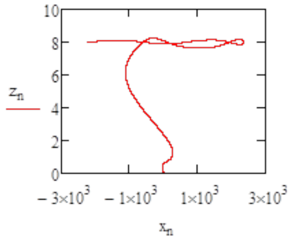
4. And finally, we had a confirmation that due to the unsteady aerodynamic phenomenon that are accentuated in the insect case , the approximation used cannot be applied.



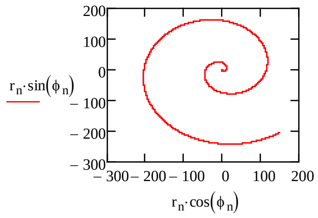
Graphs 1 *the flight path in (x,z) plan b1=0.05.*



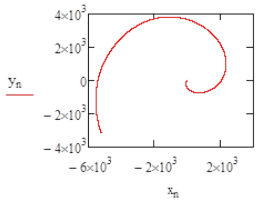
Graph 2*: the vertical coordinates b1=0.1.*



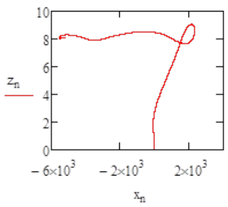
Graph 3*: the flight path in (x,z) plan*



Graph 4: *the flight path in (x,y) plan as helicoid.*



Graph 5*: effect of steering (x,y) plan.*



Graph 6*: effect of steering (x,z) plan.*

5. References:

[1] L. Petricca, P. Ohlckers, and C. Grinde, "Micro- and Nano-air vehicles: state of the art", International journal of aerospace engineering, vol. 2011, no: 1, 2011.

[2] Al-Bahi, i.m.a.-q.a.a.m., "Micro Aerial Vehicles Design Challenges: State Of The Art Review", in SSAS UAV Scientific Meeting & Exhibition. 2006: jeddah, Saudi Arabia.

[3]M. James and C. M. S. F. McMichael, "Micro Air Vehicles—Toward a New Dimension in Flight, 1997.

[4] T. J. Mueller, "Aerodynamic measurements at low Reynolds numbers for fixed wing micro air vehicles", Tech. Rep., University of Notre Dame, Notre Dame, The Netherlands, 2000.

[5] http://www.festo.com/cms/en_corp/13165.htm

[6] C. J. Pennycuick, 'Wing beat Frequency of Birds in Steady Cruising Flight: New Data and Improved Predictions", The Journal Of Experimental Biology 199, 1613–1618, 1996.

[7] A.C.Abdessemed, "Investigation Of The Flight Of A Micro Aerial Vehicle", Master thesis, Riga Technical University,2013.

[8] W.Shyy a,d al, "An Introduction to Flapping Wing Aerodynamics" 2013.

[9] A.C.Abdessemed, Janis Viba, "Investigation of flight of micro aerial vehicle with flapping wings", Proceedings of 13th International Scientific Conference Engineering For Rural Development.2014.