Journal of KONES Powertrain and Transport, Vol. 21, No. 4 2014

ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1132706
DOI: 10.5604/12314005.1132706

A CONCEPTION OF VERTICAL TAKE-OFF AIR VEHICLE WITH SELF-ALIGNING MOVING WINGS

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Abstract

The possibility of vertical take-off of an aircraft is a valuable feature in air transport. It allows to increase operational characteristics of an air vehicle and requires less field and low cost ground infrastructure. Currently the vertical take-off feature is practically reserved to helicopters and tilt-rotor aircrafts. Both types of air vehicles have their advantages and also have some important limitations. Regarding the helicopters their construction provides natural vertical take-off features and makes them useful in low altitude flight tasks. However the power required for flight and main rotor kinematics results in low cruising speed and short range performance. The tilt-rotor aircraft is an answer which provides good cruise characteristics saving the vertical take-off feature. The construction of tilt-rotor aircraft consists of rotors with adjustable position of tip-path plane. The main technical problem of tilt-rotors is necessity of change aerodynamic configuration from vertical mode to cruise mode at low flight altitude and very low flight speed. A proposed conception of a vertical take-off air vehicle using self-aligning moving wings is focused on producing aerodynamic force always on wings without participation of rotors or propellers. The self-aligning or semi-rotating wing movement enables to produce aerodynamic force in each flight speed. During take-off lift force is generated by means of power unit driving the wings. The transition from hovering to progressive flight is a smooth phase without aerodynamic configuration changes. It occur as a result of change in wing kinematics or gravity center position. As the flight speed increases the lift force is generated like in classic airplane wing and the power unit load decreases. The conception of presented air vehicle assume to join best features of airplanes and helicopters i.e. vertical take-off, good flight performances and lack of strict border between both phases of flight.

Keywords: *vertical take-off, air vehicle conception, self-aligning wings, flapping wings*

1. Introduction

The conception of flying vehicles powered by moving wings inspire researches in a natural way because this method of fly is used in bird and insect world. Following the aviation history from its beginning there were designs or even prototypes of vehicles which construction was based on observations of birds and tried to simulate their movement. This early projects failed to rise in the air but also showed how sophisticated the method of flying with flapping wing is (from the technological and aerodynamic point of view). Further development of aviation technique was focused on vehicles with fixed wings which brought successful flights. Up to this day the technology of fly with fixed wing reached high level and satisfy the need of high speed transport. The achievements in experiment methods, aerodynamics, flight dynamics and material technology causes that the idea of flight with flapping wings is currently taken into consideration by many researches. The available publications shows that studies on this subject mainly refers to flying insects and are focused on aerodynamics of flapping wing, flapping mechanism kinematics and control studies. It is reasonable way to perform research on flying insects at first before the birds because insects have simplier wing structure. While the birds have as well as flapping wings and complicaded flexible wing geometry. The aim of this paper is to propose the conception of flapping wing air vehicle which provide vertical take-off, wide range of speed and lact of strict border between hovering and cruising flight phases. The conception on this stage will base on insect fly analysis and it will applies to flapping wing micro air vehicle (FWMAV) class.

2. Flapping wing features

2.1. Kinematics

Variety types of wing and body kinematics exist in insect world. In general, nature solutions rely on up and down moving wings. The problem is which solution is worth to take into consideration in the design of FWMAV. Several authors pay their attention on insects like butterfly (*Papilio xuthus*) [1], beetle (*Allomyrina Dichatoma*) [2] or fly (*Diptera*) [3]. The listed examples represent different kind of wing-body kinematics during fly and these mechanism types are convenient to construct and test. The detailed comparsion can be found on Fig. 1. and Tab. 1. and on its basis it is possible to find useful features in FWMAV applications.

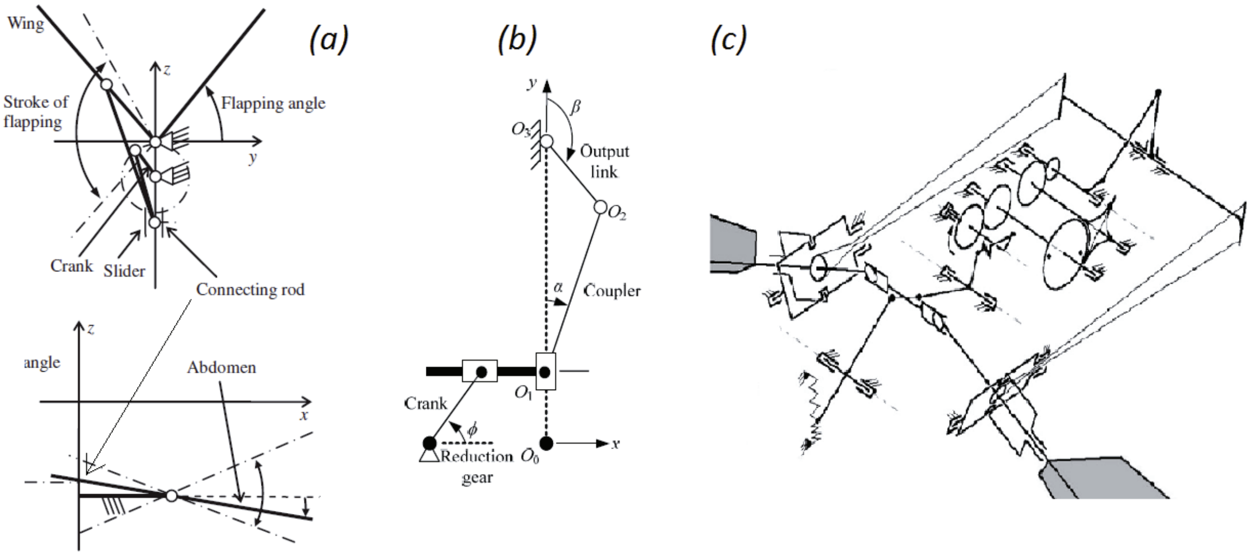

Fig. 1. Kinematics mechanism for (a) butterfly [1], (b) beetle [2], (c) fly [3]

Tab. 1. Comparsion of insects features

Insect	Butterfly	Beetle	Fly
Mechanism Type (technical equivalent)	Slider crank	Scotch yoke and linkage	Four bar, Watt's linkage
Stroke plane	Vertical	Almost horizontal (in hovering), significantly inclined (in forward fly)	Inclined
Wing tip path	In line (down and up storke)	In line (forward and backward strke)	Figure-of-eight symetrically to stroke plane
Oscillation frequency	10 Hz	40 Hz	200 Hz
Insect size	Length 69mm, Span 125 mm, weight 550 mg	Lenghth 50mm, Span 130 mm, weight up to 10g	Lrngth 8mm, span 10mm, weight 20mg
Additional data	Wing-body common oscillations (Abdomen oscillations controls peaching angle)	-	-

2.2. Aerodynamics

The aerodynamic force produced on flapping wing is periodically variable. Phase of movement of the wing is responsible for generating lift, thrust and drag. In general the down stroke phase results in producing lift while the upstoke phase produces thrust. However, it is not strict rule. In cases where stroke plane is inclined and attituded closer the horizontal direction both up- and down stroke (or forward and backward stroke) produces lift and thrust at once.

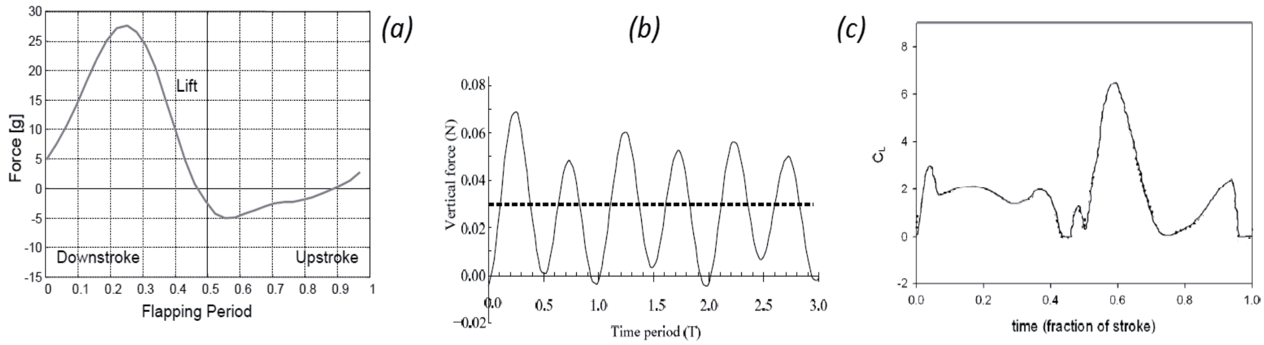

Fig. 2. Lift force sequence for (a) model of wing with vertical stroke plane [4], (b) beetle wing model [6], (c) fruitfly aerodynamic anlaysis [5, modified figure]

Figure 2. represents model [4, 6] and real insect [5] characteristics therfore these are destined to qualitative lift force analysis. The quantitative estimation of lift force can be performed on existing models. During concept stage there is a need for assumption that average lift force will be equal to the model weight.

3. Vehicle conception

3.1. Specifications of features

The conception of FWMAV must fulfil the items specified in the aim of this paper i. e. vertical take-off, wide range of speed and lact of strict border between hovering and cruising flight phases. Moreover it should possess natural stability and ease of controll characteristics, produce possible high lift force, provide lightweight and technoligical construction, be flexible to modificate.

Vehicle conception uses horizontal stroke plane of wings which has efficient lift chatacteristics in each phase of flapping and it is controllable by means of inclining the stroke plane. This solution is similar to beelte flight method, one of the heaviest insect (Tab. 1). Driving of the wings is performed by slider crank mechanism (Fig. 1a, Fig. 3). The wing conception has specific geometry and mount which cause that during forward stroke and backward stroke the aerodynamic characteristics of wing remains the same (Chapter 3.3).

3.2. Driving mechanism

The slider crank mechanism choosen to drive the vehicle has construction which minimalise mass and amount of elements. Support O inserts aerodynamic forces to body, therfore this is main part of vehicle and centre of gravity must be positioned close to it.

The drive is transmitted from A to O support by means of rotating crank (r) and connecting rods (b) and (l). Joint of connection rods (C) performs reciprocating movement and shares the drive between rocker arms (x). The rocker arms are parts of wing arms (w) and provide wing semi-rotational movement.

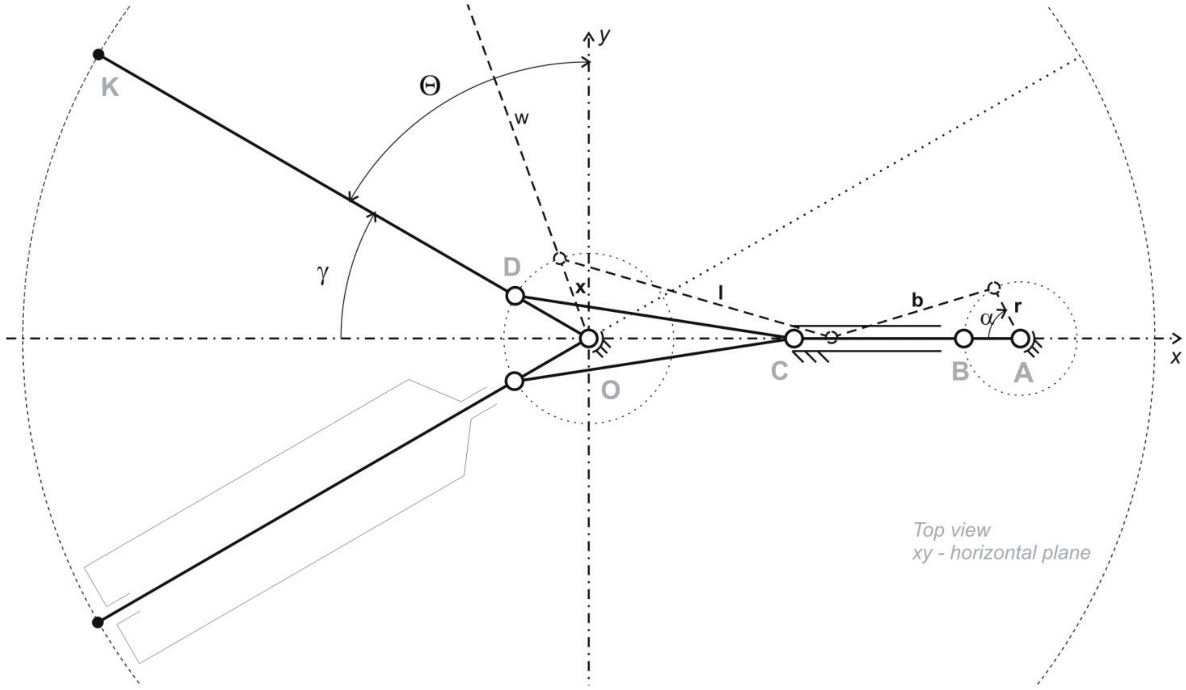

Fig. 3. Vehicle driving mechanism scheme. Where: A, O – supports; B, C, D – joints; K – tip; AB = r – crank; BC = b, CD = l – connecting rods; OD = x – rocker arms; OK = w – wing arms, α – crank phase, γ – wing phase, 2Θ – stroke angle

To describe kinematic characteristics of the machanism the input parameters are r, x, w, Θ and ω. These parameters allow to shape velocities distribution and oscillations of wings in driving mechanism. The output formulas are as follow:
initial position of wing arm (for α=0):

$$\gamma_0 = \frac{\pi}{2} - \Theta, \tag{1.1}$$

distance along x-axis covered by joints C and D:

$$l_x = 2r = 2x\sqrt{1 - sin^2 \gamma_0}, \tag{1.2}$$

wing arm angular position due to crank position:

$$\gamma(\alpha) = \frac{\pi}{2} + \Theta cos(\alpha - \pi), \tag{1.3}$$

joints linear velocity component:

$$V_{Bx} = V_c = V_{Dx} = \omega r \cdot sin\alpha, \tag{1.4}$$

where:
V_{Bx}, V_{Dx} – linear velocity component along x-axis for joint B and D,
V_C – linear velocity of joint C,
ω – driving crank angular velocity,
linear velocity of joint D:

$$V_D = V_{Dx} sin\gamma, \tag{1.5}$$

angular velocity of wing arm:

$$\omega_w = x \cdot V_D, \tag{1.6}$$

linear velocity of win arm tip:

$$V_K = x \cdot \omega_w . \tag{1.7}$$

While the angular velocity of driving crank (ω) remain constant the angular velocity of wing arm varies and depends on driving crank phase (α). The maximal linear velocity of wing arm is placed at the tip (K) and lineary decreases to the point O. It is necessary to describe velocities magnitude as a function of crank phase. These are important characteristics for further estimation of aerodynamic force possible to procuce by the vehicle.

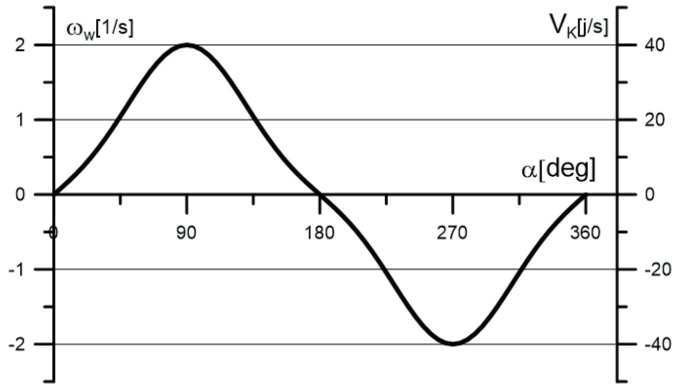

Fig. 4. Wing arm velocities distribution

Figure 4. illustrates example kinematic characteristics of drving mechanism. The dimensions of mechanism parts are as follow: *r=1 [j], x=2r [j], w=20r [j], where [j]* - length unit, *ω=1 [1/s], Θ=60[deg].*

3.3. Wing

The geometry of wing in vehicle concept assumes that the aerodynamic profile will reach maximal thichness and camber at 50% chord and also its shape will be symmetric relative to *yz* plane placed at maximum airfoil thickness. In that way aerodynamics characteristics of wing remain the same in forward and backward movement. The wing is mounted on its arm at 50% of chord length with the possibility to rotate along *y*-axis. The mass unbalance along *y*-axis will provide self-algining switch on proper angles of attack (AoA) during forward and backward stroke. The advantages of this solution are: ease to control wing AoA, rotation angle between forward and backward movemet is relatively low, the wing is able to perform gliding flight after stop the wing oscillations. Fig. 5. Shows the details of wing geometry and mount.

3.4. Control mechanism

The basis of vehicle control is to incline wings stroke plane and make the horizontal component of aerodynamic force responsible for manoeuvring. Consider the high frequencies of flapping wings it will be effective to control the stroke plane inclination using the aerodynamic forces generated on wings. The control of vehicle by gravity centre manipulations is also possible but it may be performed as a additional vehicle equipment, therefore the description of this method will be neglected in this paper.

The solution of vehicle control by aerodynamic forces is to mount a wing with the possibility of rotation along its arm (changing AoA). The mass unbalance of wing cross section will result in autonomous switch of AoA to the positive lift production in both forward and backward phase of wing flapping. To control the vehicle it is required to mount control plate which will limits the AoA during flapping period. Fig. 5. shows the scheme of control mechanism.

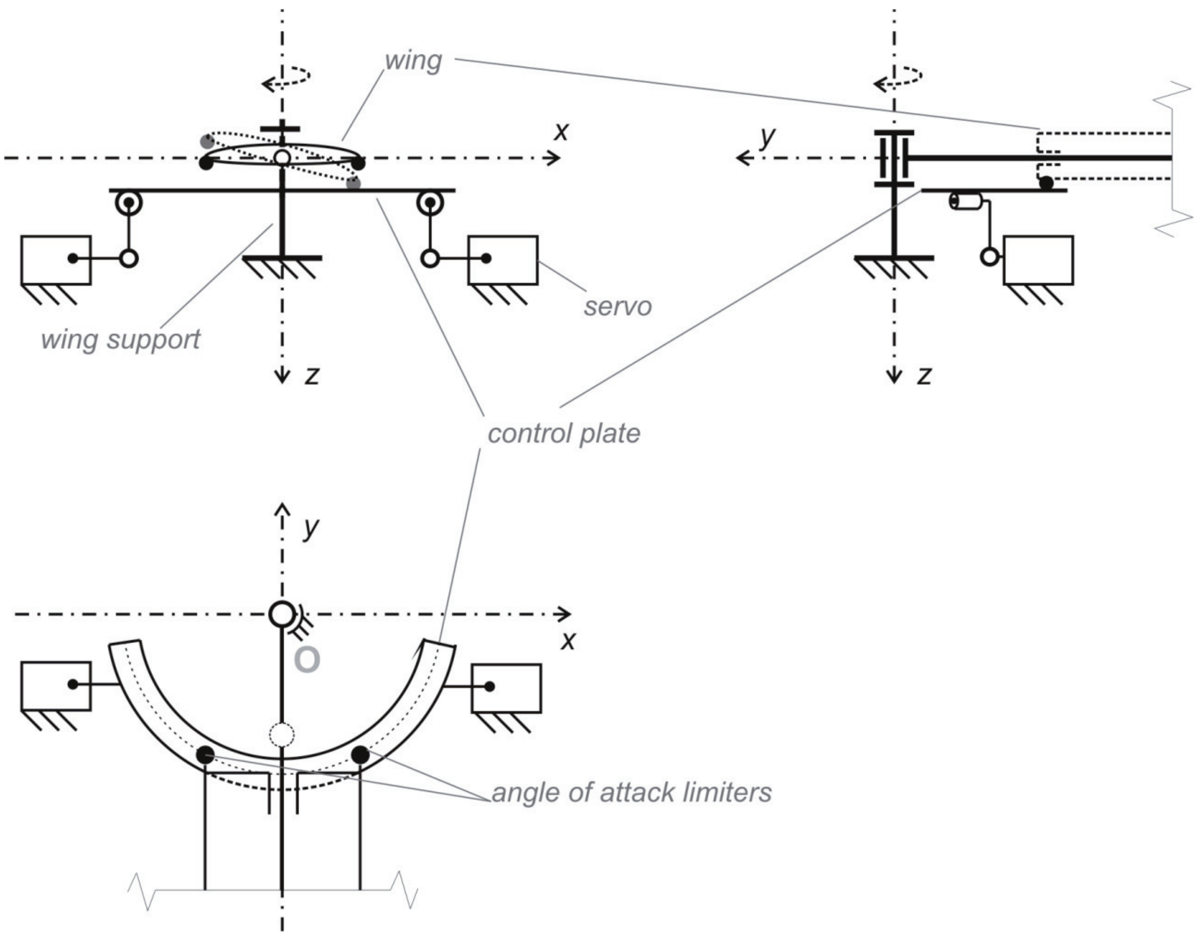

Fig. 5. Vehicle control mechanism (for left wing)

4. Conclusions

Vehicles with flapping wings have valuable flight properties, which include:

- ability to perform vertical take-off and landing and hovering,
- smooth transition from hovering to cruise phase and vice versa,
- wide range of speeds,
- good manoeuvrability.

These features distinguish it from currently used vehicles capable of performing vertical take-off, i.e. helicopters, multi-rotors or tilt-rotor systems. These vehicles have some limitations in cruise flight or necessity to change the aerodynamic configuration in different phases of flight. Consider current achievements in the field of flight dynamics, aerodynamics and materials technology. This allows to think that in future vehicles with falpping wings will find their fields of applications.

Currently main efforts are applied to research on insect flight and creation of FWMAV vehicles. This paper fits in the line of works. The study was focused on searching in the world of insects characteristics useful in technical applications and propose some new technical solutions. The result is the concept of a flapping wing air vehicle with the horizontal plane stroke, which gives good performance for payloads. Use the self-algining wings which geometry is symetrical relative to *yz* palne eliminated the need for a large angle of rotation in the phases of oscillations. Also it helps to relieve elements of the control system (levers, servos, etc.). Further research will refer to study of aerodynamic forces generated by the system and the mechanical load of structure in order to adapt the concept for a technological possibilities in flapping wings micro air vehicles construction.

References

[1] Fujikawa, T., Hirakawa, K., Okuma, S., Udagawa, T., Nakano, S., Kikuchi, K., *Development of a small flapping robot. Motion analysis during take-off by number numerical simulation and experiment,* Mechanical Systems and Signal Processing 22, pp. 1304-1315., Japan 2008.

[2] Nguyen, Q. V., Park, H. Ch., Goo, N. S., Byun, D., *Characteristics of a Beetle's Free and a Flapping-Wing System that Mimics Beetle Flight,* Journal of Bionic Engineering 7, pp. 77-86, Konuk University, Korea 2010.

[3] Galiński, C., Żbikowski, R., *Materials challenges in the design if an insect-like flapping wing mechanism based on a four-bar linkage,* Materials and Design 28, pp. 783-796, Poland 2007.

[4] Ho, S., Nassef, H., Pornsinsiriak, N., Tai, Y. C., Ho, C. M., *Unsteady aerodynamics and flow control for flapping wing flyers,* Progress in Aerospace Science 39, pp. 635-681, USA 2003.

[5] Sudhakar, Y., Vengadesan, S., *Flight force production by flapping insect wing in inclined stroke plane kinematics,* Elsevier, Computer & Fluids 39, pp. 683-695, India 2010.

[6] Nguyen, Q. V., Truong, Q. T., Park, H. Ch., Goo, N. S., Byun, D., *Measurment of Force Produced by an Insect-Mimicking Flapping-Wing System,* Journal of Bionc Engineering 7 suppl., pp. S94-S102, South Korea 2010.

[7] Zufferey, J. Ch., *Bio-Inspired Flying Robots. Experimental Solutions of Autonomous Indoor Flyers,* École Polytechnique Fédérale de Lausanne Press, Switzerland 2008.

[8] Aono, H., Liu, H., *Flapping wing aerodynamics of a numerical biological flyer model in hovering flight,* Computers and Fluids 85, pp. 85-92, Japan 2013.

[9] Shyy, W., Aono, H., Chimakurthi, S. K., Trizila, P., Kang, C. K., Cesnik, C. E. S., Liu, H., *Recent progress in flapping wing aerodynamics and aeroelasticity,* Progress in Aerospace Sciences 46, pp. 248-327, USA 2010.

[10] Rifai, H., Marchand, N., Poulin-Vittrant, G., *Bounded control of an underactuated biomimetic aerial veicle – Validation with robustness tests,* Robotics and Autonomous Systems 60, pp. 1165-1178, France 2012.

[11] Amoroso, S., Migliore, M., Catalano, M., Castelluccio, F., *Vertical take-off and landing air transport to provide tourist mobility,* Journal of Air Transport Management 24, pp. 49-53, Italy 2012.

[12] Mantia, M., Dabnichki, P., *Effect of the wing shape on the thrust of flapping wing*, Applied Mathematical Modelling 35, pp. 4979-4990, Chech Republic 2011.

[13] Truong, T. Q., Phan, V. H., Sane, S. P., Park, H. Ch., *Pitching moment Generation in an Insect-Mimicking Flapping-Wing System,* Journal of Bionic Engineering 11, pp. 36-51, Korea 2014.

[14] Pourtakdoust, S. H., Aliabadi, S. K., *Evaluation of flapping wing propulsion based on a new experimentall validated aeroelastic model,* Scietia Iranica B, pp. 472-482, Iran 2012.

[15] Bachmann, R. J., Boria, F. J., Vaidyanathan, R., Ifju, P. G., Quinn, R. D., *A biologically inspired micro-vehicle capable of aerial and terrestrial locomotion,* Mechanism and Machine Technology 44, pp. 513-526, USA 2009.

[16] Ansari, S. A., Żbikowski, R., Knowles, K., *Aerodynamic modeling of insect-like flapping flight for micro air vehicles,* Progress in Aerospace Sciences 42, pp. 129-172, United Kingdom 2006.