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SIMULATION STUDIES OF MICRO AIR VEHICLE

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Abstract

In the paper, we presented results of analysis of Micro Air Vehicle MAV stability on high Angle of Attack (AOA) by application continuation methods and bifurcation theory. Moreover, it presented two main tasks accomplished – performance analysis carried out, as well as numerical studies in order to find possible simplifications drive model, suitable for further design and analysis. This paper shows the typical MAV construction and their characteristics. Then presented results of calculations of necessary and required power (for CR3516 motor). The results shown in the Figure. The next step of MAV performance examination was calculations of dynamics stability and controllability of open loop system. Also shown state, and control matrixes for the longitudinal motion. Roots loci and open loop dynamics analysis for longitudinal motion are shown in the Figures. The next shown few function such as transfer function for the input (longitudinal velocity), transfer function for the pitch angular rate q input and for the lateral motion, state, and control matrices, etc. At the end shown results of simulations for dynamic response of MAV flight disturbance is shown in the Figure. The paper concluded short motions.

Keywords: *construction of micro air vehicles, simulation studies*

1. Introduction

Micro Air Vehicle (MAV) is a small aircraft, which recently very fast develop and there is very popular, especially in the rich countries. There are many solutions MAV, which look very nice and are quite effective. Examples of the structure shown below. The Micro Air Vehicle is remotely controlled demonstrator of innovative, bionic drive with an object on the back of a pair of wings waving. Wingspan of the Micro Air Vehicle – 25 cm, weight 14 g. The flight time 15 minutes for 1 lithium-polymer battery, flight speed of 5 m/sec.

In Fig. 2 there is the most technically advanced Micro Air Vehicles developed by the American company AeroVironment.

Before performing simulation studies, it is necessary to carry out optimization of avionics and mass analysis. Fig. 3 shows the avionics and ensuring proper distribution of fuel centre of gravity position. On the basis of this analysis and the experience of flying prototype, the new shape of the hull has been developed and designed structures. New forms have been built and work on the first structure of the new configuration is in progress. This effort is aimed at the experienced hands-on activities and future production of fully developed platform MAV. The platform should be manufacturable, stable in terms of in-flight and of ground handling services, while providing good flight characteristics. As a result, it will be selected the most efficient structures in terms of manufacturability, strength, weight, cost and operations will be selected.

2. Simulation studies and performance analysis

Numerical study was undertaken to select appropriate model of the propulsion system that is optimal for further design-analysis in terms of both accuracy and computing power requirements. Several grid with different propeller models are prepared. They represent different levels of simplification from complete model with rotating propeller blades to the disc plane with defined pressure gradient, with or without wake swirl. The goal of this task is to select the model, which provides accurate result in the shortest time since it will be used for aerodynamic, and stability numerical optimization. Many runs of aerodynamic calculations will be needed to obtain the most efficient MAV geometry, so they have to be as short as practical to finish optimization within reasonable time. The water and wind tunnel measurements allow us to aerodynamic measurements to calculate basic performance of MAV. Results of calculations of necessary and required power (for CR3516 motor) are shown in Fig. 4.

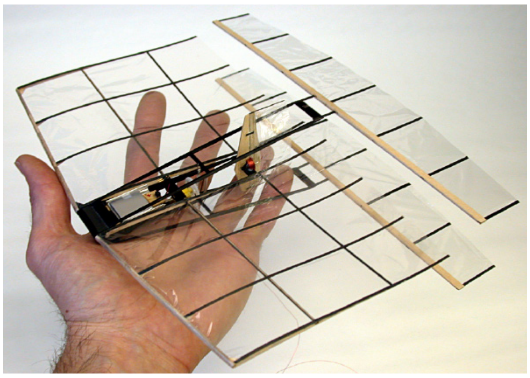

Fig. 1. Demonstrator innovative engine bionic MAV

Fig. 2. MAV: a), Wasp II", b) „Wasp III" American company – AeroVironment

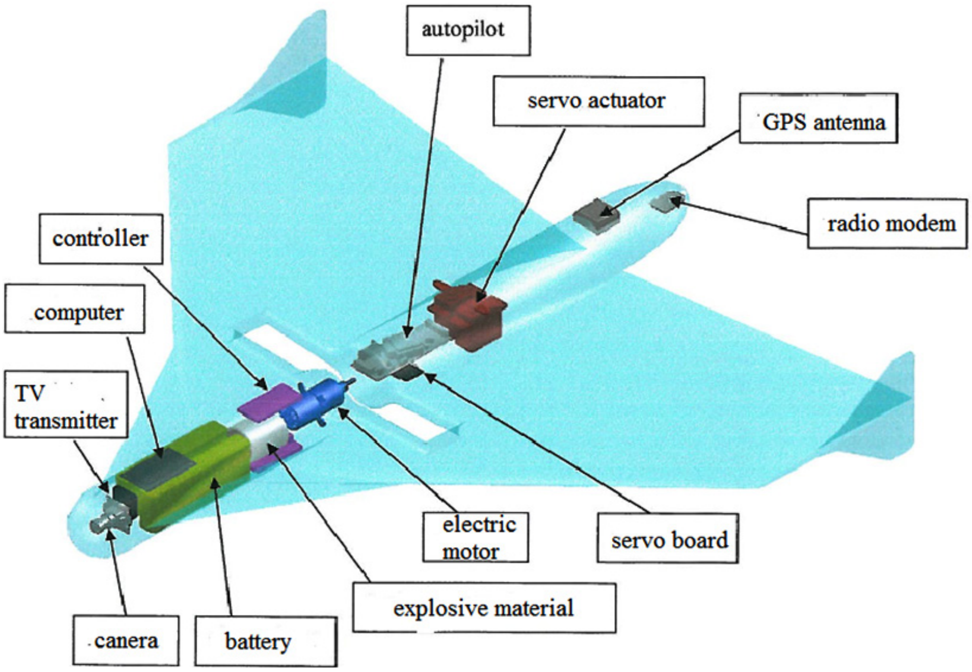

Fig. 3. Avionics distribution in the second prototype

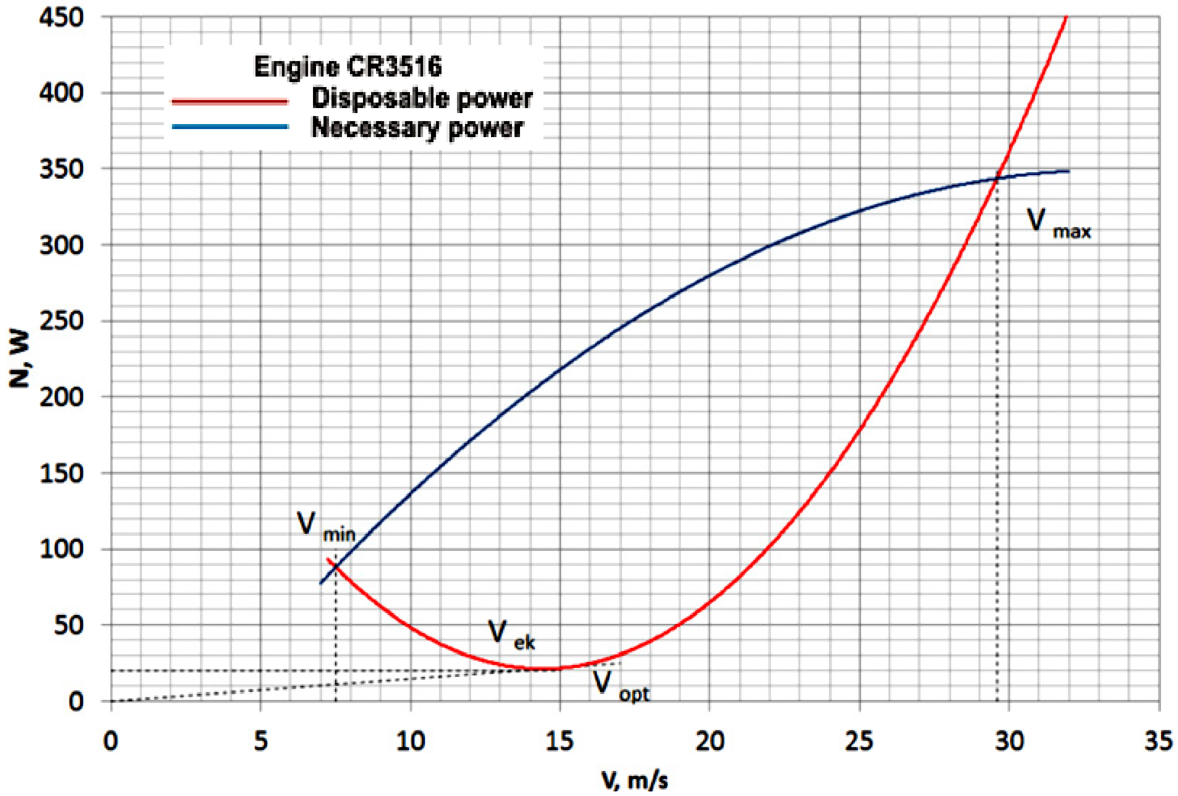

Fig. 4. Necessary and available power (results of calculations) [12]

The next step of MAV performance examination was calculations of dynamics stability and controllability of open loop system. State, and control matrixes for the longitudinal motion have the following form:

$$A=\begin{bmatrix} -0.1072 & 0.3164 & 0 & -9.81 \\ -0.2017 & 5.6117 & 12.5281 & 0 \\ -1.2047 & -5.6117 & -9.469 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix},\quad B=\begin{bmatrix} -0.0001 & 2.943 \\ -10.8044 & 0 \\ -482.063 & 0 \\ 0 & 0 \end{bmatrix}, \tag{1}$$

Eigenvalues for longitudinal motion are:

$$\begin{cases} \lambda_{1,2}=-1.9049+11.8864i, \\ \lambda_{1,2}=-1.9049-11.8864i, \\ \lambda_{3,4}=-0.0773+0.93, \\ \lambda_{3,4}=-0.0773-0.93. \end{cases} \tag{2}$$

where $\lambda_{1,2}$ are short period roots, and $\lambda_{3,4}$ are the phugoid motion roots.

Roots loci and open loop dynamics analysis for longitudinal motion are shown in Fig. 5-9.

Transfer function for the u input u (longitudinal velocity) has the following form:

$$T_u=\frac{-0.000128s^3-3.419s^2+2796s-28220}{s^4+3.964s^3+146.4s^2+25.72s+126.2}. \tag{3}$$

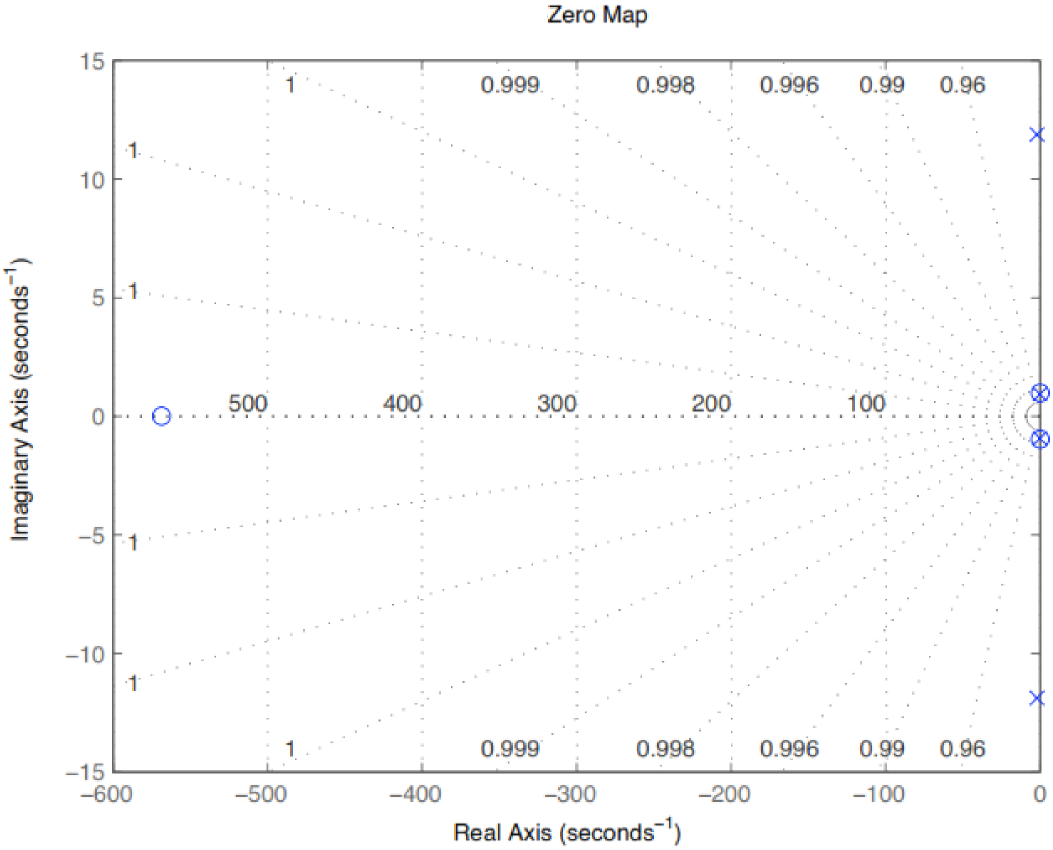

Fig. 5. Pole – zero map for the MAV longitudinal motion

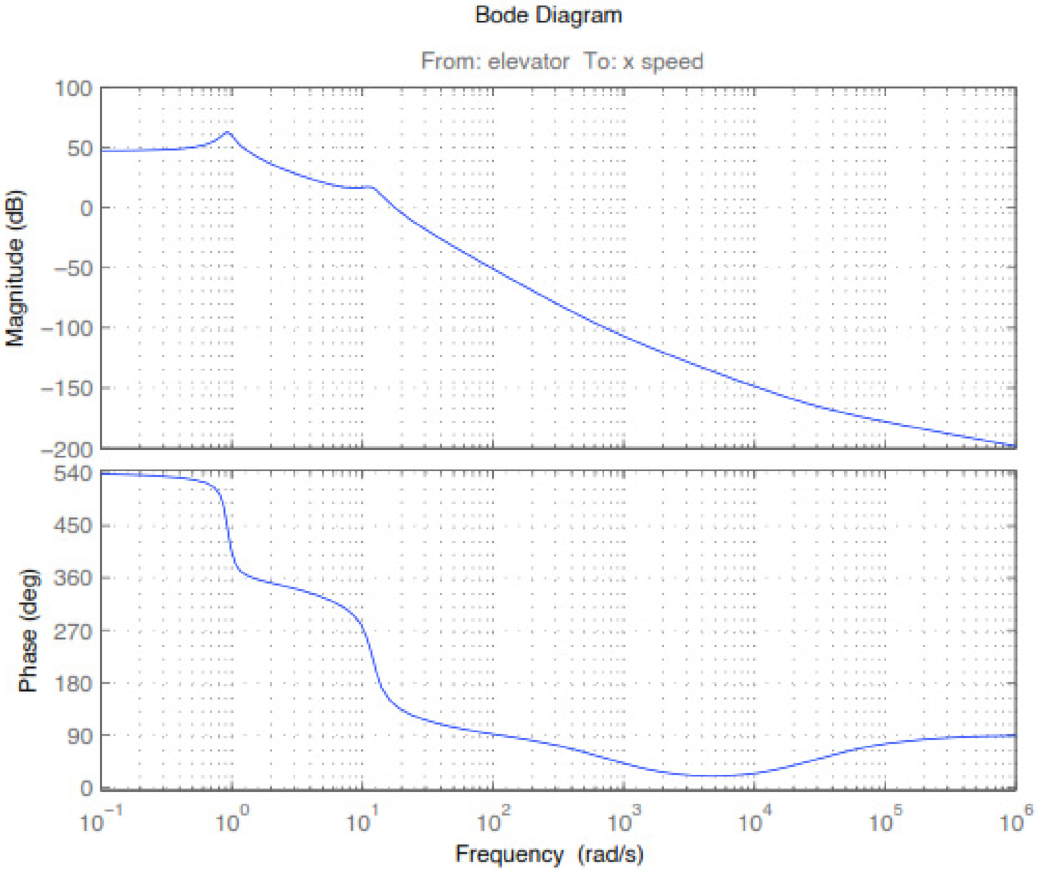

Fig. 6. Bode Diagram for the u input

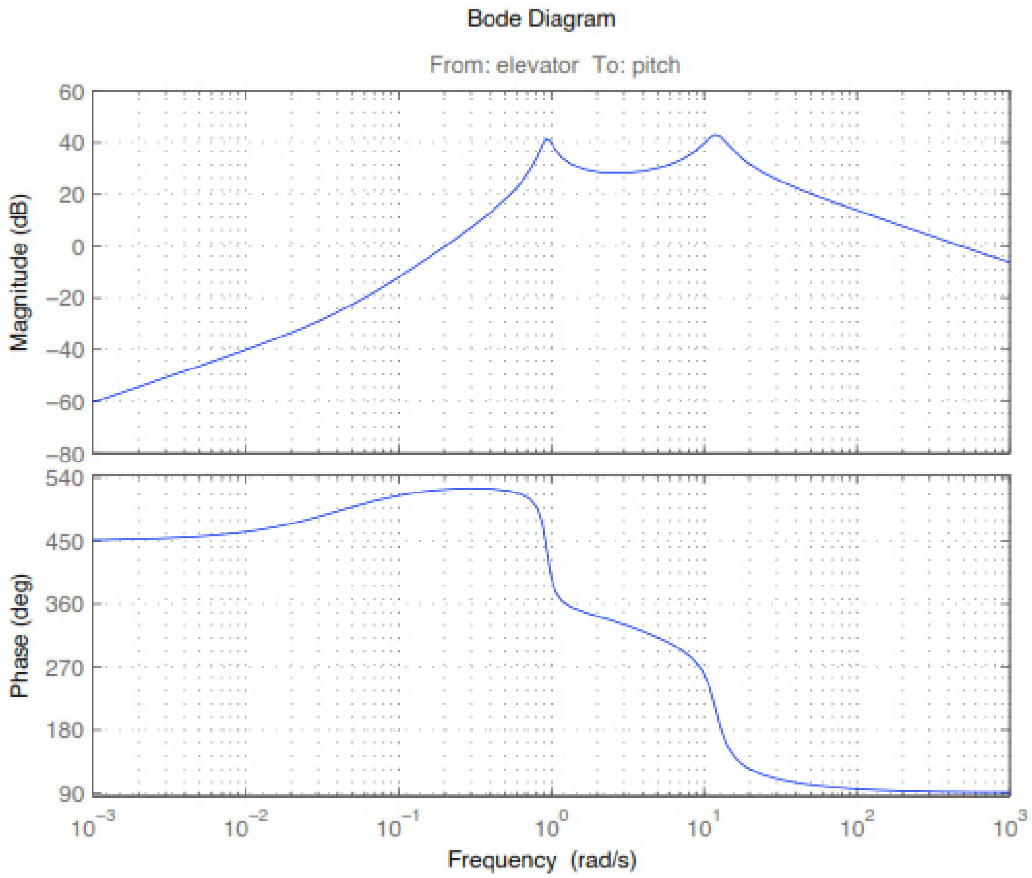

Fig. 7. Bode Diagram for input q (pitch angular rate)

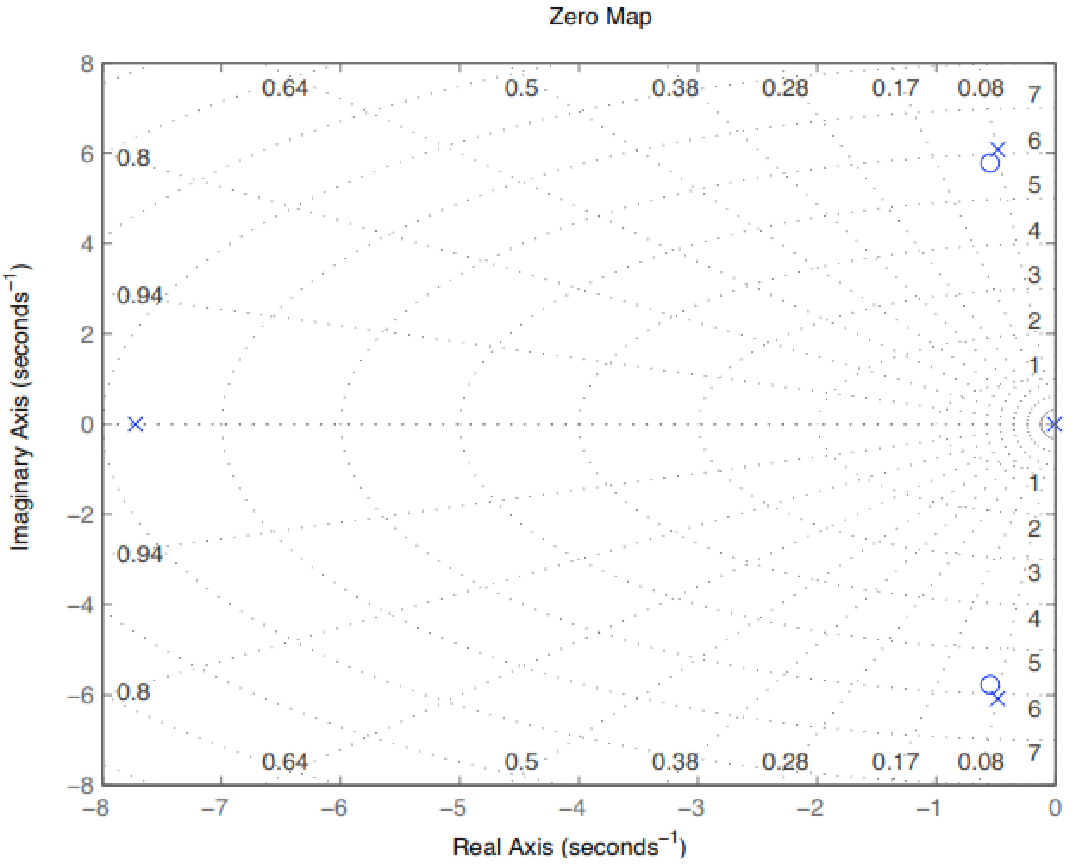

Fig. 8. Pole – zero map for the MAV longitudinal motion

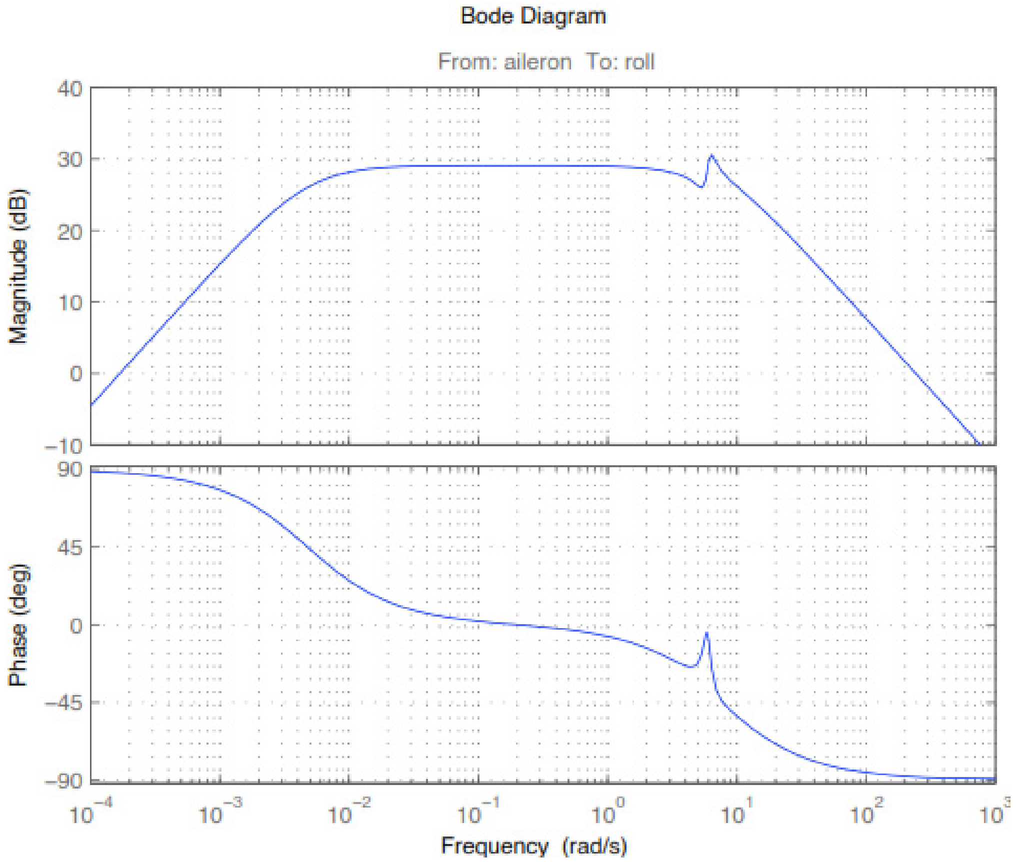

Fig. 9. Bode diagram for the roll rate p input

Transfer function for the pitch angular rate q input has the following form:

$$T_u = \frac{-482.1s^3 + 2825s^2 + 1208s}{s^4 + 3.964s^3 + 146.4s^2 + 25.72s + 126.2}. \tag{4}$$

For the lateral motion, state, and control matrixes have the following form:

$$A = \begin{bmatrix} -0.4438 & 0.0973 & -15.1213 & 9.81 \\ -5.4225 & -7.586 & 1.4382 & 0 \\ 2.3998 & 0..517 & -0.6623 & 0 \\ 0 & 1 & & 0 \end{bmatrix}, \quad B = \begin{bmatrix} -1.6754 \\ 242.0995 \\ -8.3728 \\ 0 \end{bmatrix}. \tag{5}$$

Eigen values for longitudinal motion are:

$$\begin{cases} \lambda_{1,2} = -0.4824 + 6.0854i, \\ \lambda_{1,2} = -0.4824 - 6.0854i, \\ \lambda_3 = -7.7226, \\ \lambda_4 = -0.0048. \end{cases} \tag{6}$$

where $\lambda_{1,2}$ are the Dutch roll periodical roots, λ_3 is the aperiodical roll motion root, and λ_4 is the spiral motion mode roots. Roots loci and open loop dynamics analysis for lateral motion are shown in Fig. 10-11.

Transfer function for the rolling motion angular rate p input has the following form:

$$T_u = \frac{242.1s^3 + 264.8s^2 + 8165s}{s^4 + 8.692s^3 + 44.76s^2 + 288s + 1.375}. \tag{7}$$

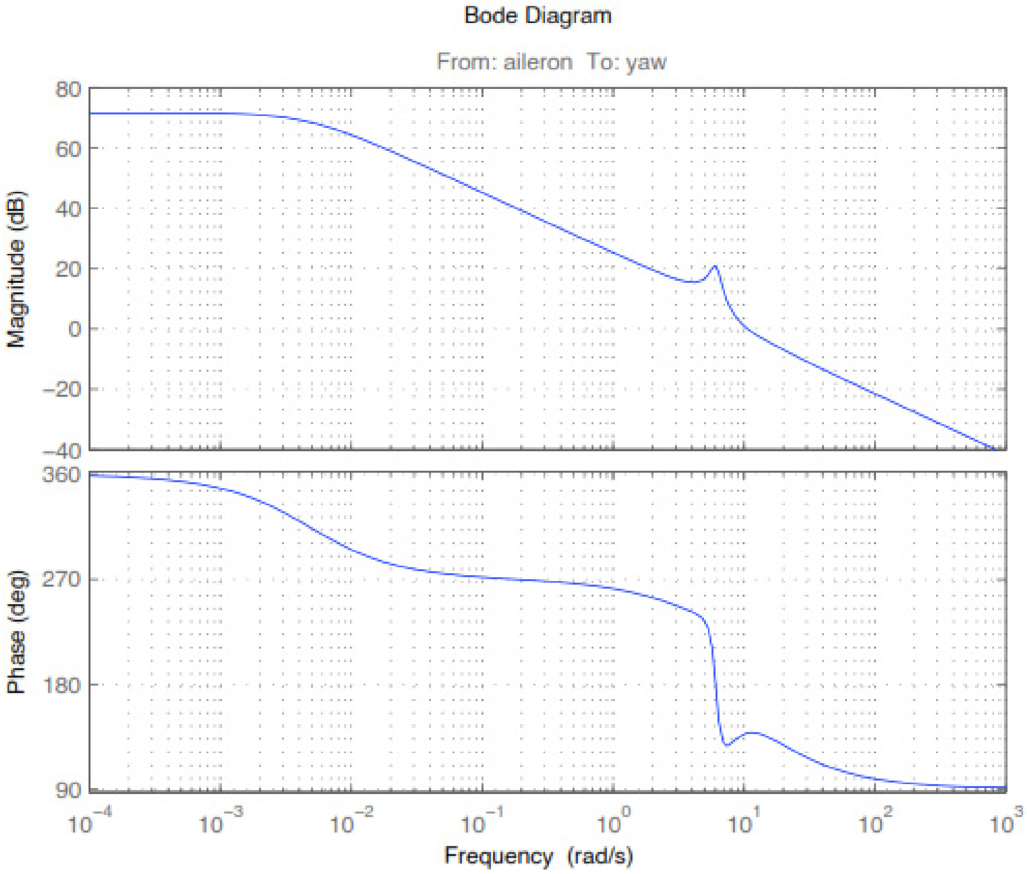

Fig. 10. Bode diagram for the yaw rate r input

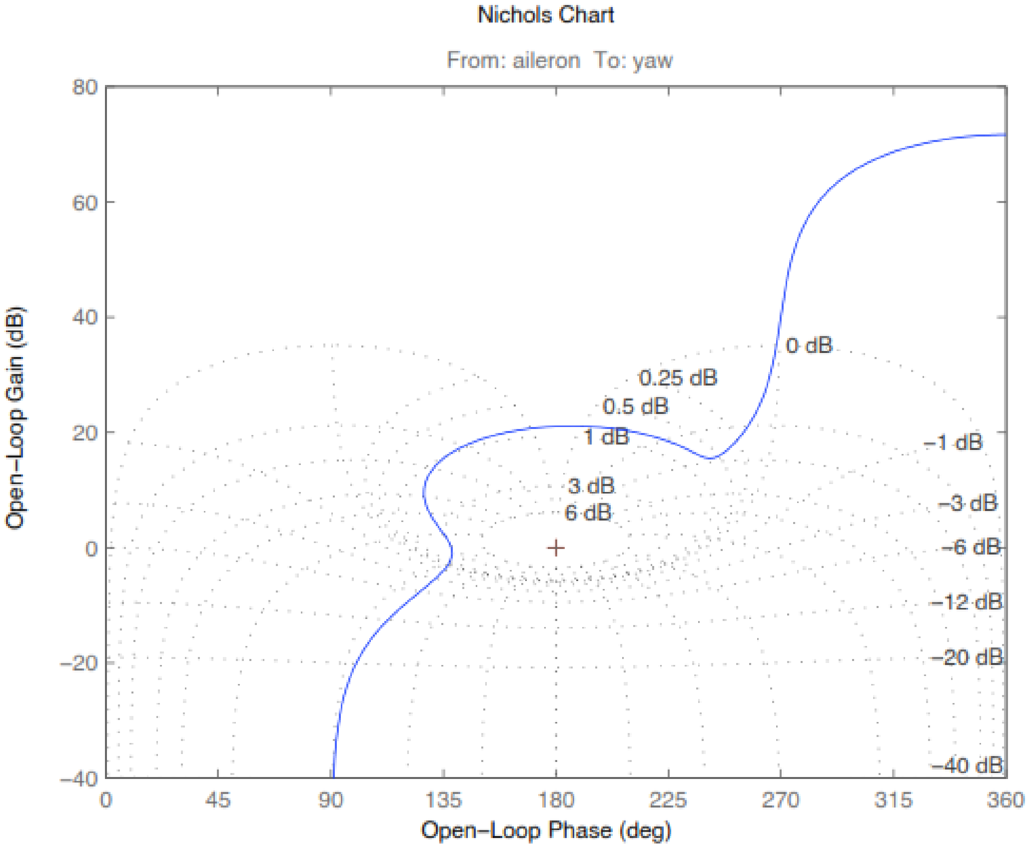

Fig. 11. Nichols chart for the yaw rate r input

Transfer function for the yawing motion angular rate *r* input has the following form:

$$T_u = \frac{-8.373s^3 + 53.92s^2 + 853.69s + 5254}{s^4 + 8.692s^3 + 44.76s^2 + 288s + 1.375}. \tag{8}$$

Results of simulations for dynamic response of MAV flight disturbance is shown in Fig. 12-15.

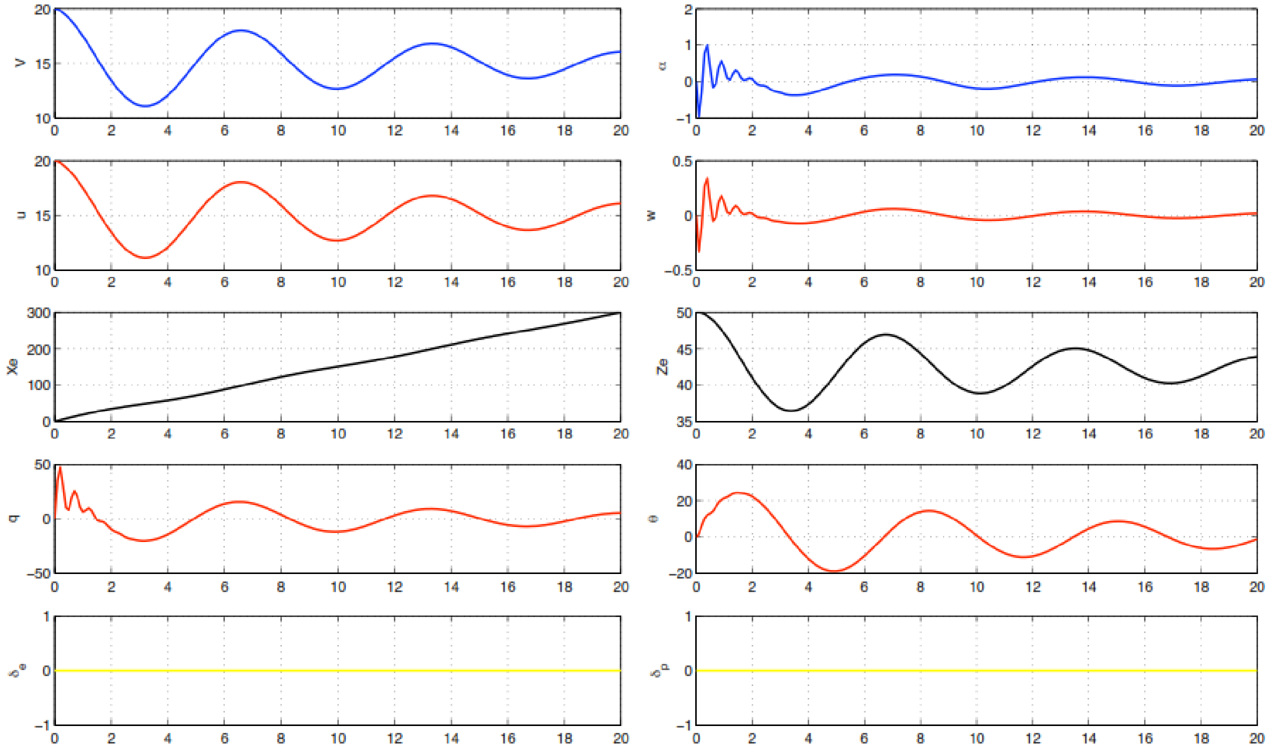

Fig. 12. Dynamic response of MAV system on longitudinal disturbance

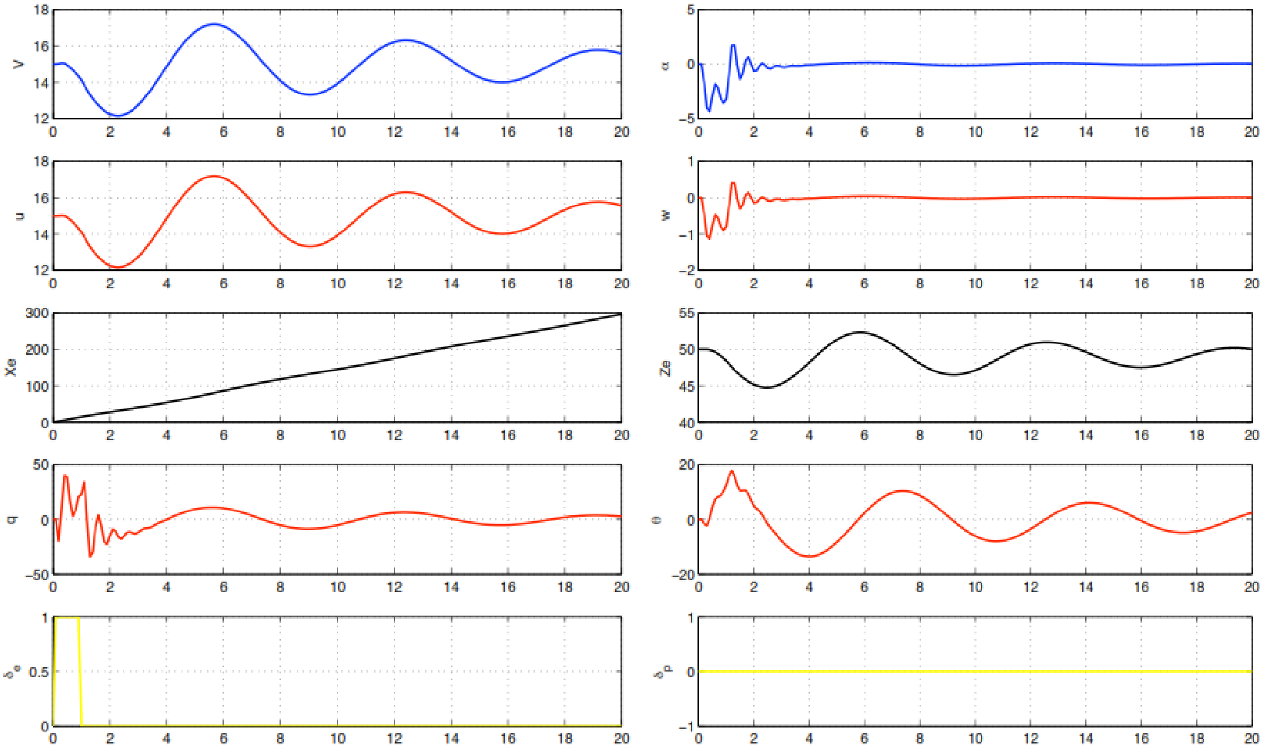

Fig. 13. Dynamic response of MAV on elevator control input

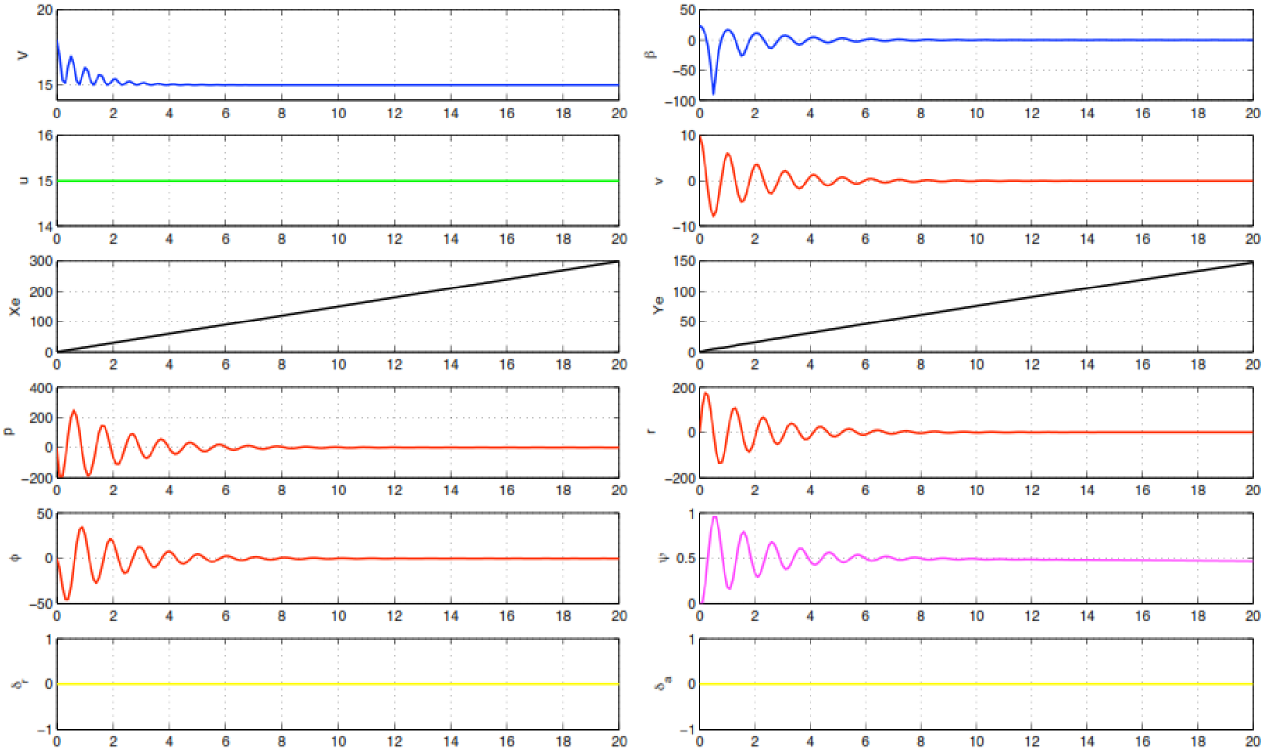

Fig. 14. Dynamic response of MAV system on lateral disturbance

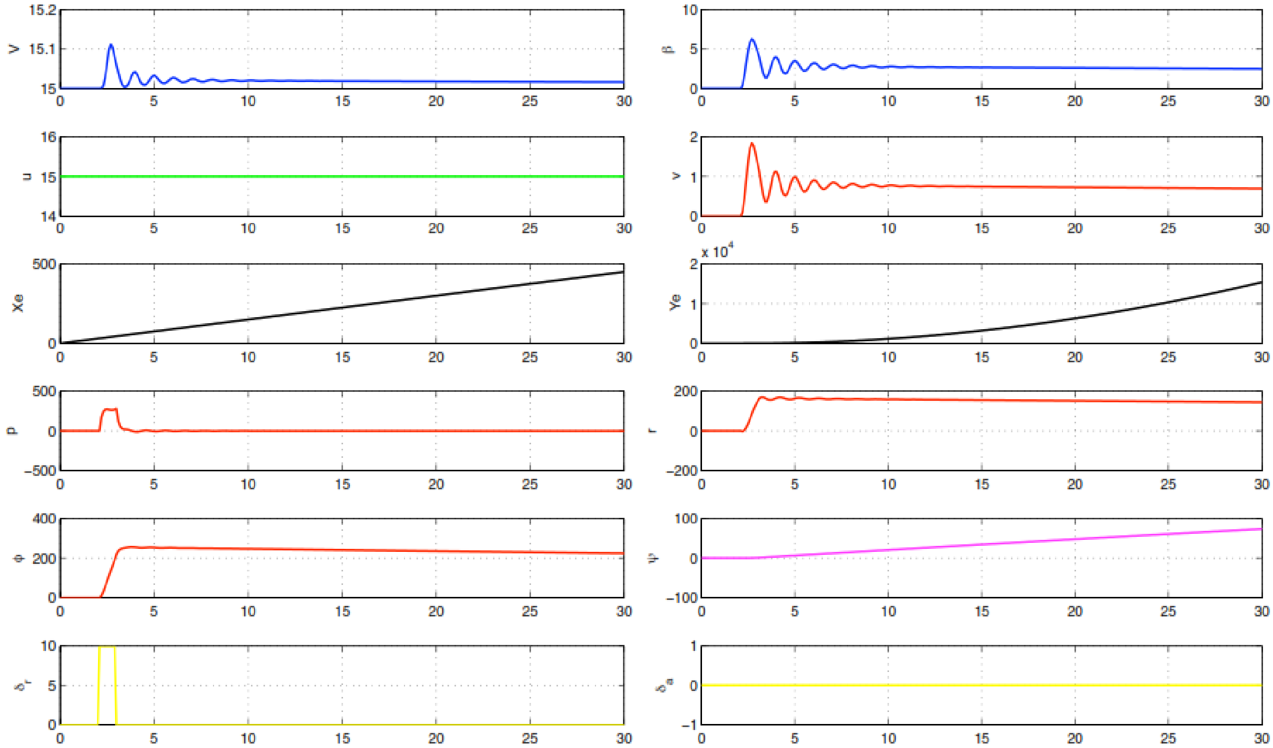

Fig. 15. Dynamic response after short aileron distribution

Conclusions

All analysis confirmed that MAV is dynamically stable in the wide range of flight conditions. Demonstrated great effectiveness of simulation methods. This allows for a fairly inexpensive research, which shows pre-effects, problems and benefits of a given structure.

References

[1] Morris, S. J., *Design and Flight Test Results for Micronized Fixed-Wing and VTOL Aircraft*, Proceedings of the First International Conference on Emerging Technologies for Micro Ai Vehicles, Georgia Institute of Technology, Atlanta, GA, February 1997.

[2] Bovais, C., Mackrell, J., Foch, R., Carruthers, S., *Dragon Eye UAV Concept to Production*, Proceedings of UAVs XVIII International Conference, Bristol, UK, 31 March − 2 April 2003, pp. 3.1-3.12.

[3] Grasmeyer, J. M., Keennon, M. T., *Development of the Black Widow Micro Air Vehicle*, AIAA Paper 2001-0127, January 2001

[4] Watkins, S. W., *Melbourne Atmospheric Winds: Implications for MAVs*, Proceedings of the VIII international UAV Conference, 31 March − 2 April 2003, Bristol, UK.

[5] Polhamus, E. C., *A Concept of the Vortex Lift of Sharp-Edge Delta Wings Based on a Leading-Edge-Suction Analogy*, NASA Technical Note TN D-3767, December 1966

[6] Lamar, J. E., *The Use and Characteristics of Vortical Flows Near a Generating Aerodynamic Surface: a Perspective*, Prog. Aerospace Sci. Vol. 34, No. 3/4, pp. 167-217, 1998.

[7] Galiński, C., Mieloszczyk, J., *Results of Gust Resistant MAV Programe*, Proceedings of the 28th ICAS Congress, Brisbane, Australia, 24-28 September 201212.

[8] Galinski, C., *Gust Resistant Fixed Wing Micro Air Vehicle*, Journal of Aircraft, AIAA, Vol. 43, No. 5, September-October 2006, pp. 1586-1588.

[9] Mieloszczyk, J., *Solver Preparation for Reliable Aerodynamic Computations for Micro UAV*, International Conference READ 2010, Warsaw, 2010.

[10] Shyy, W., Klevenbring, F., Milsson, M., Sloan, J., Carrol, B., Fuentes, C., *Rigid and Flexible Low Reynolds Number Airfoils*, Journal of Aircraft, Vol. 36, No. 3, pp. 523-529, 1999.

[11] Galinski, C., *Strike Wing Unmanned Aerial Vehicles*, Final Report; Grant no. N509 025836, National Centre of Research and Development, Warsaw 2011 (in Polish).

[12] Mystkowski, A., *Robust Optimal Control of MAV Based on Linear Time Varying Decoupled Model Dynamics*, Solid State Phenomena, Vol. IV, 2012.

[13] Mystkowski, A., *An Application of Mu-synthesis for Control of a Small air Vehicle and Simulation Results*, Journal of Vibration and Control, Vol. 14, No. 1, pp. 79-86, 2012.

[14] Garbowski, M., Sibilski, K., *Application of Indicial Function Theory to Identification of MAV Aerodynamic Derivatives from Water Tunnel Testing*, Mechanics in Aviation, ML XV, PTMTiS, 2012.

[15] Jaroszewicz, A., Garbowski, M., Sibilski, K. Zyluk, A., *Estimation of MAV Unsteady Aerodybanic Parameters From Water Tunnel Testing*, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 4-7 January 2011, Orlando, Florida, AIAA 2011-1162CP, 2011.