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AERODYNAMIC MEASUREMENTS MICRO AIR VEHICLE

Andrzej Zyluk, Krzysztof Sibilski, Miroslaw Kowalski

Air Force Institute of Technology
Ksiecia Boleslawa 6, 01-494 Warszawa, Poland
tel.: +48 22 6851300, fax: +48 22 6851300
e-mail: krzysztof.sibilski@itwl.pl, andrzej.zyluk@itwl.pl, miroslaw.kowalski@itwl.pl

Witold Wiśniowski

Institute of Aviation
Krakowska Avenue 110/114, 02-256 Warsaw, Poland
tel.: +48 22 8460993, fax: +48 22 8462912
e-mail: witold.wisniowski@ilot.edu.pl

Abstract

In present times, constructions of micro air vehicles arouse more and more interest researchers and manufacturers. Air turbulence is perceived as a major problem for Micro Air Vehicles (MAV) in outdoor applications. According to the literature, short duration vertical gusts may have velocity comparable to MAV airspeed, so brief periods of flight at very large angles of attack have to be considered. In these circumstances, it seems reasonable to apply the design with as high stall angle of attack as possible. In particular, the flow has to be attached to control surfaces to perform effective control in order to damp air turbulence effect. Therefore, an aircraft configuration was developed with cranked delta wing and propeller located inside the wing contour. To prove the value of the concept, wind tunnel experiment was undertaken. The prototype demonstrated ability to fly controllably at extremely high angles of attack. Moreover we present few disadvantages of these construction for example it was very sensitive to the motor settings, since every rpm change required immediate airplane trimming to maintain straight path of flight. This drawback can be eliminated by application of counter-rotating propeller. The status of the program is presented in the paper, including the most recent results, as well as currently undertaken experiments and plans for the nearest future.

Keywords: *construction of micro air vehicles, aerodynamic measurements*

1. Introduction

Micro Air Vehicle (MAV) is defined here as a small (hand launched, storable in portable container), light, and inexpensive unmanned flying vehicle for direct, over the hill reconnaissance. The focus is on fixed wing, forward thrust airplane since the ability to negotiate strong opposing winds is required.

Several prototypes of fixed wing MAVs were built to date [1-3]. They achieved good range and endurance performance. However, they suffer from near earth boundary layer turbulence that creates high variations in angle of attack. The potential solution of this problem was noted in the course of the project described in [5], when one of the tested MAV configurations exhibited existence of leading edge vortex. Leading edge vortex is a well-known phenomenon [6, 7], that allows the design of super-manoeuvrable jet fighters, capable of flying at very high angles of attack. It was assumed that highly manoeuvrable MAV could be stable in the turbulent air, if equipped with a fast enough autopilot. Therefore, it was decided to apply cranked delta wing configuration, however, integration with propulsion system was not straightforward. Moreover, it was necessary to testing the constructions in the wind tunnel. The testing was carried out in a wind and water tunnel.

2. Wind and water tunnel testing of MAV aerodynamics

Propeller propulsion seems to be the most suitable for a fixed wing MAV. Propeller at the vehicle front would decrease the angle of attack locally, thus vanishing the effect of the leading edge vortex. On the other hand, pusher configuration would be dangerous for hand launching. Direct contact of the propeller with the hand of the launching person, could cause personal injury, as well as damages to the airplane. Therefore, an airplane configuration, with the propeller located in the slot, inside of the wing contour, was developed (Fig. 1). The propeller blows directly at the control surfaces in this configuration, which is perceived as an additional advantage, almost equivalent to the thrust vectoring of a modern fighter aircraft.

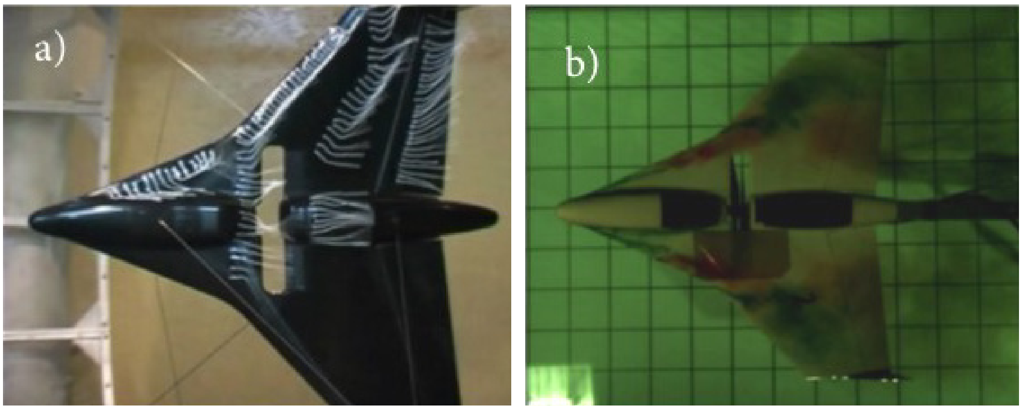

Fig. 1. Wind resistant MAV: a) wind tunnel 5 and b) water tunnel visualization

The model of this configuration was tested in the wind tunnel of the Military University of Technology, and water tunnel of the Wroclaw University of Technology Low Reynolds Number Laboratory, as described in [8], to investigate the co-operation of the leading edge vortex with the propeller stream.

After final design of MAV, it was performed number of steady and unsteady test of vehicle model in the wind tunnels and water tunnel. Some results of measurements are shown in Fig. 2 and 3. The measurements were performed in the wing tunnel of the Military University of Technology [5], low turbulence wind tunnel of Institute Aviation Technology and Applied Mechanics of the Warsaw University of Technology [12], and the RHRC water tunnel of Division of Aviation Engineering of the Wroclaw University of Technology [16]. We can noticed good agreement between tests in different laboratories.

Because of testing possibilities Wroclaw University of Technology water, it was preformed number of unsteady measurements, (oscillatory motion of MAV on measurement support). For unsteady measurement, the following similarity criterion was set – reduced frequency of the oscillatory model motion. For each of four test cycles, five frequencies were setting. Range of Angle of Attack (AOA), and sideslip angle movement was α=(-180-180°), and β=(-25-25°). For unsteady trials every test were oscillatory movement with amplitude ±5° along mean angle of attack equals 5°, 15°, 25°, 35°, 45° and 55°. Total range for every unsteady measurements set for angle of attack was α = (0-60°). In turn of sideslip, angular range for steady trials was β = (-25-25°), while sideslip oscillatory tests were performed along the mean sideslip angles equals -15°, -7.5°, 7.5° or 15° with the amplitude of movement equals ±10°.

Sideslip and roll measurements were performed due to steady angle of attack starting from 0° up to 60° for every 10° step. Because of construction of the balance only unsteady roll trials were performed, sideslip tests were both steady and unsteady. Roll unsteady tests were performed for every angle of attack described above at mean roll angle γ = 0° with the movement amplitude ±5°. Exemplary results of tests are shown in the Fig. 4, and 5.

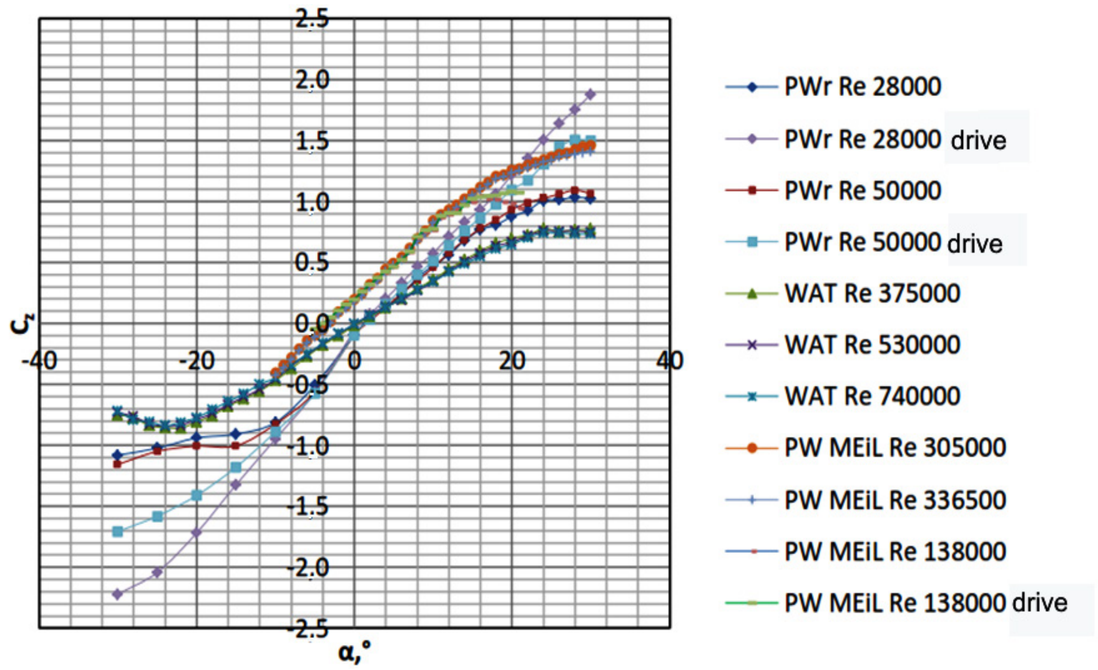

Fig. 2. Comparison of Lift Force coefficient measurements: PWr – Wroclaw University of Technology water tunnel, WAT – Military University of Technology wind tunnel, PW MEiL Warsaw University of Technology wind tunnel

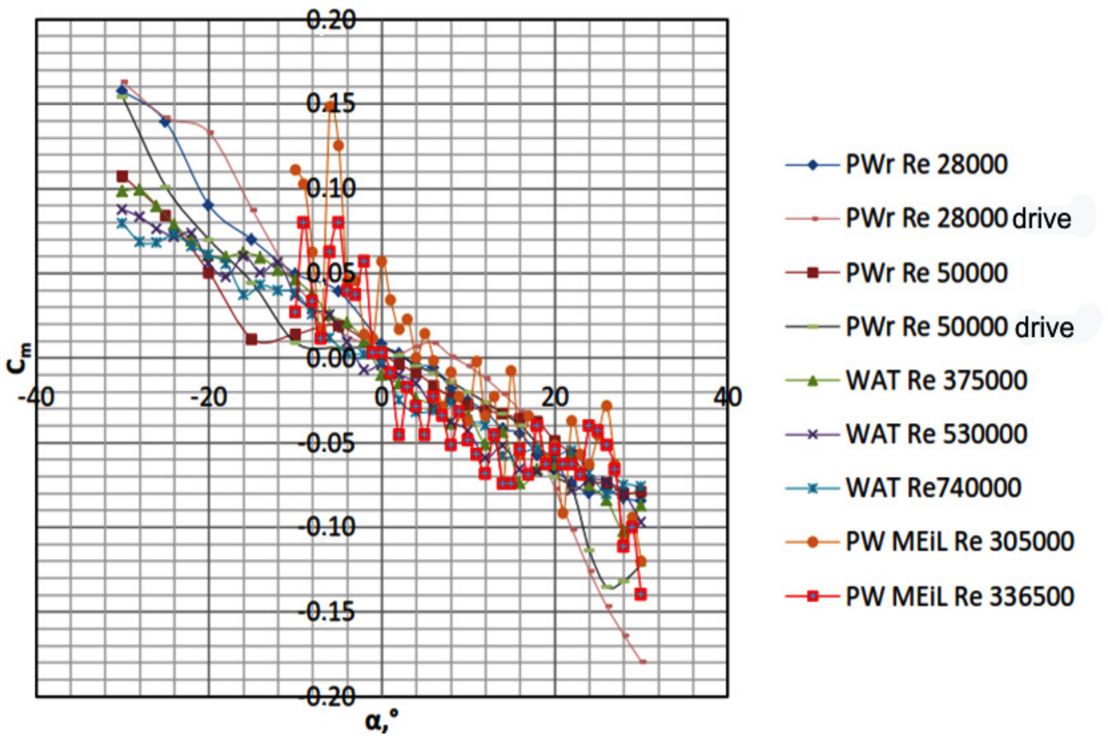

Fig. 3. Comparison of pitching moment measurements: PWr – Wroclaw University of Technology water tunnel, WAT – Military University of Technology wind tunnel, PW MEiL Warsaw University of Technology wind tunnel

Results of water tunnel tests allow us to identify aerodynamic derivatives by application of Initial Function Theory [16, 15]. Some results of identification are shown below in the figures. For example the results of dynamic tests in the plane tilt are presented below for fixed angles of attack in the range of α = (0°, 60°) in increments of 10º. Angular range oscillating motion was γ = ± 5º.

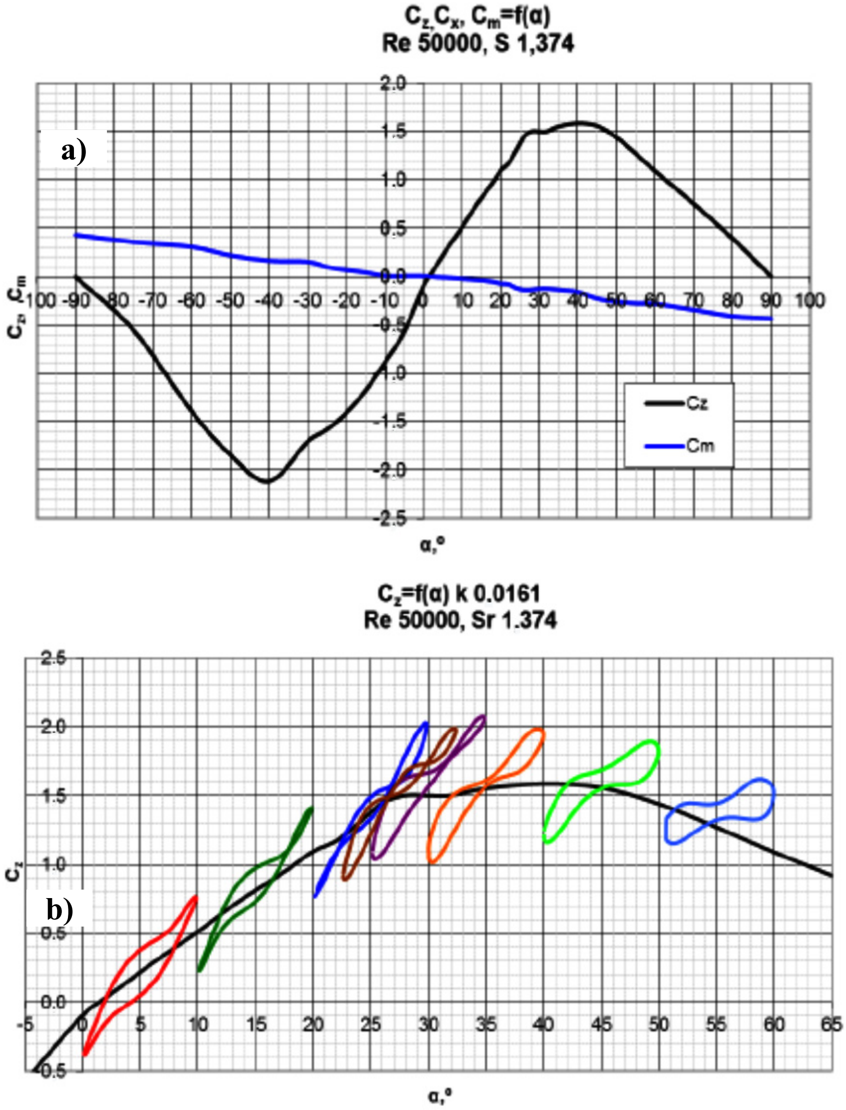

Fig. 4. a) Results of measurements (static characteristics of lift force Cz, and pitching moment coefficient Cm, b) Hysteresis effect on lift coefficient

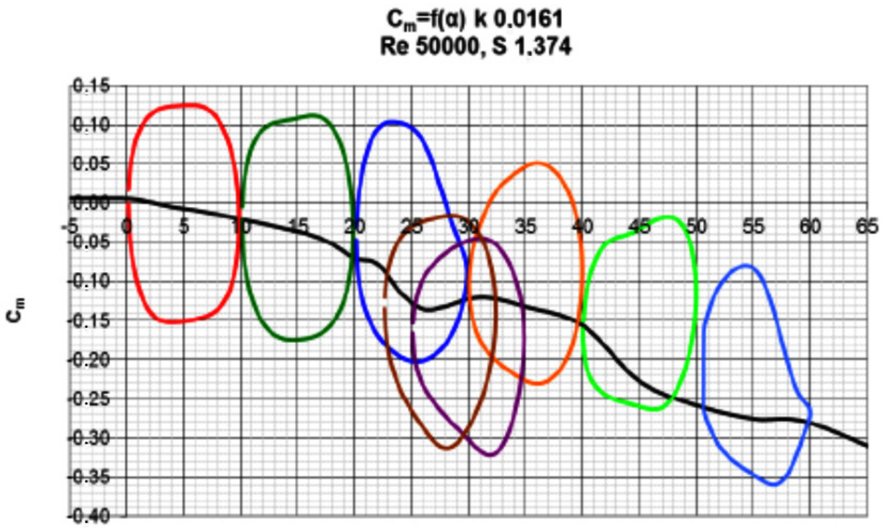

Fig. 5. Exemplary results of unsteady characteristics of pitching moment coefficient

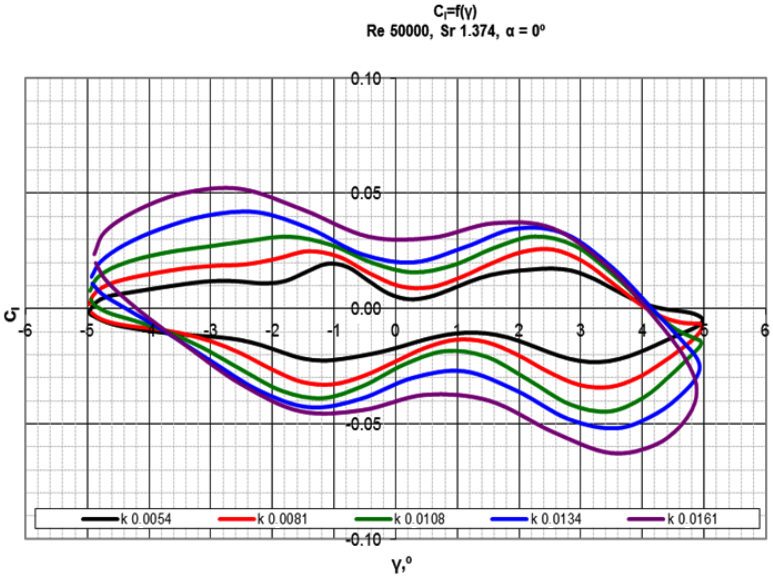

Fig. 6. The dynamic characteristics of the heeling moment coefficient for α = 0°

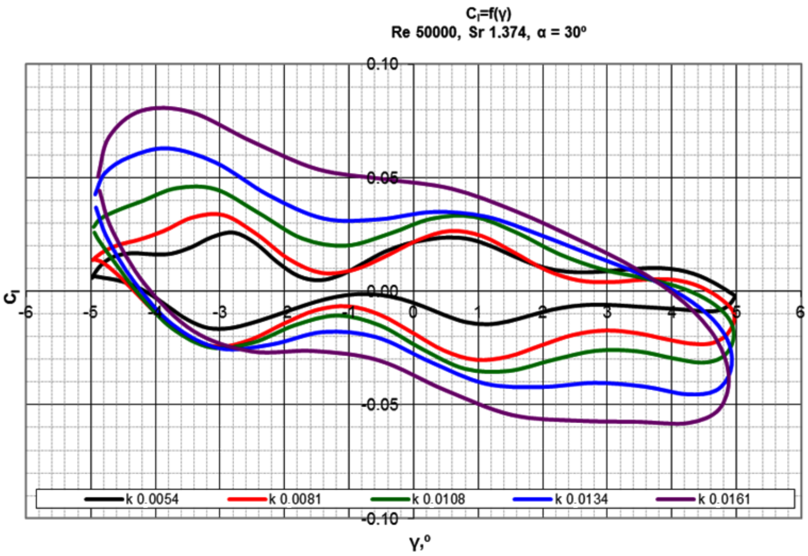

Fig. 7. The dynamic characteristics of the heeling moment coefficient for α = 30°

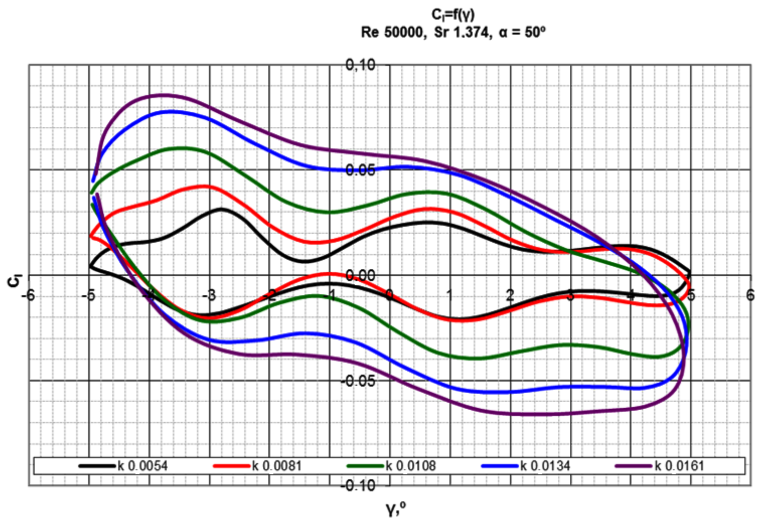

Fig. 8. The dynamic characteristics of the heeling moment coefficient for α = 50°

The test results show deviations in the plane collectively dynamic characteristics in terms of yaw angles β = (-25º, 25º) for the four ranges of motion of the oscillating carried out in relation to the average slip angle β = -15º, -7.5º, 7.5º and 15º with an amplitude of ± 10º movement. We present the results for three of the five frequencies of reduced traffic k = 0.0099, 0.0197 and 0.0296.

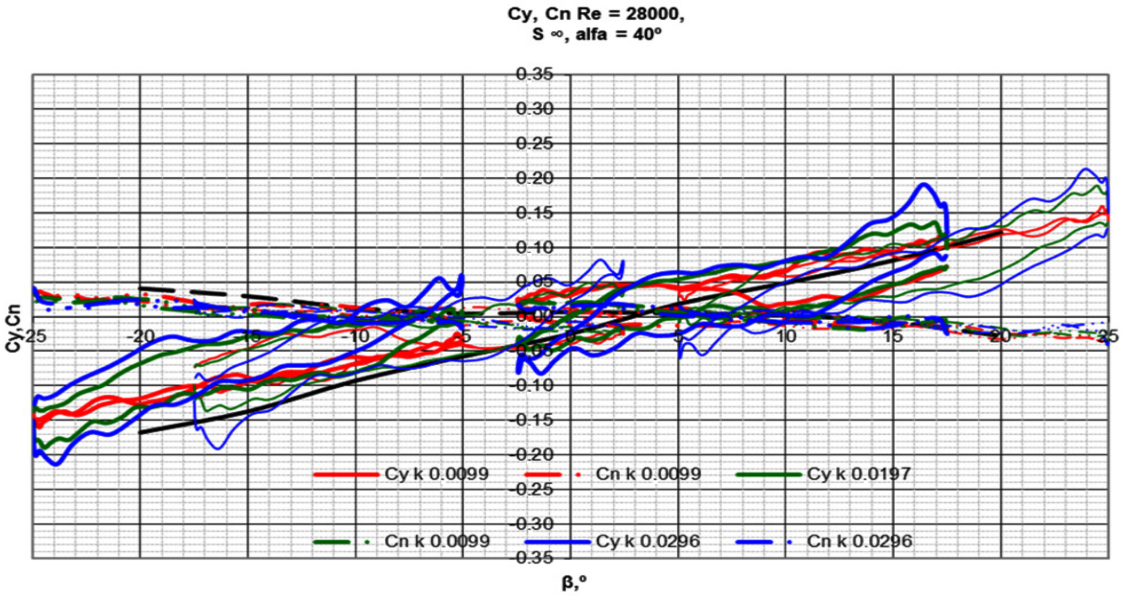

Fig. 9. The characteristics of dynamic coefficients of side force and yaw moment for α = 40º

In the plane of deviation for static tests can clearly see the deterioration of characteristics with above 40° angle of attack and the plane became directionally unstable.

In the case of dynamic characteristics, as well as in a plane tilt can be clearly seen the irregular course of the characteristics of both Cy and Cn resulting from vibrations, which fell into the model while moving.

Derivatives aerodynamic of deviation plane:

$$C_{y_r} = \frac{\delta C_y}{\delta \frac{r\ell}{V}} \qquad C_{y_\beta} = \frac{\delta C_y}{\delta\beta} \qquad C_{n_\beta} = \frac{\delta C_n}{\delta\beta} \qquad C_{n_r} = \frac{\delta C_n}{\delta \frac{r\ell}{V}}$$

Examples of the characteristics shown below in Figures.

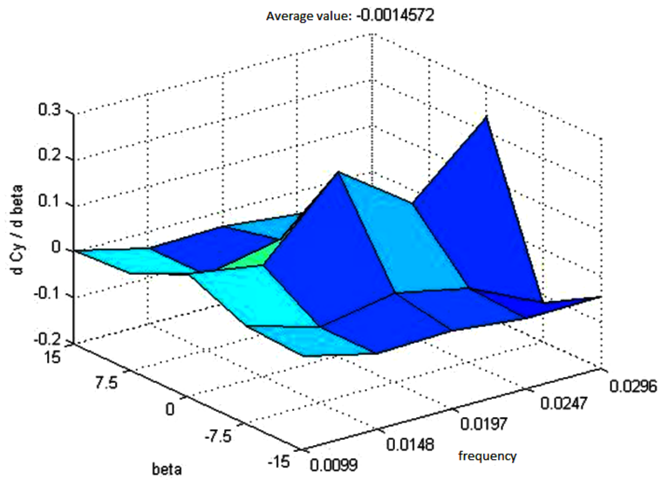

Fig. 10. The results of the identification of aerodynamic derivatives dCy/dβ for α = 0°

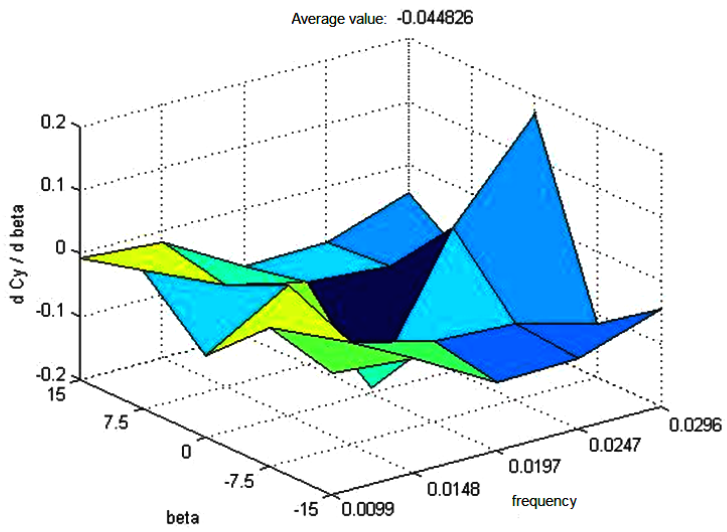

Fig. 11. The results of the identification of aerodynamic derivatives dCy/dβ for α = 30°

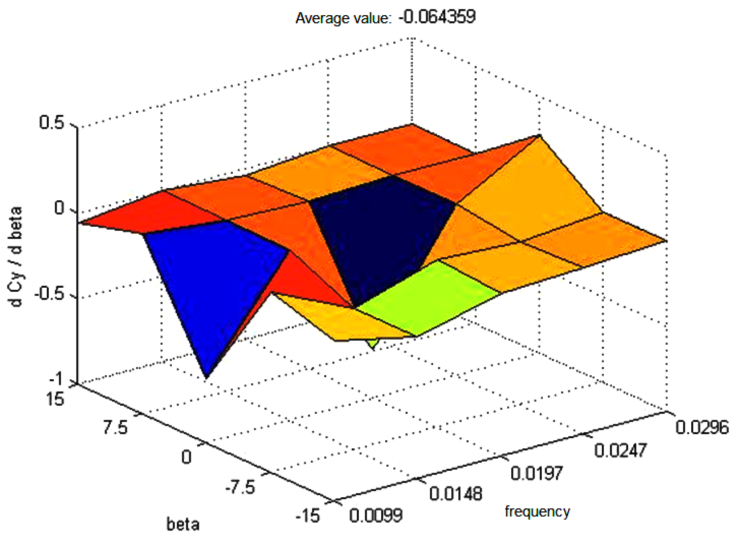

Fig. 12. The results of the identification of aerodynamic derivatives dCy/dβ for α = 60°

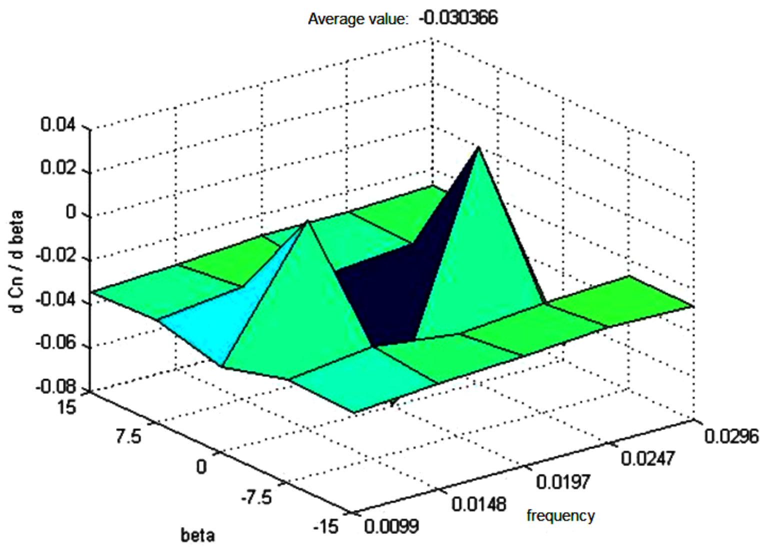

Fig. 13. The results of the identification of aerodynamic derivatives dCn/dβ for α = 0°

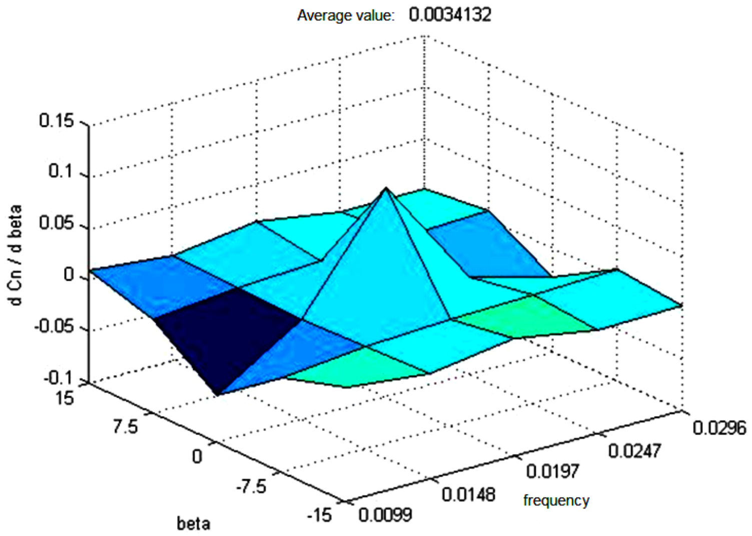

Fig. 14. The results of the identification of aerodynamic derivatives dCn/dβ for α = 30°

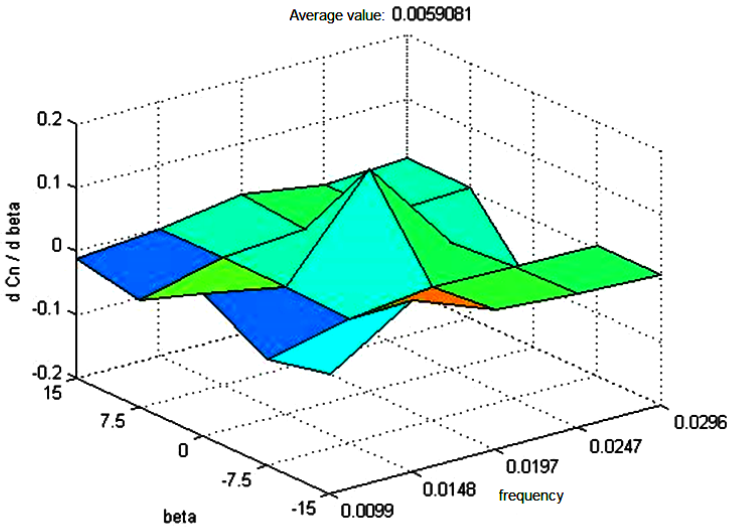

Fig. 15. The results of the identification of aerodynamic derivatives dCn/dβ for α = 60°

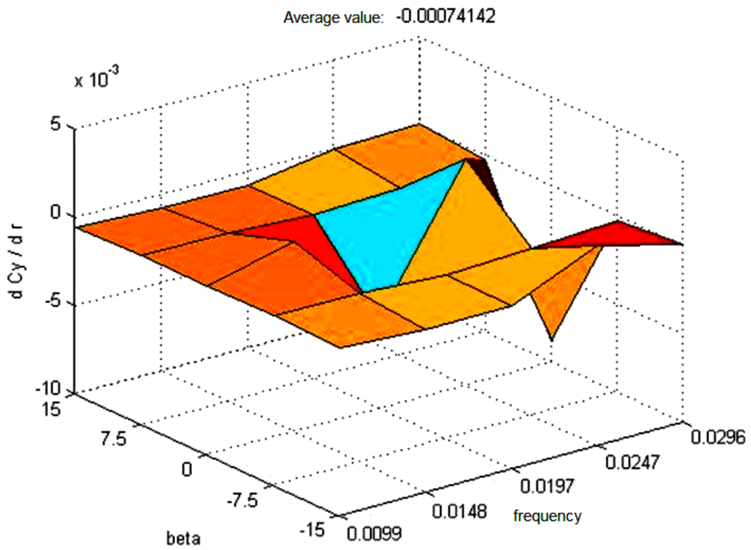

Fig. 16. The results of the identification of aerodynamic derivatives dCy/dr for α = 0°

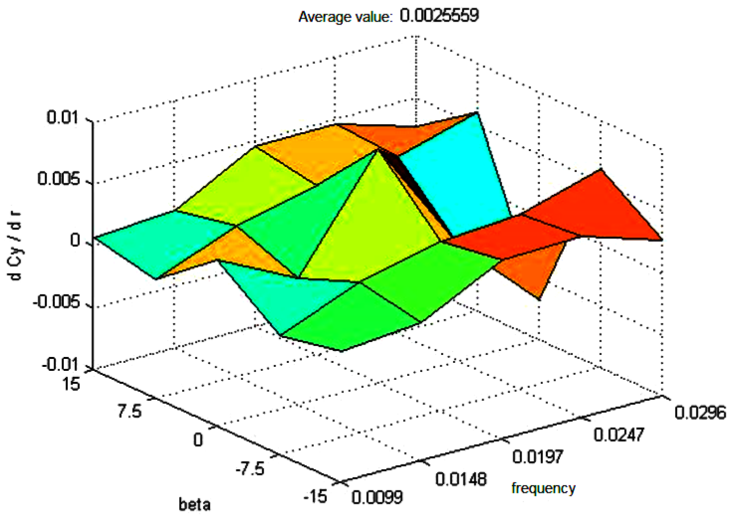

Fig. 17. The results of the identification of aerodynamic derivatives dCy/dr for α = 30°

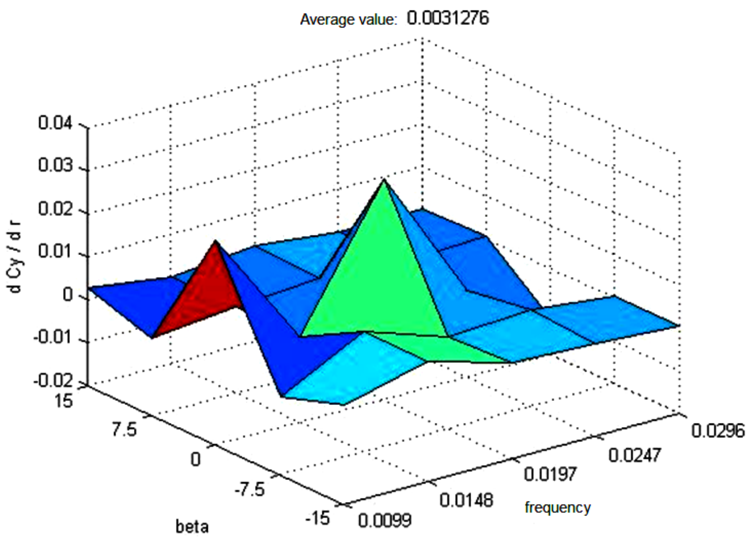

Fig. 18. The results of the identification of aerodynamic derivatives dCy/dr for α = 60°

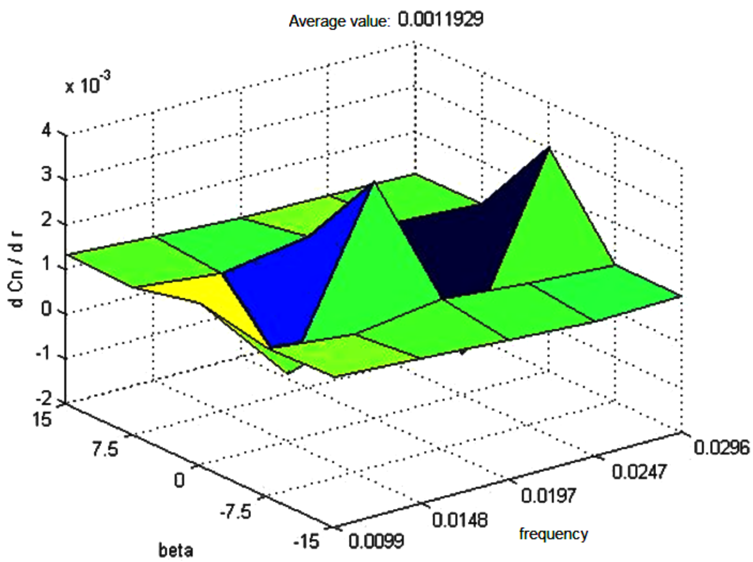

Fig. 19. The results of the identification of aerodynamic derivatives dCn/dr for α = 0°

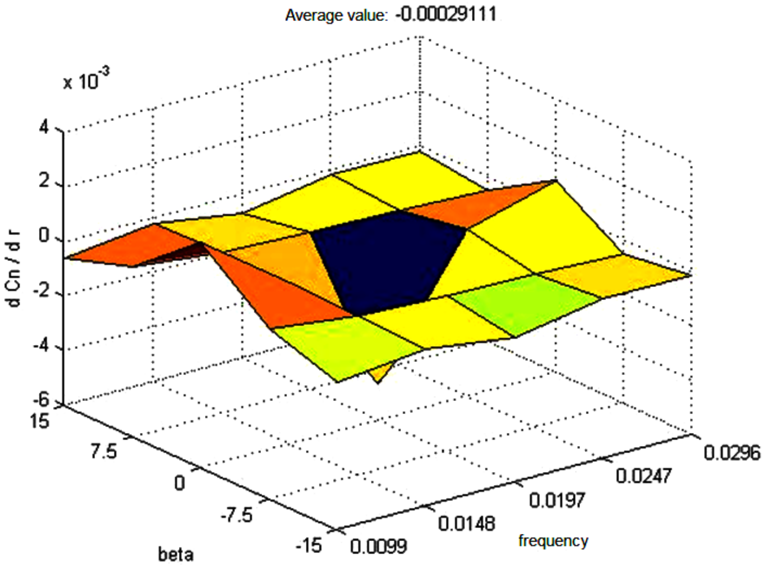

Fig. 20. The results of the identification of aerodynamic derivatives dCn/dr for α = 30°

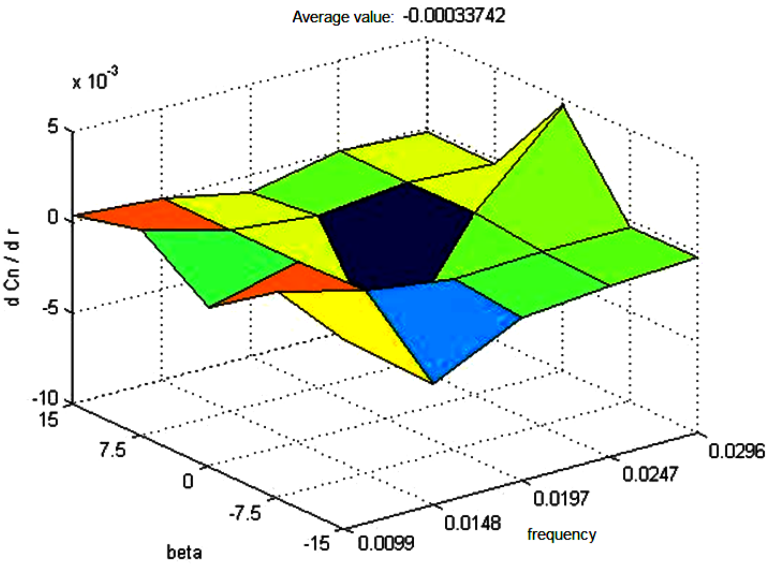

Fig. 21. The results of the identification of aerodynamic derivatives dC_n/dr for α = 60°

We can noticed that vehicle is static stable in the wide range of AOA.

Conclusions

Vertical lift can be generated by cranked delta wing at low Reynolds numbers, which allows creating MAV capable of flying at high angles of attack. Leading Edge Extensions can be successfully integrated with the propeller propulsion, generating a leading edge vortex in the neighbourhood of the propeller stream. Oversensitivity to the propeller torque is a problem if conventional propeller is considered. However, it should disappear if contra- rotating propeller is applied since the total torque of the contra-rotating propeller is neglible. Contra-rotating propeller has greater efficiency than conventional one in the same, small size.

During the testing of stationary plane deviation of no effect in changing the coefficients of force and yaw moment resulting from the Reynolds number changes or use propulsion.

For angles of attack, more than 40° test model it became unstable directionally, so the test cycle was completed on that value of the angle of attack.

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