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Engineering Notes

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Gust Resistant Fixed Wing Micro Air Vehicle

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Nomenclature

C_L = lift coefficient
n_n = load factor normal to the fuselage axis and the wing span
n_t = load factor along the fuselage axis
n_y = load factor along the wing span
V = airspeed

Introduction

MICRO air vehicle (MAV) is defined here as a small (hand launched, storable in portable container), light, simple, and inexpensive unmanned flying vehicle for direct, over the hill reconnaissance. The focus is on fixed wing, forward thrust airplane because the ability to negotiate strong opposing winds is required. The ability to maintain slow flight or ideally to hover is also desirable.

Several prototypes of fixed wing MAV were built to date [1–3]. They achieved a quite good range and endurance performance. However, they suffer from near Earth boundary layer turbulence that creates a high variation in angles of attack as explained in [4]. 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 the existence of leading edge vortex. Leading edge vortex is a well-known phenomenon [6,7] that allows the design of supermaneuverable jet fighters, capable of flying at very high angles of attack. It was assumed that highly maneuverable MAV could be stable in turbulent air. Unfortunately available data presented only flow visualization results for low Reynolds number regimes. Therefore, at the end of the project a brief experiment was undertaken to measure the effect of leading edge extension (LEX) application on MAV characteristics in propulsionless configuration. The result was positive (Fig. 1), but integration with propulsion was not straightforward.

Propeller propulsion seems to be the most suitable for a fixed wing MAV. A 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 a pusher configuration would be dangerous for hand launching, as direct contact of the propeller with the hand of the launching person could cause both personal injury as well as damages to the airplane. Therefore an airplane configuration was developed with the propeller located in a slot inside the wing contour (Fig. 2). 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 the modern fighter airplane.

The model of this configuration was tested in the wind tunnel as described in [8] to investigate the cooperation of the leading edge vortex with the propeller stream. Results were positive (Fig. 3) because the effect of the leading edge vortex appeared to be stronger in motor ON mode than in motor OFF mode. These results seemed to be similar to unsteady effects observed during experiments with acoustic excitation of the flow [9–13] and during experiments with flapping wings [14–16], however, the excitation method was different in this case. Another reason for the observed increase of lift coefficient and stall angle of attack could be the advantageous pressure gradient in the propeller stream. On the other hand, the possibility of an error in the experiment should be considered as well. Flight testing is an ultimate method validating results. This would be quite easy, because a sufficient load factor achieved during the rapid pull-up maneuver could exclude the possibility of this error. In case of MAV, flight testing is also quite economical because the flying vehicle is inexpensive and easy to build. Therefore a flight test was undertaken to prove the quality of the developed configuration. This Note presents the vehicle used and results of the flight experiment.

The Airplane

The airplane was almost identical to the wind tunnel model applied in the experiment described in [8]. The only differences were slightly increased fuselage to accommodate all necessary equipment and slightly thicker LEX root to accommodate avionics and experimental wiring. Wing geometry was the same in both cases.

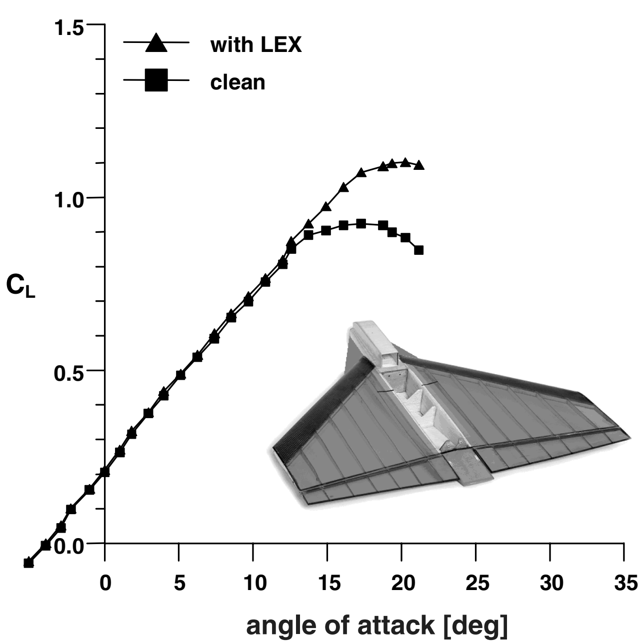

Fig. 1 Initial measurements of the lift generated by the delta wing MAV in clean configuration and with LEX attached.

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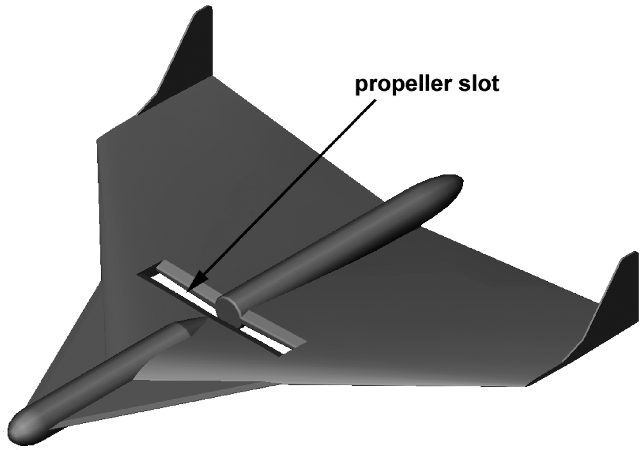

Fig. 2 Proposed MAV configuration.

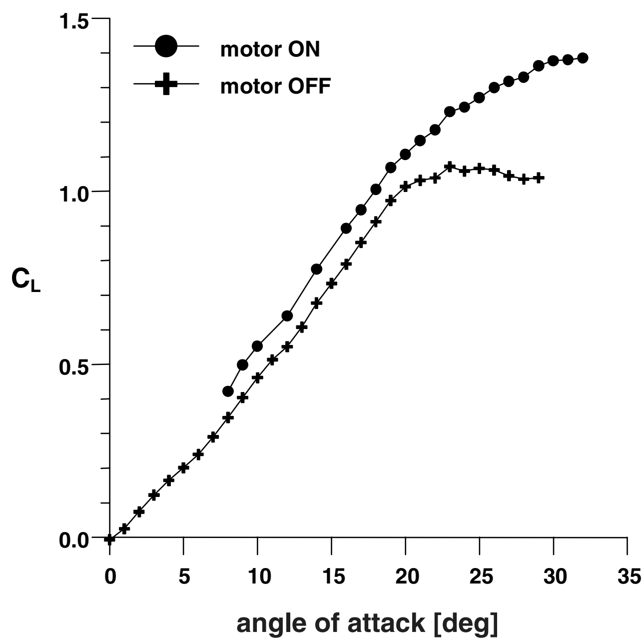

Fig. 3 Lift generated by the cranked delta wing MAV in motor ON and OFF modes, elevator in cruise position.

Fig. 4 A view of the MAV showing the batteries and avionics bays with the power plant controller and the data acquisition system (photo by Jarosław Hajduk).

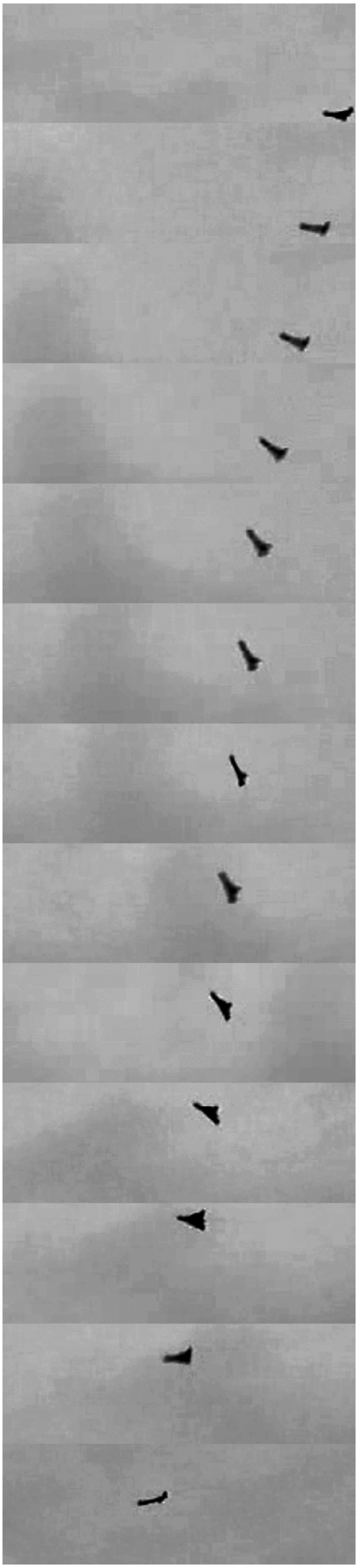

Fig. 5 Cobralike maneuver.

Airplane structure was based on the carbon torsion box in the nose part of the wing and ribs covered by flexible membrane in the remaining part of the wing. This structure was selected because of greater flow stability as described in [17].

Electric motor MEGA Acn 16/7/8 with Jes 18-3P Advance controller and APC 5.7 × 3 propeller were selected for propulsion of the airplane. Motor was supplied from Li-poly batteries with capacity of 1250 mAh. Separate Li-poly battery was applied to supply the experimental equipment.

The PRP-J5 data acquisition system was used to conduct measurements together with a set of accelerometers and differential pressure velocity sensor. There was no angle of attack sensor installed because very rapid reaction was expected. Both vane and pressure sensors would not provide reliable data because of their inertia. Vane sensor would probably overestimate, whereas pressure sensor would underestimate this measurement, thus the real value would remain uncertain. Moreover it was assumed that load factor measurement alone will be enough to validate the wind tunnel test results. This set of sensors was quite constrained, but sufficient assuming that experimentation was to be conducted close to the takeoff site. Figure 4 shows the airplane before the test.

Flight testing

Large angles of attack experiments began after initial airworthiness testing. First observations exhibited easy handling qualities both at low and high angles of attack. Only small fins' adjustment was needed to achieve satisfactory stability in both regimes. Controllability was satisfactory without any modifications. Angles of attack achieved in steady conditions were high enough to make the vertical landing possible, in a fully controllable manner.

Measurements of the maximum load factor available in flight with several different velocities followed. Figure 5 shows the "cobralike" maneuver conducted to measure the maximum load factor. An example of the raw data is presented in the Fig. 6. Finally Fig. 7 shows all measured results compared with maximum load factor curves calculated from the wind tunnel measurement. As can be seen from this plot, load factors achieved in flight are greater than expected for powered flight. This can be explained by the fact that the highest angle of attack used for wind tunnel measurements was equal to 32 deg due to the constrained measurement volume. Both lift and drag influence the load factor measured orthogonal to the fuselage, so that it increases due to the drag increase if lift remains at least constant. Therefore the presented result proves that the investigated airplane is capable of flying with angles of attack greater than 32 deg. The lack of any tendency to authorotational roll or spin and full controllability during experiment support this statement.

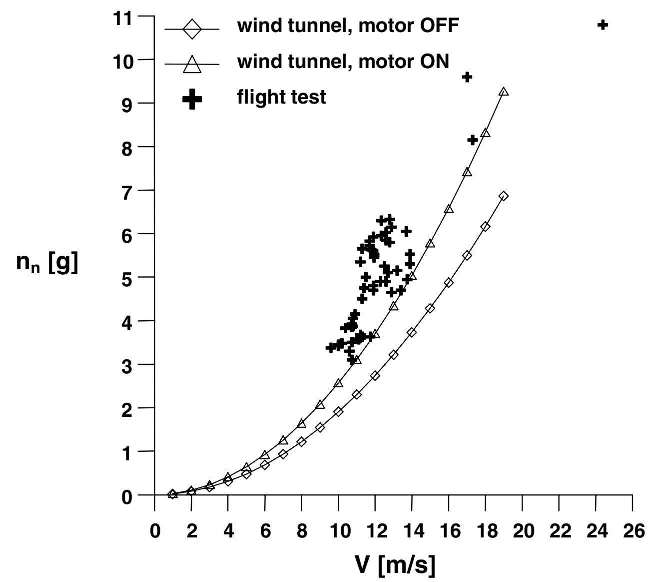

Fig. 7 Load factors measured in flight.

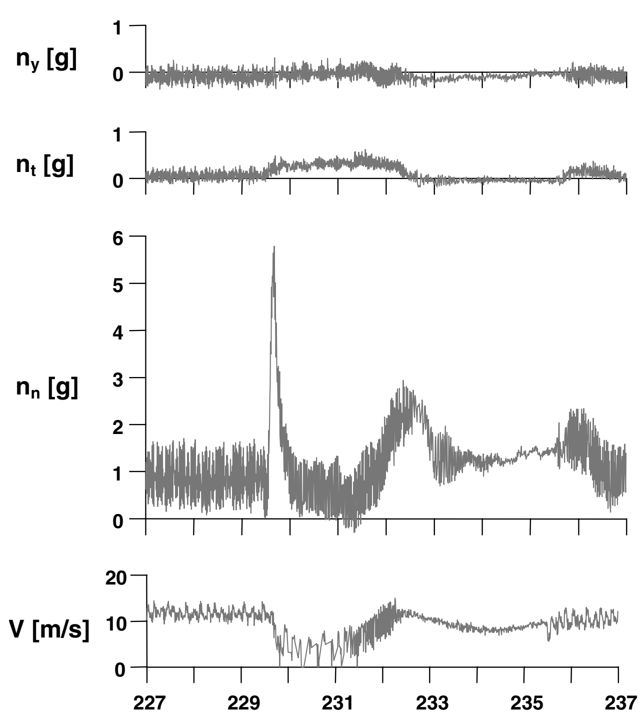

Fig. 6 Raw data from the maximum load factor measurement.

Conclusion

Leading edge extensions can be successfully integrated with the propeller propulsion. The leading edge vortex effect seems to be stronger in the neighborhood of the propeller stream. An airplane built with the application of this concept is easy to handle, maneuverable, and capable of achieving very high angles of attack both in steady and in dynamic conditions. The nature of the observed advantages remains unexplained.

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References

[1] Morris, S. J., and Holden, M., "Design of Micro Air Vehicles and Flight Test Validation," *Proceedings of the Conference on Fixed, Flapping and Rotary Wing Vehicles at Very Low Reynolds Numbers*, 2000.

[2] Bovais, C., Mackrell, J., Foch, R., and Carruthers, S., "Dragon Eye UAV: Concept to Production," *Proceedings of UAVs XVIII International Conference*, 2003, pp. 3.1–3.12.

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

[4] Watkins S., and Melbourne W., "Atmospheric Winds: Implications for MAVs," *Proceedings of the XVIII International UAV Conference*, 2003, pp. 26.1–26.11.

[5] Galinski C., Eyles M., and Zbikowski R., "Experimental Aerodynamics of Delta Wing MAVs and their Scaling," *Proceedings of the XVIII International UAV Conference*, 2003, pp. 37.1–37.11.

[6] 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.

[7] Lamar, J. E., "The Use and Characteristics of Vortical Flows near a Generating Aerodynamic Surface: A Perspective," *Progress in Aerospace Sciences*, Vol. 34, No. 3/4, 1998, pp. 167–217.

[8] Galiński, C., Lawson, N., and Żbikowski, R., "Delta Wing with Leading Edge Extension and Propeller Propulsion for Fixed Wing MAV," ICAS Paper 2004-1.10.5.

[9] Ahuja, K. K., and Burin, R. H., "Control of Flow Separation by Sound," AIAA Paper 84-2298, Oct. 1984.

[10] Greenblatt D., and Wygnanski I. J., "*The Control of Flow Separation by Periodic Excitation*," Progress in Aerospace Sciences, Vol. 36, Pergamon, Oxford, United Kingdom, 2000, pp. 487–545.

[11] Wojciechowski J., "Active Control of the Boundary Layer on the Laminar Airfoil," *Proceedings of the National Conference with International Participation on Engineering Mechanics (Národni konference s mezinárodni úcasti Inženýrská Mechanika*), 1999.

[12] Rist U., and Augustin K., "Control of Laminar Separation Bubbles," *Proceedings of Von Kármán Institute Lecture Series RTO-EN-AVT-104 "Low Reynolds Number Aerodynamics on Aircraft Including Applications in Emerging UAV Technology"*, NATO Research & Technology Organization, Neuilly-sur-Seine, France, July 2005; Paper 5, 2003.

[13] Rist U., "Instability and Transition Mechanisms in Laminar Separation Bubbles," *Proceedings of Von Kármán Institute Lecture Series RTO-EN-AVT-104 "Low Reynolds Number Aerodynamics on Aircraft Including Applications in Emerging UAV Technology"*, NATO Research & Technology Organization, Neuilly-sur-Seine, France, July 2005; Paper 6, 2003.

[14] Platzer M. F., "The Aerodynamics of Flapping-Wing Micro-Aerial Vehicles," *Proceedings of Von Kármán Institute Lecture Series RTO-EN-AVT-104 "Low Reynolds Number Aerodynamics on Aircraft Including Applications in Emerging UAV Technology"*, NATO Research & Technology Organization, Neuilly-sur-Seine, France, July 2005; Paper 13, 2003.

[15] Jones, K. D., and Platzer, M. F., "Experimental Investigation of the Aerodynamic Characteristics of Flapping-Wing Micro Air Vehicles," AIAA Paper 2003-0418.

[16] Dohring, D., "Der Schub des Schlagenden Flügels und seine Anwendung zur Grenzschichtbeeinflussung: Eeine Experimentelle und Numerische Untersuchung," thesis, Fakultät für Luft—und Raumfahrttechnik, Universität der Bundeswehr München, München, Germany, May 1998, pp. 25–30.

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