JOURNAL OF AIRCRAFT
Vol. 44, No. 3, May–June 2007

Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes should not exceed 2500 words (where a figure or table counts as 200 words). Following informal review by the Editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Experimental Study of a Telescopic Wing Inside a Channel

Cheolheui Han*
Chungju National University, Chungju 143-701, Republic of Korea
and
Kuhyung Ruy† and Seunghee Lee‡
Hanyang University, Seoul 133-791, Republic of Korea

DOI: 10.2514/1.26267

Introduction

WING-IN-GROUND (WIG) effect vehicles use the well-known increase in the lift-to-drag ratio of a wing near the ground. Most WIG vehicles developed or under construction are water based or amphibious. Ollia [1] and Hooker [2] published historical reviews and technological knowledge of water-based WIG vehicles. Rozhdestvensky [3] presented an extensive literature review on water-based WIG vehicle developments.

Conceptual land-based WIG vehicles have also been proposed. These are designed to move faster and to consume less energy than current conventional ground transporters [4–9]. A novel form of high-speed ground transporter, called an aerolevitation electric vehicle (AEV), has been proposed in South Korea [8,9]. This is an over-the-ground-surface tracked WIG vehicle (TWIG) [4], which flies above or within the guideways of the track. It has the advantage of being able to fly faster and in close proximity to the rigid ground surface, as compared to the water-based WIG vehicles. The TWIG has a relatively small wing area (or more precisely, a low aspect ratio) because of the large lift augmentation resulting from the ground effect. However, the small wing area optimized for a design cruise condition requires some special high-lift concepts for takeoff because of the limited capability of flaps [9]. The AEV also requires effective roll control assistance when it runs inside the winding channel-type guideway.

The variable-span morphing (telescopic) wing can change its wing area symmetrically to obtain an optimally performing wing configuration at each given flight condition. It changes its wing area asymmetrically to swiftly control the roll motion of the vehicle. Tidwell et al. [10] compared various morphing strategies while demonstrating the impact of the morphing aircraft on aircraft performance. They showed that planform morphing improves the performance significantly more than that provided by airfoil morphing alone. Blondeau et al. [11] discussed the design and testing of a telescopic wing. They tested a small scale telescopic wing model within the Reynolds number range of 182,000–454,000. It was found in their study that the telescoping wing at maximum deployment did incur a slightly larger drag penalty and a reduced lift-to-drag ratio. Neal [12] used the vortex-lattice method and performed the wind tunnel testing to model the aerodynamics on the morphing aircraft and to evaluate the performance and control of the morphing aircraft maneuvering. Neal et al. [13] designed and tested a fully adaptive aircraft configuration to investigate morphing for multimission unmanned aerial vehicles (UAVs). Wind tunnel tests of five independent planform changes along with independent twist control for each wing showed that different configurations produce minimum drag over a range of flight conditions.

The present study is focused on applying the variable-span morphing wing concept [10–12] to the design of the land-based WIG vehicles [6,9] with effective roll control. Thus, it is the aim of this paper to investigate the basic aerodynamic characteristics of a telescopic wing inside of a channel guideway. The effects of the ground and sidewall (GE and SE) on the steady aerodynamic characteristics of the telescopic wing are investigated by changing the ground height and the gap between wing tips and sidewalls.

Wind Tunnel Testing and Results

Figure 1a shows the geometry of a fabricated telescopic wing model. The wing model consists of a main wing and two extension wings at each wing tip. Extension wings are connected to the main wing with stainless pipes and rods. Telescoping is actuated by using two separate servomotors. Figure 1b shows the specifications of the telescopic wing model placed inside the channel guideway. The thickness of the boundary layer on the ground board and the sidewalls are measured using a boundary layer mouse. The wind tunnel testing is then accomplished by placing the wing model in the region far outside of the boundary layer. The measured turbulence intensity is below 0.2%, and the flow uniformity is 99%. The flow speed is 30 m/s, and Reynolds number based on the chord is 3.1×10^5.

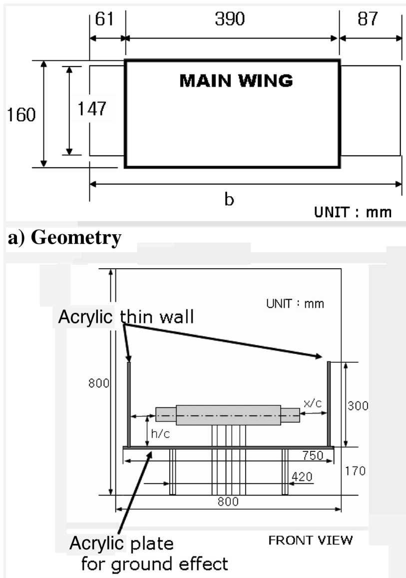
In Fig. 2, the lift-to-drag ratio of the telescopic wing is plotted as a function of the angle of attack ($0 < \alpha < 16$ deg). In the figure, x/c represents the distance from the wing tip to the sidewall. TWE refers to the case with fully extracted extension wings, whereas TWC refers to the case with both extension wings fully contracted. The aspect ratios of the TWC and TWE wings are 3.2 and 3.5, respectively. The small change in the aspect ratio is mainly due to the limitation of mechanical devices used for the wing extension. The following may be concluded from Fig. 2: 1) both the ground and the sidewalls have the effect of increasing the lift-to-drag ratio of both the fully extended and fully contracted wings; 2) the change in the aspect ratio has more significant effects on the lift-to-drag ratio than the other two (ground and sidewall) effects; 3) the TWE achieves larger benefits than the TWC if the wing is placed under either one of the ground or sidewall effects. For example, at $h/c = \infty$, the lift-to-drag ratio of the TWE at $x/c = \infty$ is larger than that TWC at $x/c = 0.2$. For a given condition of and $h/c = \infty$, the lift-to-drag ratio of the TWE at $x/c = 0.1$ is 29.12% larger than that of the TWC $x/c = \infty$. The lift-to-drag ratio of the TWE at $h/c = 0.21$ is 54.7% larger than that of the TWC at

Received 30 June 2006; revision received 31 January 2007; accepted for publication 9 February 2007.

*Assistant Professor, Department of Aeronautical and Mechanical Design Engineering, 123 Geom-Dan Ri, IRyu Myeon, Chungchungbuk Do. Member AIAA.

†Undergraduate Assistant, School of Mechanical Engineering, 17 Haengdang Dong, Seong dong Gu.

‡Graduate Assistant, School of Mechanical Engineering, 17 Haengdang Dong, Seong dong Gu.



a) Geometry

b) Specification of a test model inside a channel

Fig. 1 Geometry and specification of the telescopic wing model.

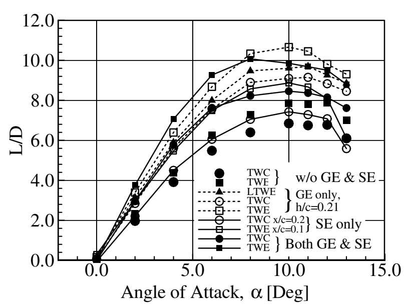


Fig. 2 Lift-to-drag ratio of the telescopic wing.

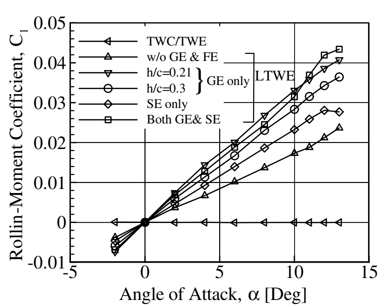


Fig. 3 Rolling-moment coefficient of the telescopic wing.

$h/c = \infty$ (with only 9.375% increase in the TWE wing aspect ratio compared with the TWC wing aspect ratio). It is observed that, when both ground and sidewall effects are combined together and the angle of attack is larger than 8 deg, the measured lift-to-drag ratio of the TWE is smaller than that of the TWE in ground effect alone.

Figure 3 shows the rolling-moment coefficient variations as a function of angle of attack. Both TWC and TWE symmetric wings do not produce any rolling moment. When the wing is influenced by one of the ground and sidewall effects, the high-pressure air trapped in between the lower surface of the wing and the ground (or sidewall) results in the positive rolling moment. The ground has a more significant effect than the sidewalls on the rolling-moment characteristics.

Summary

The aerodynamics of a telescopic wing inside a channel guideway is investigated experimentally. It is found that the change in the aspect ratio produces a larger favorable effect on the lift-to-drag ratio than the ground and sidewalls. It is shown that for a given angle of attack, the extension of the wing tip is not efficient at controlling the rolling moment. However, the current study is restricted to a relatively small change in the aspect ratio, due to the limitation of the mechanical device, which requires further study.

Acknowledgment

This work was supported by a Korea Research Foundation Grant funded by the Korean government (The Ministry of Education and Human Resources Development, Basic Research Promotion Fund) (KRF-2005-206-D00007).

References

[1] Ollia, R. G., "Historical Review of WIG Vehicles," *Journal of Hydronautics*, Vol. 12, No. 3, 1980, pp. 65–76.

[2] Hooker, S. F., "A Review of Current Technical Knowledge Necessary to Develop Large Scale Wing-In-Surface Effect Craft," AIAA Paper 1989-497, 1989.

[3] Rozhdestvensky, K. V., *Aerodynamics of a Lifting System in Extreme Ground Effect*, Springer–Verlag, Berlin, 2000, Chap. 1.

[4] Sancrithi, M., "The Tracked Wing In Ground-Effect," Ph. D. Dissertation, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ, 1983.

[5] Hiemcke, C., "NACA 5312 in Ground Effect: Wind Tunnel and Panel Code Studies," AIAA Paper 1997-2320, 1997.

[6] Kono, T., Kohama, Y., and Matsui, N., "Stability of Guide Way Type Wing in Ground Effect Vehicle," *Proceedings of the Third JSME-KSME Fluids Engineering Conference*, JSME, Tokyo, Japan, 1994, pp. 715–718.

[7] Kohama, Y. P., Kikichi, S., Watanabe, H., Ohta, F., and Ito, T., "Evaluation of the Transportation System in Relation to Environmental Problem," *Workshop on Drag Reduction of Aircraft and Ground Transportation*, Institute of Fluid Science, Tohoku University, Sendai, Japan, 2000, pp. 12–13.

[8] Han, C., Cho, J., Moon, Y. J., Yoon, Y., and Song, Y. K., "Design of an Aerolevitation Electric Vehicle for High-Speed Ground Transportation System," *Journal of Aircraft*, Vol. 42, No. 1, 2005, pp. 93–104.

[9] Cho, J., Han, C., and Yoon, Y., "Aerodynamic Analysis and Design of an Aero-Levitation Electric Vehicle for the High-Speed Ground Transportation System," AIAA Paper 2003-3505, 2003.

[10] Tidwell, Z., Joshi, S., Crossley, W. A., and Ramakrishnan, S., "Comparison of Morphing Wing Strategies Based upon Aircraft Performance Impacts," AIAA Paper 2004-1722, 2004.

[11] Blondeau, J., Richeson, J., and Pines, D. J., "Design, Development and Testing of a Morphing Aspect Ratio Wing Using an Inflatable Telescopic Spar," AIAA Paper 2003-1718, 2003.

[12] Neal, D. A., "Design Design, Development, and Analysis of a Morphing Aircraft Model for Wind Tunnel Experimentation," M.S. Thesis, Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2006.

[13] Neal, D. A., Good, M. G., Johnsto, C. O., Robertshaw, H. H., Mason, W. H., and Inman, D. J., "Design and Wind-Tunnel Analysis of a Fully Adaptive Aircraft Configuration," AIAA Paper 2004-1727, 2004.