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Engineering Notes

Basic Induced Drag Study of the Joined-Wing Aircraft

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Introduction

JOINED-WING configuration was considered for the first time by Prandtl in 1924 [1]. The first attempt to build a joined-wing airplane was undertaken by the Moscow Institute of Aviation in the 1940s, when they redesigned a classic biplane called the Polikarpow Po-2 to create the joined-wing airplane [2]. More recently, the configuration was studied by Wolkovitch [3] and Kroo and Gallman [4] in the 1980s. A project described in [5] was inspired by these works. It consisted of a series of wind-tunnel tests with models of a small transport airplane (see Fig. 1). The most interesting result obtained in this project was that a greater L/D was achieved for negative angles of attack than for positive ones (see Fig. 2). This observation suggests that the front wing of the aircraft in a joined-wing configuration should be located on top of the fuselage and the rear wing at the bottom to obtain greater aerodynamic efficiency. This complicates the design because it is not possible to use the fin as a pylon for the rear wing and fuselages usually are not particularly high. Anyway, this front-high-joined-wing configuration can be considered in cases of small 2–4 seat general aircraft, small transport aircraft, and very large commercial double-deckers. Later, in the 1990s, a few papers on the joined-wing configuration were published [6], most of them focusing on mass-strength analysis.

Assumptions

Recently, the authors returned to the results reported in [5] and ran a numerical sensitivity study, to see if the earlier conclusions could be confirmed and used in a small experimental airplane. Figure 3 defines the joined-wing parameters used for the study.

For the comparison, a numerical model of a small general aviation airplane in a conventional configuration was created and tested. The configuration and main dimensions of the conventional model were based on a Cessna 152 with a wing equipped with a NACA 23012 airfoil.‡ It was assumed that the conventional and joined-wing models should have the same airfoil and wing area (a sum of wing areas in the case of the joined wing), whereas the joined-wing model should have a smaller wing span and total length.

In both cases, induced drag was calculated with the application of the AVL software package.§ AVL code is based on the vortex lattice method. It allows the modeling of a lifting surface together with its wake, so that the influence of the front wing on the rear wing is accounted for to the extent defined by the potential flow model.

Trim drag was neglected, which is a conservative approach, assuming that the elevator is located on the front wing in the joined-wing model. Other drag components were estimated after [7]. This estimation gave a C_{D0} of approximately 0.0325. Therefore, the following formula for the total drag was assumed for both configurations: $C_D = 0.0325 + C_{D\mathrm{induced}}$. This is a simplified approach because details of the design are not accounted for, but it seems justifiable for an initial investigation.

At the beginning of the study, realistic but otherwise arbitrary dimensions were assumed for the joined-wing model. Then, the selected configuration parameters were modified one at a time to explore their influence on L/D. The dimension that gave best result in each step was used as the initial values for the next step. The order of steps was the following: 1) the wings' stagger (A) (it was assumed positive for the front high wing and negative for the front low wing), 2) the wings' sweep angle (γ), 3) the gap between the wings (H), 4) the wings' aspect ratio (b^2/S), 5) the wings' area ratio ($S_{\mathrm{front}}/S_{\mathrm{rear}}$), and 6) the wings' dihedral (Γ).

Finally, calculations were made for the conventional model and compared with the best results obtained for the joined-wing configuration.

Results

Figures 4–9 show the results of each modification step, whereas Fig. 10 shows a comparison of the conventional and joined wings.

An increase of L/D due to the positive upper wing stagger does exist (Fig. 4); however, it appears to be smaller than expected (only half of a unit between the front-high-wing and rear-high-wing configurations). At the same time, the gap between the wings revealed a similar level of influence (Fig. 6). Therefore, it is still not clear which configuration can provide greater $(L/D)_{\mathrm{max}}$, because the negative influence of the rear high wing can be balanced by installing the rear wing at the top of vertical stabilizer, whereas the front-high-wing configuration can only be installed on the top of the fuselage. However, it should be noted that, for higher angles of attack, the impact of positive stagger increases. This may be due to the fact that the real gap between the wings grows with the angle of attack in the front-high-wing configuration, whereas it decreases in the rear-high-wing configuration. This effect would probably even be magnified if viscosity and separation were included in the study.

Other modifications also gave interesting results. The difference between wing areas has almost no influence on L/D (Fig. 8), which is good because it allows for the modification of the neutral point of the stability location without a significant impact on performance. Wing sweep seems to provide maximum L/D for approximately 20–25 deg (Fig. 5). Opposite wings' dihedrals have a negative influence on the L/D (Fig. 9) with one exception: for extreme dihedrals (wings touching each other with almost no wing tip plates), induced drag rapidly decreases. This effect, however, was not explored in the present study, and so it is not clear if it is a real effect.

Finally, a comparison of the conventional and joined wings (Fig. 10) revealed the advantage of the joined wing for high angles of attack (greater than 6 deg), at which induced drag becomes important, and the advantage of the conventional configuration for low angles of attack. This result was obtained for the front-high-wing version of the joined wing. The calculated $(L/D)_{\mathrm{max}}$ is 13% greater

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‡Jane's All Worlds Aircraft, 1985–1986.

§Data available online at http://web.mit.edu/drela/Public/web/avl/ [retrieved 27 May 2009].

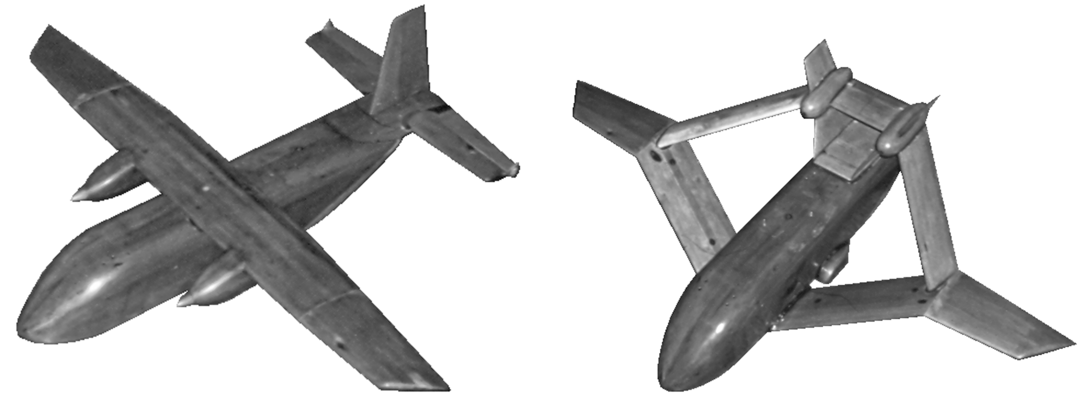

Fig. 1 Examples of models tested during the project described in [5].

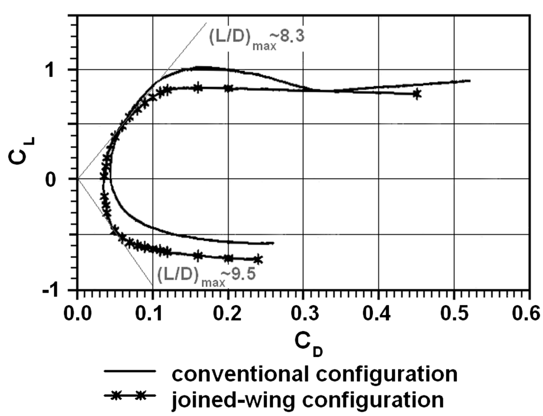

Fig. 2 Comparison of the balanced flight polars of the models shown in Fig. 1.

for the joined wing and is achieved at a higher angle of attack (close to 12 deg). An important limitation of the present study was that separation phenomena were neglected. Therefore, the issue of $(L/D)_{\max}$ cannot be positively resolved for the joined-wing configuration because it was achieved near the possible stall angle. However, it should be mentioned that elevator deflection decreases the total lift if installed on the rear horizontal stabilizer whereas it increases it if installed on the front wing, and so the advantages of the joined-

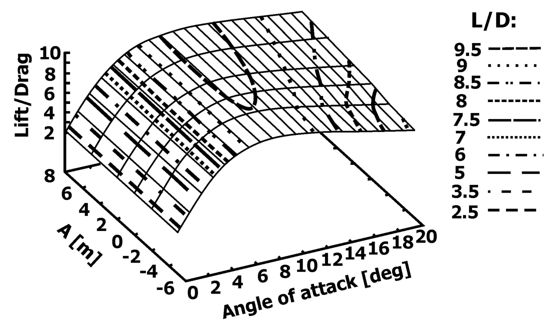

Fig. 4 Influence of the wings' stagger.

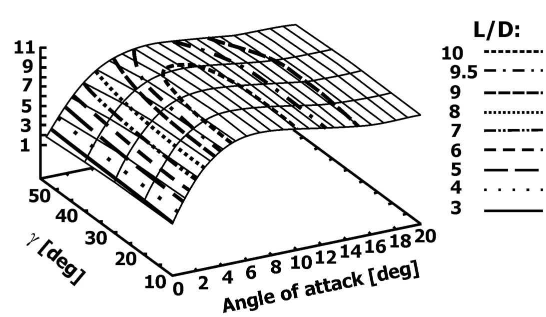

Fig. 5 Influence of the wing sweep ($\gamma_{\text{rear}} = -\gamma_{\text{front}}$).

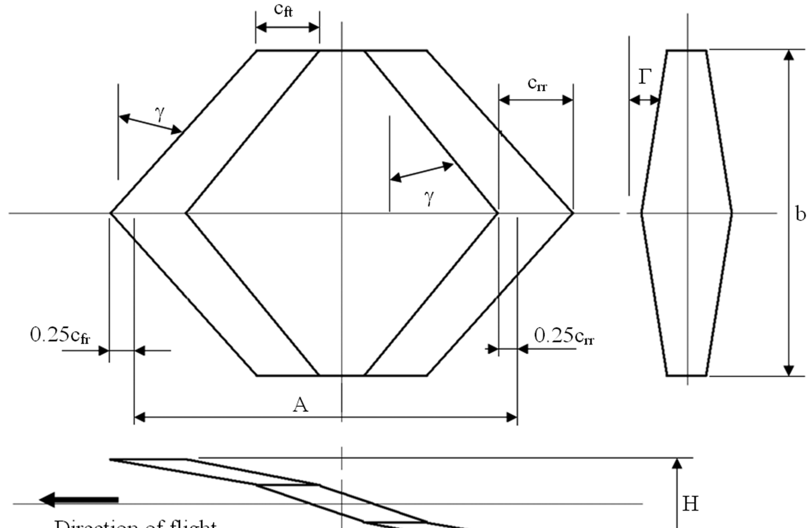

Fig. 3 Parameters analyzed in the present paper.

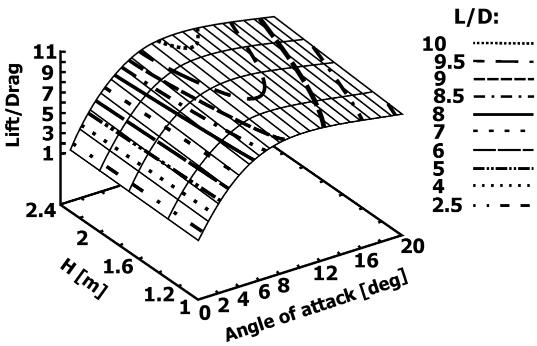

Fig. 6 Influence of the gap between the wings (H).

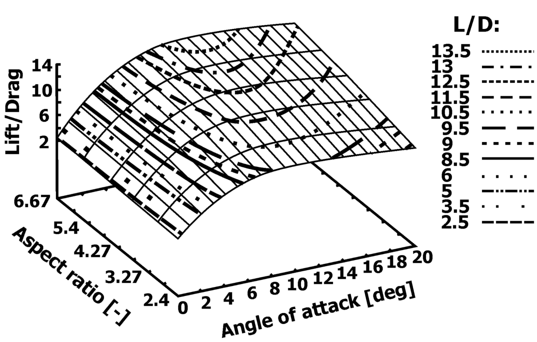

Fig. 7 Influence of the wing aspect ratio.

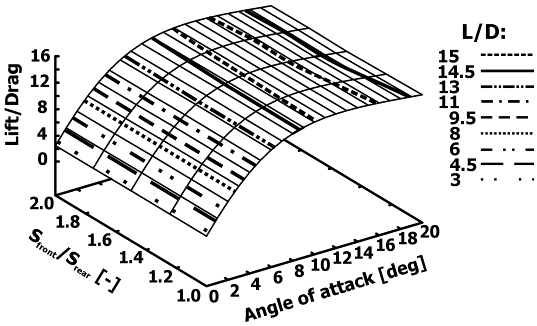

Fig. 8 Influence of the wing area ratio ($S_{\mathrm{front}}/S_{\mathrm{rear}}$).

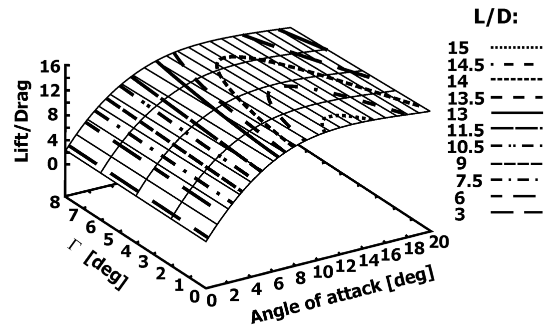

Fig. 9 Influence of the wing dihedral ($\Gamma_{\mathrm{rear}} = -\Gamma_{\mathrm{front}}$).

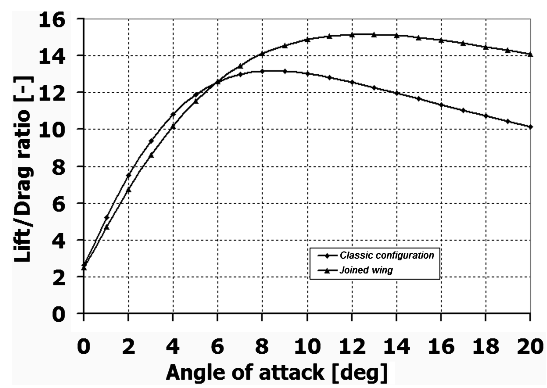

Fig. 10 Comparison of the conventional and joined-wing configurations.

wing configuration should be more apparent after trim conditions are accounted for.

Conclusions

The study proved that positive stagger is more aerodynamically efficient for a joined-wing aircraft if the gap between the wings is the same. However, the possibility of increasing the gap by installing the rear wing at the top of the vertical stabilizer does not allow the recommendation of one configuration over the other. The presented results seem to be interesting and justify further investigation in greater detail with the application of more sophisticated methods.

References

[1] Prandtl, L., "Induced Drag of Multiplanes," NACA TN 182, 1924.

[2] Makarov, I. W., *Lietalnyie Apparaty MAI*, Izdatielstwo MAI, Moscow, 1994, pp. 64–65.

[3] Wolkovitch, J., "The Joined Wing—An Overview," *Journal of Aircraft*, Vol. 23, No. 3, March 1986, pp. 161–178. doi:10.2514/3.45285

[4] Kroo, I., and Gallman, J., "Aerodynamic and Structural Studies of Joined Wing Aircraft," *Journal of Aircraft*, Vol. 28, No. 1, Jan. 1991, pp. 74–81. doi:10.2514/3.45994

[5] Galinski, C., "Results of Testing of Models of Joined-Wing Utility Class Aircraft," Society of Automotive Engineers Paper 921013, April 1992.

[6] Gallman, J. W., "Structural Optimization for Joined-Wing Synthesis," *Journal of Aircraft*, Vol. 33, No. 1, Jan. 1996, pp. 214–223. doi:10.2514/3.46924

[7] Stinton, D., *The Design of the Aeroplane*, Blackwell Science, Oxford, 2001, pp. 207–217.