Aerodynamic Design of High-Performance Biplane Wings

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Theme

ALTHOUGH biplanes were quite popular during the early days of aviation, they had virtually disappeared from service by the mid-1930's. The biplane seemed to be plagued by inherently high drag and low maximum lift coefficient. The purpose of the present study was to re-examine the reasons for the biplane's decline. It was found that for any practical biplane configuration, it is possible to design a wing system which has a much lower weight per unit area and which has essentially the same maximum useable lift coefficient as that of a comparable, well-designed, monoplane wing, in either clean or flapped configurations. Improvements in the design of fairings permit large drag reductions, relative to the earlier designs.

Because of these improvements, it is possible to design a biplane whose performance is superior, for some applications, to that of a well-designed monoplane. These applications are those for which excellent low-speed maneuverability, good short-field performance, good load-carrying ability, low cost, and rugged construction are of primary importance.[1]

Content

If a biplane wing system is to develop a high $C_{L\max}$, both wings must stall nearly together. A method presented by Fuchs was used to identify those configurations for which a good stall match could be obtained. Each wing is idealized in this method as a single horseshoe vortex, with the bound part of each vortex located at the center of pressure. Satisfactory stall match was defined as a ratio of leading wing to trailing wing C_L equal to unity at an assumed $C_{L\max}$ for the combination. Some results of this analysis are given in Fig. 1, and some nomenclature is defined in the sketch. The airfoil chord lines are parallel; results of this study showed no advantage to be gained from the use of decalage. The geometric stagger angle σ for best stall match is quite insensitive to the gap/chord ratio, and it decreases as the aspect ratio increases. The best stall match always corresponds to small values of β, the aerodynamic stagger angle.

The chordwise variation in vertical velocity induced by one airfoil upon the other corresponds to a local curvature of the flow. Since within the framework of thin airfoil theory, this effect is identical to the effect of a change in the mean camber line, it will be referred to as induced camber.

Data for NACA airfoils of the four- and five-digit series show increases in the maximum section lift coefficient $C_{\ell\max}$ with increasing camber, up to an ideal C_ℓ of approximately 0.5. The usual sense of induced camber in a biplane is to reduce the effective camber of the airfoil, thus increasing the severity of the nose suction peak at a given C_ℓ and reducing $C_{\ell\max}$.

The flow about an airfoil may be divided into the mean velocity vector, Q (including the mean value of the induced flow parallel to the chord), and the perturbation velocity components u and v, parallel and normal to the chord line. The condition of tangential flow at the airfoil boundary may be approximated as

$$\alpha + (v_k/Q) = (\mathrm{d}y/\mathrm{d}x) - (v_i/Q) \qquad (1)$$

where $y(x)$ is the mean camber line, α is the local angle of attack, k refers to velocity components induced by the vortex distribution of the given wing at the given spanwise station, and i refers to the induced flowfield. The induced downwash has the same effect as an increase in the local camber line slope.

An analysis presented by Millikan[2] has been used to calculate effects of induced camber. Millikan uses a horseshoe vortex and a vortex pair to represent each wing. Some results in the form of chordwise and spanwise average values are presented in Fig. 2, where $(\Delta C_L)_c$ is the increment in C_L caused by induced camber, and C_{Li} is the lift coefficient of the inducing wing. These results show that induced camber is almost exclusively a two-dimensional effect, since it is quite insensitive to aspect ratio. It is largest near $\beta = 0$ and decreases as $|\beta|$ or gap/chord are increased. Effects of gap and stagger on measured values of $C_{L\max}$ for biplanes are in reasonable agreement with these results, if $(\Delta C_L)_c$ is interpreted as an estimate of the change in $C_{L\max}$.

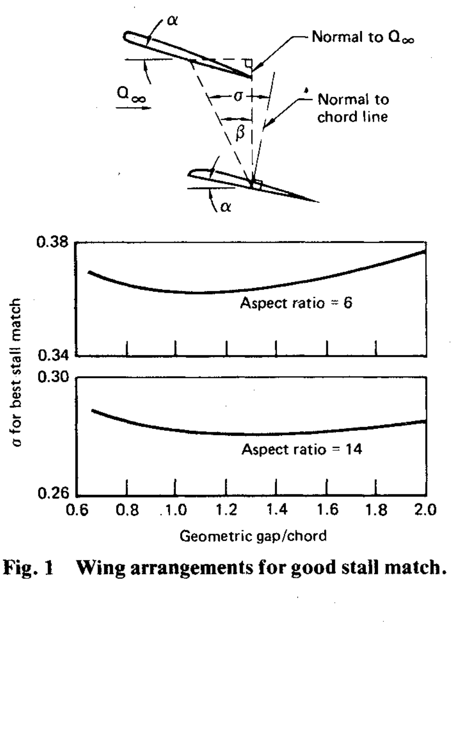

Fig. 1 Wing arrangements for good stall match.

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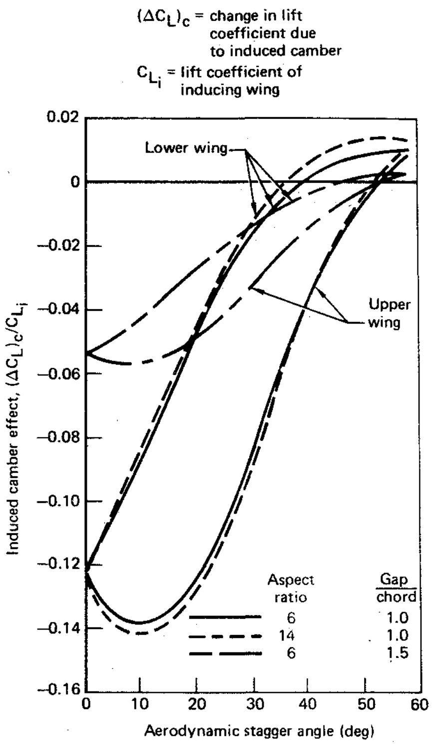

Fig. 2 Influence of wing arrangement on induced camber.

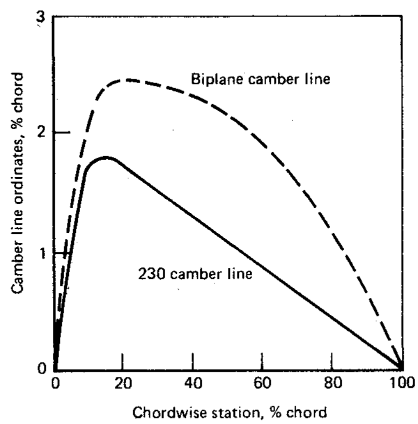

Fig. 3 Comparison of biplane mean camber line with original 230 mean camber line.

A design procedure is proposed in which a known airfoil section is selected. The gap/chord ratio and stagger angle are chosen to provide a good stall match and structural efficiency. The induced flowfield is then calculated for a C_L for which the C_ℓ of the most heavily loaded section equals $C_{\ell\max}$. The camber line of this section is chosen to have the same chordwise vortex distribution as that of the two-dimensional airfoil, i.e.,

$$(\mathrm{d}y/\mathrm{d}x)_b = (\mathrm{d}y/\mathrm{d}x)_{2-D} - (-v_i/Q) \qquad (2)$$

This camber line is used for the full span of both wings. The process does not require iteration, since the spanwise lift distribution is not changed. It can be extended in a straightforward manner to separate optimization of upper and lower wings, or to spanwise camber-line tailoring.

The method of Blackwell was chosen to calculate the induced flow. This method, in which the lifting surface is represented by a distribution of horseshoe vortices, has been shown to give satisfactory predictions of lift curve slope and induced drag factor for elliptic and rectangular wings of moderate aspect ratio.[1]

Changes in the mean camber line of the parent airfoil will, in general, change its drag characteristics. The method for computing airfoil drag used in this study is similar to that described by Spence and Beasly. Their method was programed as an iterative procedure in which the potential flow and the boundary-layer development were matched, and has been shown to give accurate results for cruise of conventional airfoils.[1]

Calculations have been made for two configurations, based on the NACA 23012 airfoil section. One wing arrangement consisted of equal, rectangular wings of aspect ratio = 7.11, geometric gap/chord = 1.138, and geometric stagger/chord = 0.539. The value of $C_{L\max}$, 1.30 in this case, was defined as the C_L for which C_ℓ first reached $C_{\ell\max}$(1.51 at $Re_c = 3.5 \times 10^6$) at the most heavily loaded station of either wing. The design procedure was applied only at this station. The biplane airfoil has significantly more camber than the 230 camber line from which it was derived; see Fig. 3. The computed increase in C_d is 0.0001, indicating that no drag penalty is incurred by the increased camber.

Similar calculations were made for a configuration having aerodynamic gap/chord = 1.0 and stagger/chord = 0, a configuration for which the unfavorable induced camber is quite large. Structural analyses indicated that there are no advantages to be gained by designs which employ smaller gap/chord ratios. There was no significant increase in C_d at cruise C_ℓ. Apparently the gap/chord and stagger can be chosen to satisfy stall match and structural requirements, and the airfoil section can then be designed to compensate for the resulting induced camber.

The preceding ideas have been extended to the case of biplanes having simple flap designs. Using conservative assumptions, a $C_{L\max}$ is predicted to be essentially the same as that for a monoplane wing having the same type of flap.

A design study was carried out, using results of the previous analysis, in which a biplane and a monoplane were compared under the ground rules of equal gross weight (8000 lb), the same engine, and the same equivalent parasite area for computing the drag of the fuselage, tail surfaces, and landing gear. It was concluded that: a) the biplane wing weight, including bracing, should be less than 60% of that for a comparable monoplane. b) The biplane bracing system can be streamlined and faired so that the resulting drag penalty is small; 2) A biplane can have superior slow-speed maneuverability and short field performance. d) The biplane has a greater payload, which offsets its slightly lower cruise speed, giving it greater cargo carrying capacity.

References

[1]Addoms, R. B., "Aerodynamics and Structural Design Considerations for High Lift Biplane Wing Systems," Ph.D. thesis, Nov. 1971, Department of Mechanics and Structures, University of California, Los Angeles, Calif.

[2]Milikan, C. B., "An Extended Theory of Thin Airfoils and its Application to the Biplane Problem," Rept. 362, 1930, NACA.