Minimizing Induced Drag with Geometric and Aerodynamic Twist on a Wing of Arbitrary Planform

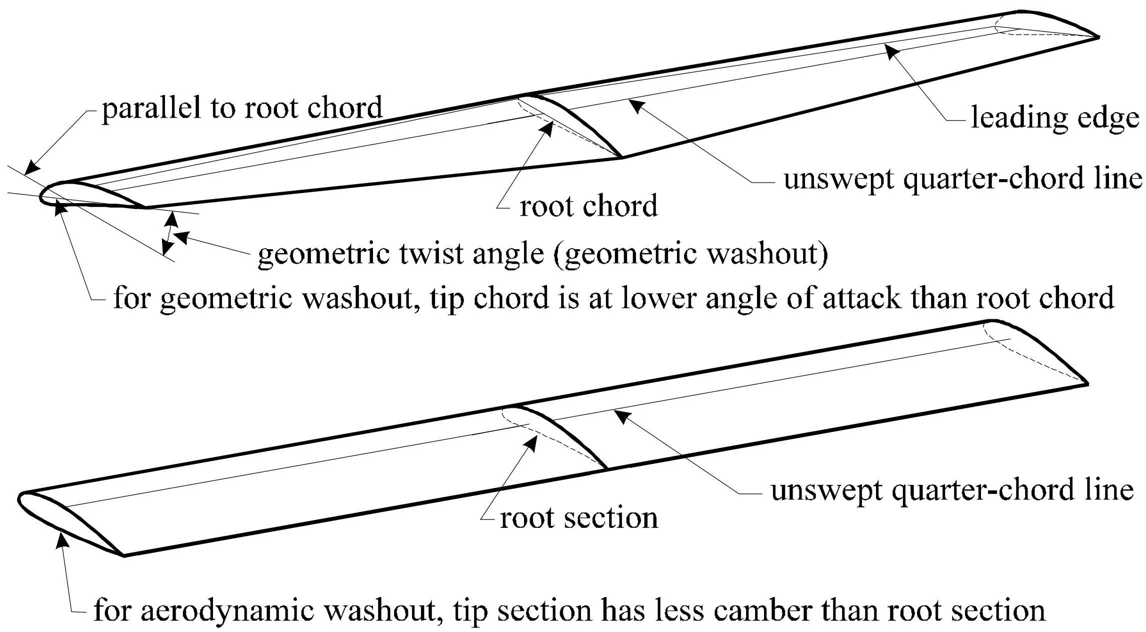
Warren F. Phillips
Department of Mechanical and Aerospace Engineering
Utah State University
Logan UT 84322-4130

Project Overview

Dr. Warren F. Phillips has recently developed and published a method for reducing induced drag through spanwise circulation control [2,* 3, 4, 5 and 6]. It has been shown that, for an unswept wing of any planform shape, there exists an optimum distribution of geometric and/or aerodynamic twist that will result in the production of induced drag at the same minimum level as that produced by an elliptic wing of the same aspect ratio but with no geometric or aerodynamic twist. Utah State University has filed a patent application for technology based on this discovery. The technology has the potential for reducing induced drag by up to 16 percent, depending on aspect ratio and taper ratio. Since wing twist is very easily implemented, even as a retrofit to existing aircraft, this development has the potential for significant fuel savings. The fuel savings associated with minimizing induced drag is an obvious benefit in both civilian and military applications.

* This paper received an award as the "2003 AIAA Best Paper" awarded by the AIAA Atmospheric Flight Mechanics Technical Committee.

Implementation of Fixed Wing Twist to Minimize Induced Drag for a Single Design Lift Coefficient

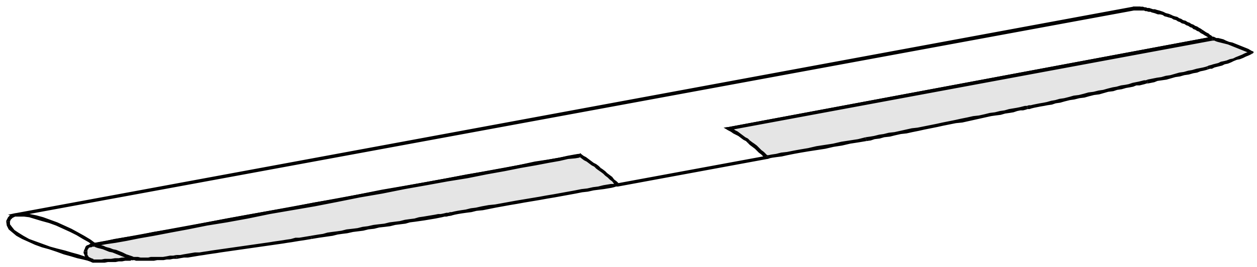


Dr. Phillips has recently developed and published a method for minimizing induced drag through spanwise circulation control. In its simplest form, the method can be used to minimize the induced drag acting on a wing of any planform shape through the implementation of either geometric or aerodynamic twist, which is commonly called *washout*. To minimize the induced drag, the geometric and/or aerodynamic twist must vary along the span of the wing in a special way that depends on the planform shape of the wing. The total amount of twist required to minimize the induced drag is directly proportional to the lift coefficient developed by the wing,

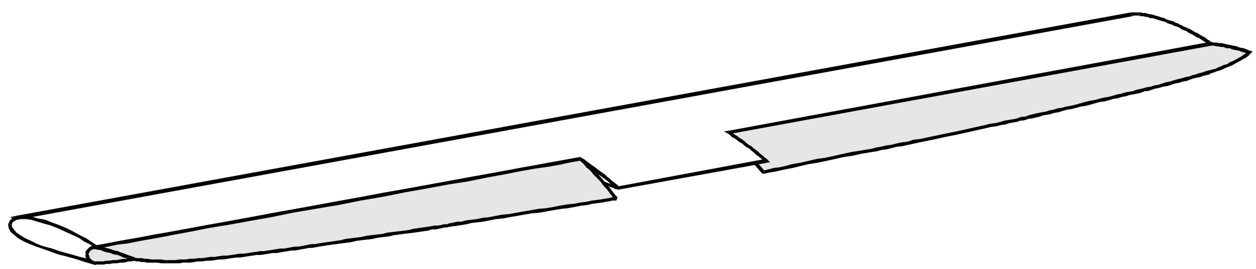
$$C_L = \frac{Wn}{\frac{1}{2} r V^2 S_w}$$

where W is gross weight, n is load factor (normal acceleration, g), r is air density, V is airspeed, and S_w is wing area. With proper twist implementation, a wing of any planform shape can be designed to produce the same minimum induced drag as an elliptic wing of the same aspect ratio, operating at the same lift coefficient. Such twist-optimized wings are much simpler and less costly to manufacture than an elliptic wing. Proper twist implementation can reduce the induced drag acting on a lifting wing by as much as 15 percent. In cruise configuration, the induced drag is typically about 50 percent of the total drag acting on the airplane, and in landing configuration, the induced drag can be as much as 90 percent of the total drag. Thus, implementation of optimum twist can significantly reduce the total drag on an airplane. However, if spanwise circulation control is implemented solely through the use of fixed twist, the wing can only be optimized for one design lift coefficient. This means that, if the airplane is designed to operate over a wide range airspeed and/or gross weight, the implemented twist must be a compromise for the range of lift coefficients that will be encountered during different mission phases.

Implementation of Twisterons to Minimize Induced Drag for a Broad Range of Lift Coefficients



a) Twisteron configuration with no flap deflection and washout set to minimize induced drag at $C_L = 0.6$.



b) Twisteron configuration with 15° flap deflection and washout set to minimize induced drag at $C_L = 1.4$.

To avoid the limitations associated with minimizing induced drag by means of fixed wing twist, it is possible to implement the twist distribution required to minimize induced drag by employing full-span trailing-edge flaps that can be twisted along their length to produce a continuous spanwise variation in zero-lift angle of attack. For a rectangular wing little twist is required in the region near the root. Thus, the geometry shown above can be used to closely approximate the aerodynamic twist needed to minimize induced drag. These control surfaces can also be deflected symmetrically as flaps and/or asymmetrically as ailerons to establish roll control. In the following discussion the twisting control surfaces shown above are referred to as *twisterons*. The advantage of using twisterons to establish the spanwise circulation control needed to minimize induced drag is that the twist can be varied with the parameters that affect the lift coefficient. This allows us to maintain minimum induced drag over a wide range of operating conditions. The aircraft can be fitted with sensors to determine gross weight, normal acceleration, air density, and airspeed. The sensor outputs can be used in an active feedback control system to maintain minimum induced drag over a wide range of operating conditions. Because most of the parameters that affect the lift coefficient also affect the required elevator deflection, the induced drag can be nearly minimized by properly linking the twisteron deflection to the elevator deflection. Utah State University has filed a United States Patent Application for the twisteron technology.

Utah State University Experimental Aircraft with Operational Twisterons

Utah State University has designed, built, and flown an experimental UAV with operational twisterons. This electric powered aircraft has a wingspan of 10 feet, a gross weight of 35 pounds, a top speed of 100 miles per hour, and was designed for 7-*g* maneuvers. In the design and development of this aircraft a beneficial side effect of twisteron deflection was discovered. The change in wing circulation that is brought about by twisteron deflection produces a favorable change in the downwash induced on an aft tail, which reduces the elevator deflection needed to trim the aircraft over a wide range of airspeed, gross weight, and normal acceleration. This produces a further reduction in total aircraft drag, beyond that provided directly by the twisterons. For the aircraft shown above, this resulted in a total drag reduction of 20 percent during some mission phases.

References

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[3] Phillips, W. F., Alley, N. R., and Goodrich, W. D., “Lifting-Line Analysis of Roll Control and Variable Twist,” *AIAA-2003-4061*, (June 2003).

[4] Phillips, W. F., *Mechanics of Flight*, Wiley, New York, (January 2004).

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[6] Phillips, W. F., Alley, N. R., and Goodrich, W. D., “Lifting-Line Analysis of Roll Control and Variable Twist,” *AIAA Journal of Aircraft*, Vol. 41, No. 2, (April 2004, Tentative).