magnitude increase in Reynolds number capability over existing tunnels. As a national facility, the NTF will meet the high-Reynolds-number testing needs of NASA, the U.S. Department of Defense, other government agencies, the aerospace industry, and the scientific community.

For background information see REYNOLDS NUMBER: WIND TUNNEL in the McGraw-Hill Encyclopedia of Science and Technology.

[ROBERT A. KILGORE]


Wing

Recently a number of different aircraft have been developed with small, nearly vertical surfaces mounted at the wing tips (Fig. 1). These surfaces significantly decrease the drag or air resistance of the airplanes, which allows reductions in engine power and fuel consumption. These improvements provide increases in the range or payload of the airplanes. Since the shape and basic aerodynamic action of these surfaces are similar to those of wings, they are called winglets.

Function of vertical surfaces. The lift or upward force on a wing is produced by air pressures which are less than atmospheric above the upper surface and greater than atmospheric below the lower surface. At the wing tip the reduced pressures above the wing draw the air inward, while the increased pressures below the wing force it outward (Fig. 2). These cross flows persist behind the wing, where these effects, together with a downflow behind the wing and an upflow beyond the wing tip, combine to cause a vortex or swirling flow behind each wing tip. These vortexes are similar to small tornadoes. Substantial so-called induced drag is associated with these vortexes; at the usual airplane cruise flight conditions it is about 40 to 50% of total airplane drag. It has been recognized for many years that vertical surfaces at the wing tips should decrease the cross flows at the tips, lessen the strength of the resulting vortexes, and thus reduce the drag. As early as 1897 a patent was obtained by F. W. Lanchester for vertical surfaces at the wing tips. During the period from about 1925 to 1955 a number of wind tunnel experiments were conducted on various such surfaces, called end plates. However, all of these experiments indicated very little or no reduction in drag at airplane cruise conditions.

Design of winglets. Research on winglets was initiated at the Langley Research Center of the National Aeronautics and Space Administration in 1974. In contrast to the simple flat end plates tested earlier, winglets are designed with the same attention to detail as is used in designing wings. In particular, as for wings, the surfaces have specially designed airfoil shapes. (Airfoils are the cross sections of the wing or winglet parallel to the flight direction and perpendicular to the span or length of the surface.) For wings the airfoils are “cambered,” that is, the curvature of the upper surface is greater than that of the lower. With such a shape, lift is produced more effectively. For winglets mounted above the wing tips (Fig. 1) the airfoils are cambered such that the inner sides have more curvature than the outer sides, as shown in Fig. 3. Further, as for wings, the winglets usually have relatively high aspect ratios, that is, the ratios of the length or span dimensions to streamwise or chord dimensions (Fig. 1).

Action of winglets. The action of the winglets is illustrated in Fig. 3. Because of the camber of the winglet airfoil, the winglet produces a significant side force directed inward. This inward force results in an outward redirection of the airflow behind the winglet in the same manner that the upward force on a wing causes a downward flow behind the wing. This redirection of the flow reduces the inflow behind the tip, resulting in a decrease in the strength of the associated vortex downstream of the tip and a reduction in the drag. Theoretical analyses and experiments indicate that the effectiveness of winglets in reducing induced drag is approximately proportional to the heights of the surfaces. However, increasing the height increases the aerodynamic loads imposed on the winglets and wing, which then require stronger, heavier structures to withstand these added loads. Analyses have indicated that a winglet height approxi-

Fig. 1. Winglets on Gates Learjet model 28. (Gates Learjet Corporation, Wichita)

Fig. 2. Diagram of airflow causing vortex formation behind a wing tip. View is looking downward from above the wing tip.
ultimately equal to the tip chord provides the most satisfactory compromise between the favorable aerodynamic effect and the adverse structural problem.

Positioning of winglets. For a given winglet height a winglet extending downward from the tip is almost as effective as the upward-extending version shown in Fig. 1. For such an arrangement the winglet airfoil is cambered with the greatest curvature on the outer surface, since the winglet in this position must reduce outflow behind the wing (Fig. 2). However, for an airplane with the wing mounted in a low position with respect to the fuselage, a lower winglet of the desired length would impact the ground during landing and takeoff. Therefore, for such airplanes the primary winglet must extend upward. For a wing mounted high on the fuselage, a downward-extending winglet is practical. Also, a winglet combination incorporating a rearward-located upper winglet and forwardly placed lower winglet may reduce the drag by a somewhat greater amount than a single upper or lower winglet. However, the aerodynamic gain may not justify the added cost and structural weight.

At the high subsonic flight conditions of jet transports and business jets, local regions of supersonic flow develop on the upper surface of the wing and the inner side of winglets mounted above the wing. When these regions are superimposed, a local shock wave which develops at the juncture of the two surfaces may cause a significant drag increase. To reduce or eliminate this problem, the upper winglets on such airplanes are placed rearward on the wing tip as shown in Fig. 1. Also, this problem is reduced by inclining the winglets outward from the vertical slightly and providing fairings at the junctures of the wing and winglets (Fig. 1).

Effectiveness of winglets. Extensive wind tunnel investigations of winglets on a number of different airplane configurations have indicated that these surfaces reduce induced drag by 10 to 20%, depending on the specific design of the airplane wing and the flight conditions. These improvements result in reductions of total airplane drag at cruise conditions of 4 to 8%. Further, these wind tunnel tests have indicated no adverse airplane stability or control problems associated with adding winglets. Winglets are now incorporated in the

Rutan Varieze, the Israeli Aircraft Industries cargo aircraft, and the Gates Learjet model 28 (Fig. 1). They are part of the design of the forthcoming Grumman Gulfstream III. Also, winglets will be tested in flight on the U.S. Air Force KC-135 in 1979. If flight tests confirm the wind tunnel results, these surfaces will be retrofitted to most of the Air Force fleet of these aircraft. Further, wind tunnel tests of winglets on several commercial and military jet transport airplane configurations are continuing.

For background information see AIRFOIL; AIRPLANE; WING in the McGraw-Hill Encyclopedia of Science and Technology.

[BIBLIOGRAPHY]

Wood preservation

Due to their toxic nature, all of the commercial wood preservatives presently used in the United States are effective in preventing attack by microorganisms. Most are classified as broad-spectrum preservatives, that is, they are effective against several different types of living systems. Because of environmental concerns and because prevention of wood decay is necessary to extend timber resources by increasing their service life, alternative methods of wood preservation which are not based on broad-spectrum toxicity are presently under investigation. Such nonconventional treatments are in the experimental stage. However, significant developments in the last year or two have shown the feasibility of these approaches.

Over the years, several nonconventional approaches for wood preservation have been reported. Research has been conducted on heat treatments, irradiation, polymer composites, and thiamine destruction, but none has been commercialized.

Chemical modification. One very promising approach is chemical modification of wood cell-wall components. Microorganisms, such as fungi, attack wood in the same way that the human stomach and intestine attack food. Both secrete enzymes which break down the chemical structure of the food source into small, soluble units of nutrients. These enzyme reactions are very specific, so that if the food source or substrate is chemically changed, this digestive-type action can no longer take place.

The wood components that the fungi attack for food are cellulose and hemicelluloses contained in the cell wall. If these components have chemicals covalently bonded to them, the highly selective enzyme-substrate reaction is blocked. The chemicals used for substrate modification need not be toxic to the microorganism, because their effectiveness derives from rendering the substrate unrecognizable as a food source to support microbial growth.

By far the most abundant reactive chemical sites in wood are hydroxyl groups on the cellulose,