7.8.8 Winglet Design

As Raymer describes, a winglet is in the crossflow induced by the wingtip vortex, and produces a small component of forward thrust. This is analogous to a sailboat sailing close-hauled, where the sails are at an incidence to the fore-and-aft axis of about 15^0, and for which the apparent wind vector could be as small as 25^0 to the longitudinal axis of the boat. The sails produce a forward thrust component on the boat which drives it through the water. The aerodynamic side force is balanced by the hydrodynamic lift on the keel or centerboard.

At the wingtip of an airplane the crossflow angles are much smaller, so the ratio of thrust to sideforce is also smaller. The inflow angle in Fig. 7.8.8.1 is exaggerated. A small change in the angle of the net force vector will turn winglet thrust into drag. There is corresponding outflow angle on the underside of the wing, and some airplanes, such as the A310 and Boeing 737-Max, also have a downward projecting winglet.

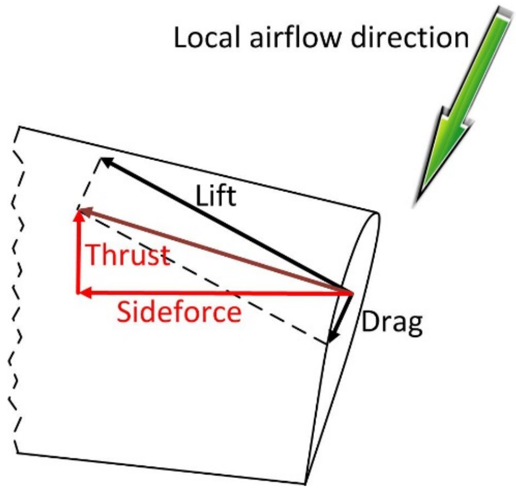

Fig. 7.8.8.1 Winglet Upper Surface Force Vectors

Although winglets can be added to an existing design, this can be fraught with difficulty. If the existing wing design is optimal, then bolting on winglets will significantly affect the flow, especially over the wing upper surface near the wingtips. The flow without winglets is already being accelerated over the upper surface, and the winglets produce additional flow acceleration. This could cause the flow near the wingtips to go supercritical (i.e. supersonic) earlier than on other wing sections, possibly producing a significant change in drag or aircraft handling qualities at high speed. An additional problem is that of boundary layer buildup at the intersection of the wing and winglet, and great care must be taken in the design of the fillet at the intersection of the two lifting surfaces, otherwise the flow will separate unexpectedly. The best approach is to design the wing and winglets as a single aerodynamic shape, but that might involve some structural changes that are prohibitive from a cost perspective. Failing that, the outer wing sections should be redesigned to accommodate the winglet.

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As Raymer points out, there is increasing evidence that a winglet design that consists of a large-radius arc from the front view (or “blended winglet”) will minimize the aerodynamic problems described above, and produce the greatest drag reduction. The radius of the arc is of about the same magnitude as the wing chord at that location. For the Boeing 737/757/767 the winglet designs produced by Aviation Partners Inc. are claimed to produce up to 6% drag reduction, improved takeoff performance, lower noise and emissions, plus enhanced appearance.

On the other hand, winglets for the 737MAX have small corner radii. It must be assumed that the outer wing section was designed for the presence of winglets, so that the integrated design was able to avoid the problems described above.

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