FULL-SCALE IN-FLIGHT PRESSURE MEASUREMENTS ON A WINGLET FITTED TO AN AS-W 20

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ABSTRACT

In order to gain more insight into the effectiveness of a custom-built winglet on an AS-W 20, full-scale in-flight pressure measurements were performed. A 96-port scannivalve was used to measure pressures at 78 positions on the surface of a specially built hollow winglet. Data was recorded on a data logger. It was found that a change of lift coefficient from 0.43 to 0.6 caused a very substantial change in the pressure distribution on the inner surface of the winglet. There was also substantial spanwise variation in the pressure near the leading edge of the winglet, leading one to conclude that the twist angle is probably quite far from optimum.

In order to evaluate the validity of a three dimensional panel method to this kind of problem, the experimental results were also compared to a CFD (Computational Fluid Dynamics) analysis. Although good agreement was found at one spanwise station, experimental and computational results generally differed substantially, even when wake relaxation was used. It is concluded that satisfactory computational results for this kind of problem can probably only be obtained from a full field method, like an Euler code.

1. Introduction

Winglets have by now become an accepted part of modern gliding. Even though at least one notable designer has expressed concern about this evolution in glider design [1], winglets are now widely used. It is notable that even this particular designer is using them now. The advantage to be gained from winglets is well understood, following pioneering work by Whitcomb [2]. Although Whitcomb's research was aimed at transport aircraft flying at high subsonic Mach numbers, the advantages are also valid for gliders. Somewhat surprisingly though, transport aircraft cruise at quite high lift coefficients, typically in the order of 0.5 to 0.6 [3]. To place these figures in gliding perspective, they correspond to speeds of 120 to 110 km/h for an unballasted AS-W 20. It is therefore relatively easy to improve the glider's low speed performance significantly, because winglets were originally developed for these relatively high lift coefficients,

It became clear at a very early stage of sailplane winglet development that the low speed advantages are generally offset by high speed losses. The art/science of winglet design is thus to improve low speed perfor-

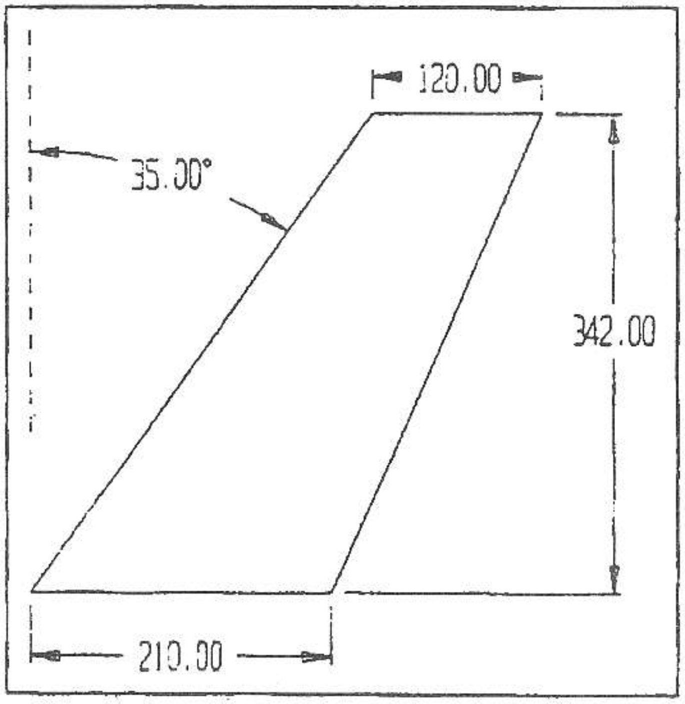

FIGURE 1. Dimensions of the winglet.

mance, while limiting the high speed losses. [4] It is necessary for a winglet to have both 'toe-out' and twist to function most effectively. In order to select the correct toe-out and twist, it is necessary to evaluate the performance of an existing winglet. It can be deduced from the competitive performance of the glider used for this study (an AS-W 20 F), that the winglet fitted to it is reasonably effective. In order to gain a better understanding of this particular winglet, it was decided to perform surface pressure measurements. It would have been ideal to perform these measurements in a wind tunnel, but only if at least a full half-span of the wing could be mounted in the working section. It was decided at an early stage that inaccuracies resulting from low Reynolds numbers virtually necessitated full-scale testing. The unavailability of a wind tunnel with at least a 9 meter wide working section made it essential to perform the measurements in flight.

2. The winglet

The dimensions (in mm) of the winglet studied in this investigation are given in Figure 1. The winglet also has 5° of toe-out and 4° of twist. The trailing edge of the root of the winglet is aligned with the trailing edge of the wingtip. A Wortmann FX-60-126 profile is used. These winglets are normally constructed from glassfibre/epoxy over a polystyrene core. In order to incorporate the pressure ports on the surface of the winglet, a hollow one was built, in molds taken from the original winglet.

3. Experimental setup

Each of the 78 surface orifices on the winglet had a diameter of about 0.5 mm, and had a short (about 5mm) 1 mm outside diameter aluminum tube epoxied to the inside of the winglet surface. PVC tubes were connected to these Aluminum tubes, and exited the winglet through two holes at the root. Two corresponding holes were cut in the wingtip, to allow these PVC tubes to be connected to two bundles of silicon tubing which were in turn connected to a 96-port scannivalve, mounted inside the wing, about 1.5 m from the tip.

The solenoid driven scannivalve consists of two 48-port valve units, each with its own pressure transducer. The two valve units are mounted on a common driveshaft, along with a position encoder. At all times, three signals were recorded: valve position and the voltage output from each transducer. The reference static and total pressures were obtained from a pitot-static tube mounted outboard of the wingtip. The pitot tube was found to be acceptably insensitive to yaw angles of up to 20°. Pressure coefficients were obtained directly by dividing the transducer output voltage for the selected port by the voltage output when the valve was connected to the total pressure port of the pitot tube. All measurements were recorded on a data logger, which was fitted in the cockpit, along with the scannivalve's solenoid driver, position decoder and transducer signal conditioners/amplifiers. 220 Volt/ 50 Hz AC power for all these boxes was supplied by a standard Uninterruptable Power Supply, as used for personal computers. The 6.5 A.h battery was found to be ample for at least 45 minutes, and quite possibly more.

The data logger was triggered by a cockpit mounted push button, and recorded data for 10 seconds at a sampling rate of 100 Hz. The scannivalve's solenoid stepper was activated by an on/off switch. It was thus necessary for the pilot to maintain a constant speed for 10 seconds, during which time about 20 pressure measurements were taken for each pressure port. After each measurement run, the solenoid stepper was deactivated, the valve 'homed' with a second push button, and the glider stabilized at a new speed. About 10 measurement runs could be performed during a single flight from a 2500' aerotow. After each flight the data was downloaded from the data logger onto a personal computer.

4. Computational Fluid Dynamics Analysis

The use of a computational fluid dynamics (CFD) method to perform parametric studies would be a real advantage in the design of winglets. For example, the next logical step in winglet evolution would be the ability to adjust the winglet's toe-out angle in flight, to obtain minimum drag under all flight conditions. However, trying to achieve this goal purely experimentally is likely to be excessively expensive and time-consuming.

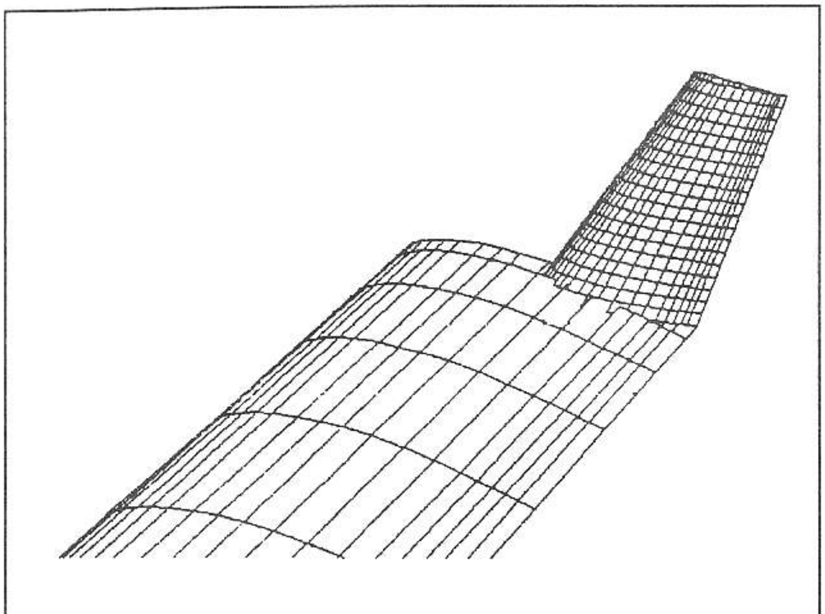

FIGURE 2. Surface grid in the vicinity of the wingtip.

A valid CFD method could be used to design an optimum winglet relatively quickly. To investigate the validity of the CFD approach, the experimental results were to be compared to a CFD simulation.

The most economical CFD method used to model full three-dimensional configurations is an inviscid panel method. Most panel methods model trailing vorticity by discrete rigid trailing horseshoe vortices. In practice, sufficient accuracy can normally be obtained this way. However, to obtain better accuracy in the vicinity of the wingtip, it would be advisable to model the actual 'roll-up' of the trailing vortices. This can be achieved to some extent by relaxation of the wake.

A further objective of this study was to investigate the influence of wake relaxation on the pressure distribution on the winglet. The panel method used was the British Aerospace 'SPARV' (Source Patch and Ring Vortex) code. [5] The surface grid for this simulation is illustrated in Figure 2. The grid consisted of 361 quadrilateral panels on each surface of the wing and winglet. Only the right hand half of the configuration was modeled, as the flow was symmetrical about the longitudinal axis. The surface panels were concentrated near the leading edge and trailing edge of each lifting surface. Although spanwise grid clustering was used on the main wing in the vicinity of the wingtip, uniform spanwise spacing was used on the winglet.

The results of the panel method for a wing lift coefficient of 0.6 are compared to the experimental values at two spanwise stations in Figure 3. Reasonable agreement was found at a spanwise position of y/s = 0.675, but at y/s = 0.421 the CFD and experimental results differed by an unacceptable amount. The good agreement found at y/s = 0.675 is quite probably fortuitous. It is clear from these graphs that the theoretical values are not acceptably accurate. Although wake relaxation resulted in a significant change in the pressure distribution, the accuracy was not improved substantially. It is concluded from these results that panel methods are unlikely to be accurate enough for design purposes. To

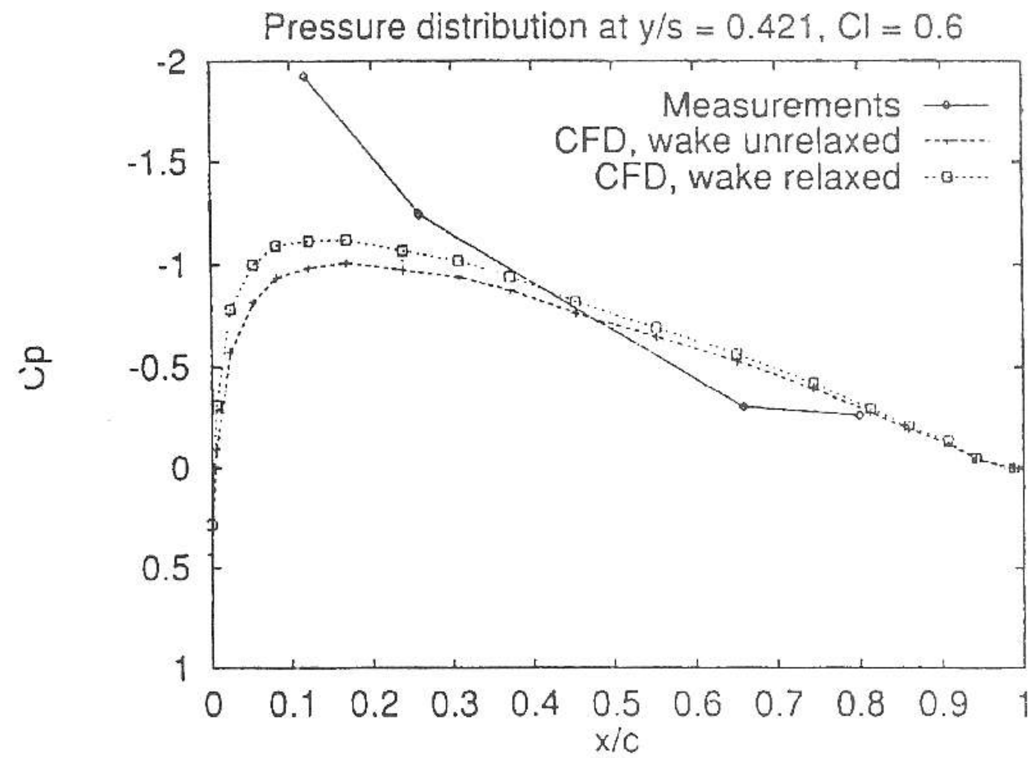

FIGURE 3. Comparison between CFD and experimental results for the inner surface of the winglet, at the spanwise station y/s = 0.421.

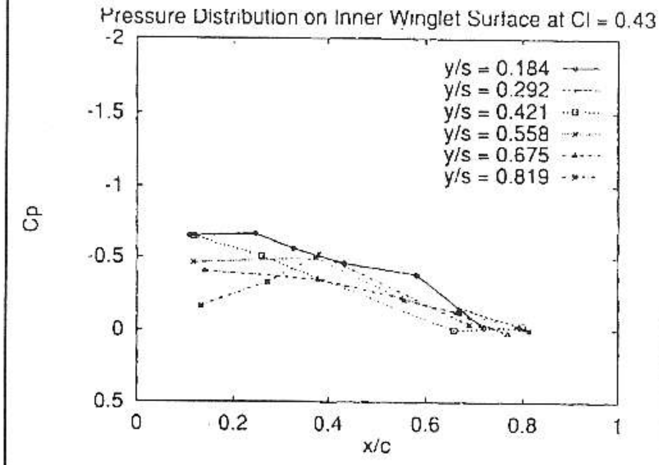

FIGURE 4. Inner surface pressure distribution at Cl = 0.43.

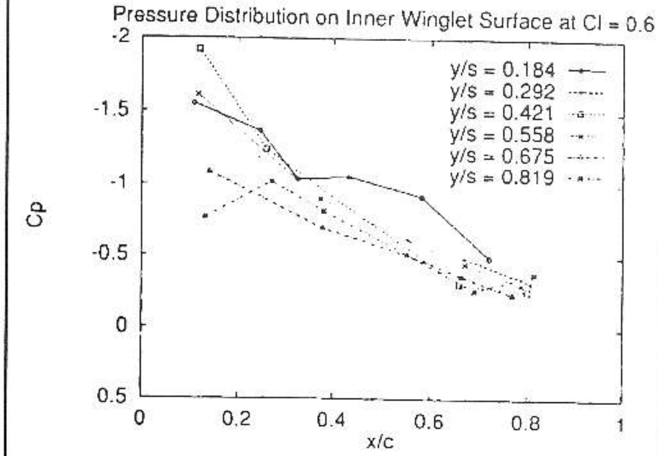

FIGURE 5. Inner surface pressure distribution at Cl = 0.60.

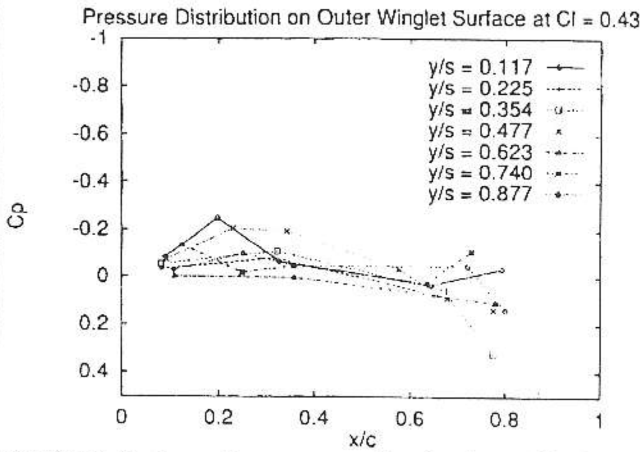

FIGURE 6. Outer surface pressure distribution at Cl = 0.43.

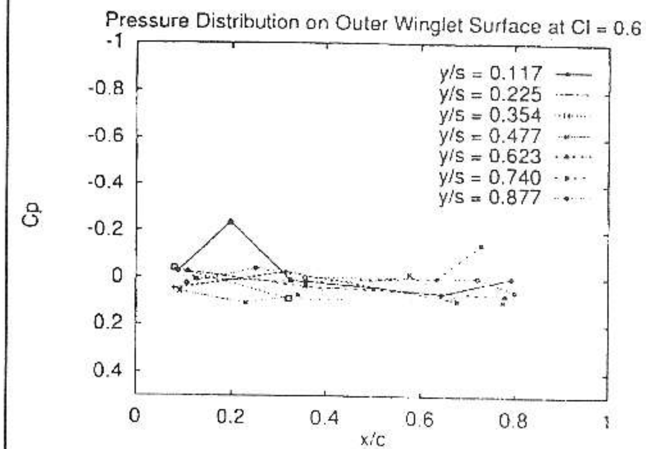

FIGURE 7. Outer surface pressure distribution at Cl = 0.60.

obtain more accurate CFD results it will be necessary to use a method that solves the entire flowfield near the winglet, probably an Euler code, which demands computational resources that are significantly more powerful than are necessary for a panel method. Pressure distributions are also shown for both the inner winglet surface and outer winglet surface at lift coefficients 0.43 and 0.6 in Figures 4, 5, 6 and 7.

6. Conclusions

Results from a three dimensional panel method differed significantly from in-flight pressure measurements on the winglet. It appears that the panel method used in this study is unlikely to be sufficiently accurate for design purposes, even when the wake is relaxed. For accurate design, an Euler code will probably be more useful. Pressure measurements at lift coefficients of 0.43 and 0.6 revealed that 4° of twist is not sufficient. Although the toe-out angle of 5° is suitable at a lift coefficient of 0.43, more toe-out would be an advantage at the higher lift coefficients.

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