WING GLOVE TEST BED FEASIBILITY STUDY

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1.0 Introduction

Wind tunnels are at present used to obtain the bulk of the experimental data on airfoils and on the properties of the boundary layer. In-flight testing is being used increasingly, however, to promote knowledge of laminar flow technology, to calibrate wind tunnels which in general suffer specifically from wind tunnel type turbulence and to obtain experimental data at high Reynolds numbers. In particular, in-flight testing has been used to evaluate boundary layer transition prediction schemes.

In-flight testing has been carried out using a number of different configurations of test bed. The University of Braunchweig, Germany has, for example, used a "glove" containing pressure sensing equipment which fitted very closely over the wing of an LFU 205 propeller aircraft (Figure 1, Reference 1).

This aircraft was used intensively for laminar flow investigations and the experimental transition data obtained used to find a limiting value of N in the "N-factor method" for predicting boundary

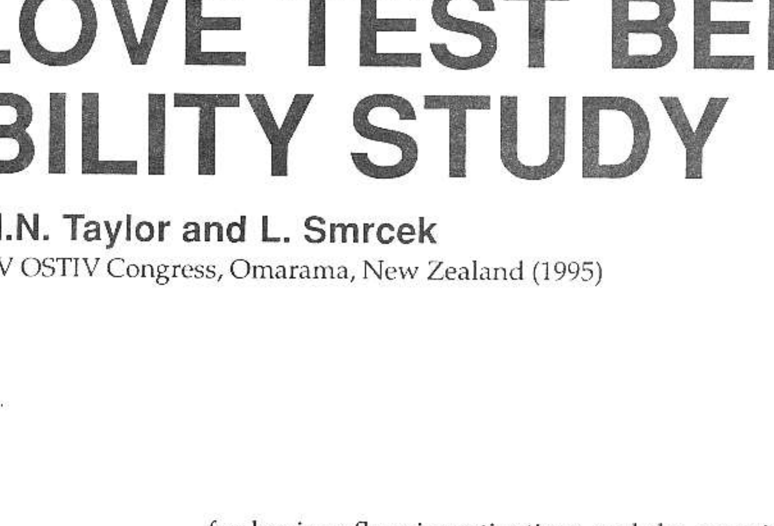

Figure 1. LFU 205 propeller aircraft as used by Braunschweig University for laminar flow investigations (Reference 1.)

layer transition. Flight testing in this manner is limited, however, in that only the characteristics of the wing airfoil section may be investigated and a wake survey is not possible.

A second approach, used independently by Braunschweig University of Germany and the ESAG Institute in Lithuania has been to mount a large test section on pylons directly over the c.g. position of a glider (References 2, 3). While this test bed configuration allows a variety of sections to be tested and a wake survey to take place. substantial and expensive modification to the test aircraft is required with resulting loss of performance and increase in both structural loads and weight.

A third approach to the problem, requiring the minimum of modification to the test aircraft while allowing a variety of airfoil sections to be tested, has been to attach an outsized airfoil section to the wing. Both T.U. Delft and the ESAG institute have independently used this form of test bed (Reference 2). In the latter case an L-13 Blanik trainer glider was fitted with a glove attached close inboard to either wing and several experiments, including determination of the boundary layer velocity profile, pressure distribution measurement and a wake survey took place.

Glasgow University is currently undertaking a feasibility study into the use of an L13-Vivat Motorglider as a test aircraft to which a wing glove, allowing the in-flight testing of airfoil sections. would be attached (Reference 4). The glove would be slid over the wing tip and into position approximately mid-wing. This approach is similar to the third case outlined above, however, the location of the glove further outboard should place it in a region of less disturbed flow. In addition. the use of a motorglider as the test aircraft will decrease test costs, as no tow aircraft is required, and allow greater flexibility in type and duration of testing.

This glove should allow better measurement of the lift drag and transition region than can currently be carried out by many wind-tunnels. In addition, test Reynolds numbers in excess of 5.5×10^6 are possible – larger than those achievable by many research facilities. The following sections discuss the design of the glove, the instrumentation used within it and assess the feasibility of the aircraft/wing glove combination both aerodynamically and structurally. The cost effectiveness and flexibility of the concept in comparison with other forms of in flight testing are also investigated.

2.0 The Test Aircraft

The L13 Vivat is a Czech built motorglider which is based on the design of the famous L13 Blanik trainer glider. The front part of the fuselage has a tubular steel structure with a glass fiber skin which makes for easy technological access to the cockpit. The aircraft has a retractable undercarriage and a well streamlined body and fuselage/wing junction. Technical data for the aircraft is given in Table I below.

TABLE I: Performance & Geometry

Stalling speed	60 km/h
Maximum flight speed	185 km/h
Never exceed speed	205 km/h
Range	530 km
Span	16.8 m
Wing Area	20.2 m^2
Mass Empty	500 kg
Maximum take-off mass	720 kg

In flight testing can take place over a wide range of velocities and the engine will not run for the duration of the test to ensure an undisturbed flowfield.

2.1 Glove Positioning and Geometry

The high aspect ratio wings of the Vivat allow the glove to be located approximately mid-wing in an area where the flowfield is undisturbed by either fuselage or wing tip effects (Figure 2). The glove will therefore be positioned one rib in from the aileron on the port wing and will extend over four wing ribs. In this position its width is 1.4 m and its geometric centre is 3.7 m from the fuselage center line. The inboard edge of the glove is located more than 1.5 fuselage diameters from the wing root. The glove covers the port airbrake in this position and hence both airbrakes must be disabled. If the port airbrake is removed, however, convenient access is gained to the wing interior. According to the manufacturer's report, the aircraft can be safely flown with the airbrakes disabled.

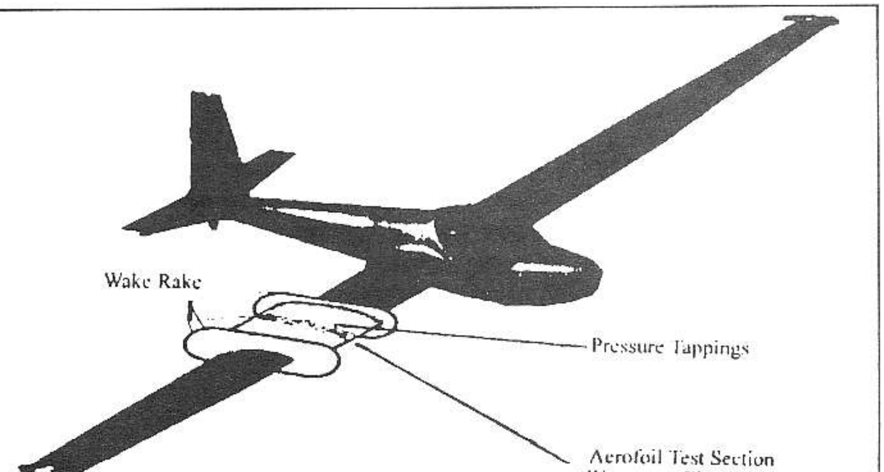

Figure 2. L13 Vivat with wing glove attached (Reference 4).

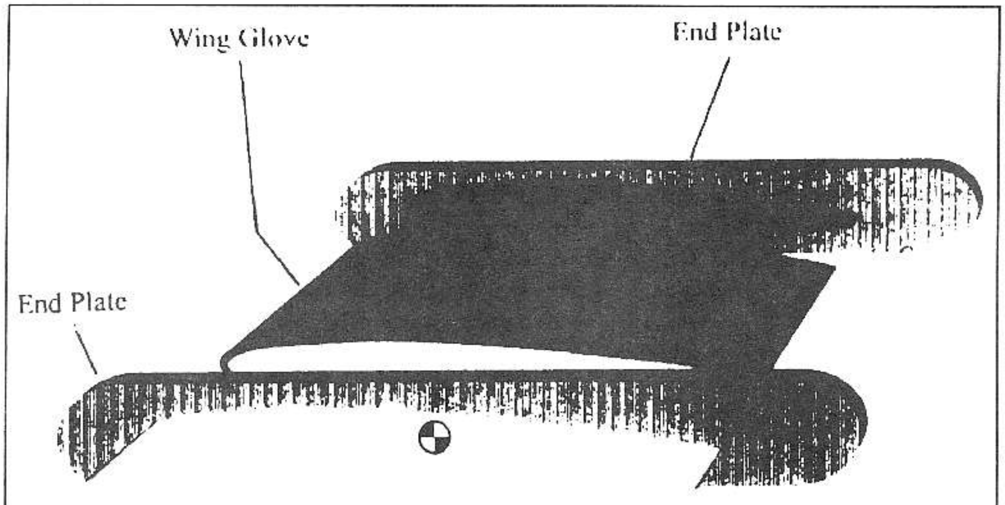

Figure 3. Diagram of main wing glove components. (Reference 4.)

The wing glove test section will be made from a glass fiber sandwich with the required stiffness and strength. The glove will then be slid over the end of the wing into position and fixed to standard attachment points on the wing which will be designed for the purpose. The minimum chord of the test section is dependent on the relative glove/wing airfoil shapes, the finite thickness of the glass fiber molding and the need for space for instrumentation.

The preliminary design calculations have been worked out with the Wortmann FX 67-17A airfoil as the test section. (This airfoil is used on the Czech L-33 *'Solo"* World Class Competition Glider). The wing chord at the midpoint of the glove is 1.26 m; the wing airfoil is a NACA 63_2-615 section. Because the Wortmann section has a cusped trailing edge the minimum glove chord will be 1.7 m and this can only be achieved by offsetting the glove/wing chords by +2.5°. It is clear that the choice of the Wortmann airfoil represents something of a worst case. If, for example, a NACA 6 series airfoil were used, a substantially smaller glove chord with little or no offset in glove/wing chords would be possible. To ensure a 2D flow over the glove, its planform will be rectangular and endplates will be used to stop any lateral flow across the test section. The endplates will also function to shield the glove/wing fixings from the flow in between them.

2.2 Effect of the Glove on Aircraft Center of Gravity Position

A simple analysis whereby each glove component is treated as a point mass with its center of mass located at its geometric center, situated at a given distance behind the fuselage firewall, has shown that the glove has only a small effect on the aircraft center of gravity position,(Reference 4, Figure 3). The glove can be considered as a point mass of approximately 20 kg lying 1.8 m from the fuselage firewall along the aircraft's longitudinal axis and 3.7 m from the fuselage center line out along the wing. The longitudinal c.g. position is moved rearwards and is found to be within the limits as specified by the manufacturer's handbook (24-38.5% MAC) in all likely combinations of the variable masses of pilots/ fuel/ baggage etc.

2.3 Effect of Glove on Aircraft Stability and Control

First order results for the theoretical load distribution on the aircraft wing due to the glove have been obtained using a Fortran code based on the Weissinger method and NACA Reports 921 and 1056 (References 5,6). Using this method, the overall load distribution on a wing can be thought of as being composed of a series of additive components. In this case the glove is modeled as having an effect on the wing similar to that of a flap or aileron deflection. Section lift coefficients are returned at the quarter chord position for a number of stations along the span. By taking the product of the dynamic pressure, section chord and section lift coefficient, the lift force can be found for each station along the span. The wing may then be modeled as a simple beam and the shear force and bending moment loads on it due to both aerodynamic and gravitational loads found via numerical integration performed on a spreadsheet.

The estimated percentage difference (increase or decrease) in bending moment due to the glove being on the aircraft wing is plotted in Figure 4. With the glove mounted portside, for example, at 70 km/h its weight would decrease the bending moment at the left wing

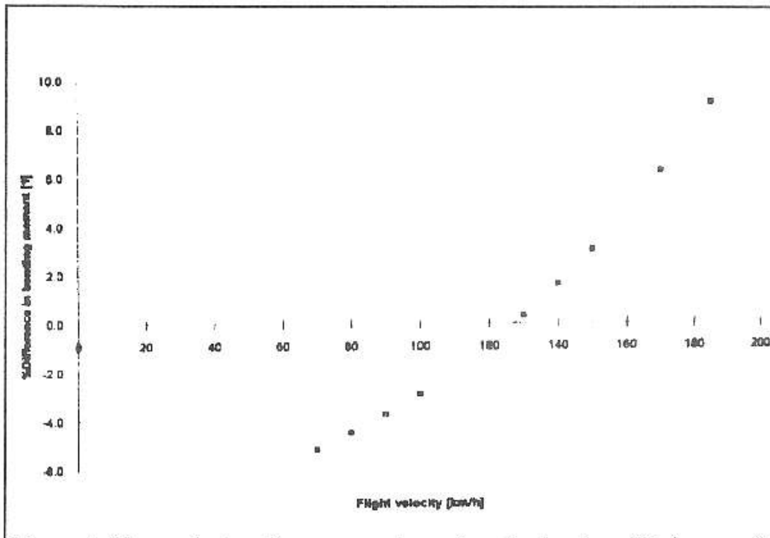

Figure 4. Change in bending moment on wing due to glove (Reference 4).

root by around 5%, and so an aileron deflection would be required to maintain level flight.

The "level flight speed" at which the bending moment at each wing root is equal occurs at around 127 km/h, whereupon any increase in velocity will result in the glove causing the aircraft to roll to the right. By putting the aircraft into a dive a test speed of 200 km/h ($Re = 6.4 \times 10^6$) should be achievable without over stressing the wing; however, a second "dummy" glove may have to be attached to the starboard wing for the aircraft to remain controllable. Further study is required to assess how much aileron deflection will be required at high and low flight speeds to maintain level flight. A permanent trim aileron deflection may affect the flowfield in the vicinity of the glove, but as the Vivat has large, efficient ailerons, trim aileron deflection is likely to be small and the aircraft should fly in trim at speeds at least up to 150 km/h ($Re = 4.8 \times 10^6$).

The Fortran code referred to above assumes a linear lift curve slope and as such fails to predict the stalling characteristics of the wing with the glove attached. A calculation performed in Reference 4, based on 2D data for the Wortmann airfoil at a Reynolds No. of 1.5×10^6, predicts that the glove section will remain stalled up to a speed as high as 86 km/h ($Re = 2.76 \times 10^6$). The lift curve slope and maximum lift coefficient on some laminar profiles increase with Reynolds No. due to a rearwards movement of the center of pressure and, as such, it is possible that the actual stalling speed will be lower than the quoted figure. (References 7, 8). In any case, a smaller offset in chords between the glove/wing airfoil would result in a lower stalling speed.

The drag created by the glove in the stalled condition at 86 km/h and neglecting the drag from the wake apparatus and fixings has been calculated to be very small using the same 2D section data. It appears, therefore, that the yawing and rolling moments due to the glove should be trimmed out by the controls over a large range of flight velocities.

3.0 Basic Glove Instrumentation

First tests with the glove will involve determination of the pressure distribution around experimental airfoils. The instrumentation inside the glove will consist of two Scanivalve ZOC23 modules feeding into a signal conditioning module (SCM). The ZOC23 unit is ideal as it is extremely compact. Consisting of a central block with 4 satellite packs of 16 pressure sensors for remote operation. i.e. 64 channels per unit. Both ZOC23 packs will be located in the recess left from the removal of the airbrake.

The pressure distribution around the glove will hence be found by locating the pressure tappings in a central strip running from leading to trailing edge on both upper and lower glove surfaces. This central location is necessary as the endplates will retard and also induce turbulence in the flow in the vicinity of the glove edges.

The signal from the ZOC23 packs will then pass through the SCM and finally into a lap-top computer data acquisition system (DAS) located in the cockpit via a wiring harness routed through the interior wing space. Electrical power for the system will be drawn from the aircraft battery.

Around 80 tappings will cover the two surfaces of the glove adequately: the remaining channels being used for the wake survey. The lift force generated by the glove will then be calculated from an integration of the vertical component of the pressure distribution. The drag produced by the glove cannot be found in a similar manner via an integration of the horizontal component of the pressure distribution owing to practical difficulties in capturing the leading edge suction peak. Drag will therefore be calculated by considering the momentum deficit in the wake behind the glove using a "wake rake".

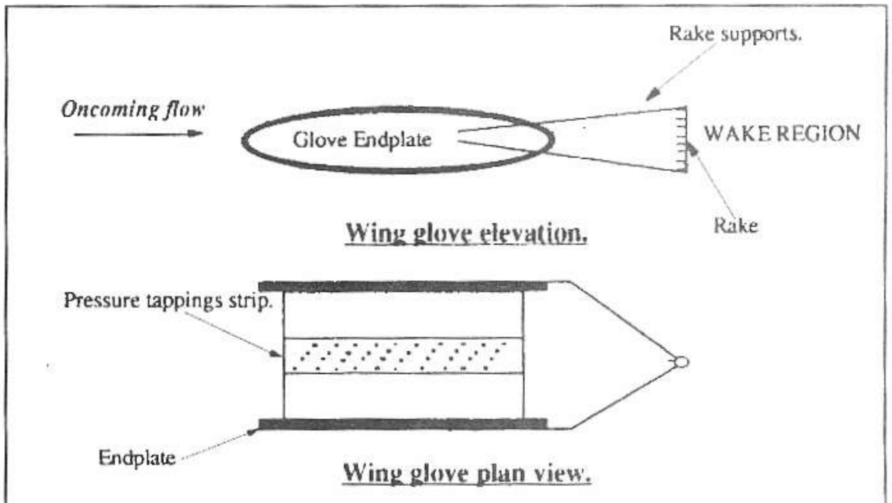

Figure 5. Elevation and plan views of glove showing wake survey apparatus. (Reference 4.)

As the glove presents a very low aspect ratio wing, the wake is very narrow and even with the presence of the endplates there will be viscous shearing in the part of the wake close to the trailing edge. This will make it difficult to obtain static pressure readings in the vicinity of the trailing edge and the static pressure will vary across the width of the wake. Reference 7 states that the rake should be placed at a distance of no less than 0.7 wing chord between rake and trailing edge at which point the static pressure variation will be small. Unfortunately the problem of fixing the rake to the glove may preclude fixing the rake this far away. The wake rake must, therefore, measure both static and total pressures across the width of the wake. A suggested configuration for the rake assembly, consisting of 4 aluminum tubes supporting a central rake and weighing not more than 1.5 kg is as shown in Figure 5.

Practical experiments could be done to assess the optimum distance of the rake to the trailing edge, but a distance of only 0.5 m could be possible. Up to 50 of the Scanivalve channels may be used in the wake survey with a maximum of 10 for the static pressure measurement.

4.0 Costing

At current U.K. prices the Scanivalve ZOC23 units cost £10,000 each; a lap top computer DAS complete with SCM will cost around £6000. The construction materials required for the manufacture of the glove are inexpensive. Some CFD modeling and wind tunnel testing may be required to assess both the flowfield around the glove and the operation of the instrumentation within it. The total development cost is estimated at under £40,000, which is the cost of the Vivat itself. The flight costs of the Vivat are approximately £40/hour which is extremely competitive in comparison with those of wind tunnel facilities capable of testing to the same Reynolds numbers.

The design of the glove should allow for rapid attachment and removal, allowing the test aircraft to be used for other purposes. No tow aircraft is required to take the test aircraft to altitude, and after a test the aircraft can easily regain height. The above factors make for cheap and efficient testing of a kind not possible before.

5.0 Conclusions

The L13 Vivat motorglider is an ideal test aircraft for use with the wing glove as it is aerodynamically clean and permits testing over a wide range of altitudes and velocities. The Vivat has a significant advantage over other glider based test beds in that a tow aircraft is not required and hence testing is more versatile and much cheaper. The wing glove itself will be located mid-wing in position over the airbrake. It will weigh not more than 20 kg and has been shown to have only a small effect on the aircraft c.g. position. Preliminary calculations performed using a Wortmann airfoil as the test section have shown that the aircraft should be able to fly in trim with the glove attached at speeds of up to at least 150 km/h. The maximum test Reynolds number based on the test section chord is approximately 6 million, which is higher than that achievable by many wind tunnel research facilities. Flight costs are only £40/hour and hence the system is a highly cost-competitive form of airfoil testing.

The initial test program will involve the determination of surface and wake pressure distributions of airfoil sections to allow the experimental validation of new computer codes and to calibrate wind tunnels. Subsequent experiments could involve the use of an infrared camera located in the cockpit or small microphones placed under the surface of the glove to determine the location of the transition region. The former method allows the increased shear stress at the surface due to the turbulent boundary layer (which results in a temperature increase of the air in the boundary layer) to be visualized. A turbulent boundary layer creates more noise than a laminar one and thus the microphones allow the location of the transition location to be heard.

6.0 Acknowledgments

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7.0 References

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