Flight Measurements of the Profile Drag of a «Skylark II» Wing

By P.A.S. Langston, B.Sc. (Eng.)

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Introduction

In recent years sailplane designers have made increasing use of the so-called "laminar flow" wing sections in attempts to decrease the wing profile drag. At high Reynolds' Numbers the advantage of these aerofoils over more conventional aerofoils is considerable but unfortunately the advantage decreases with decreasing Reynolds' Number. This is illustrated by figure 1[1]. It shows the variation of profile drag coefficient with Reynolds' Number for a series of aerofoils having the same thickness-chord ratio (15 %). It will be noted that for values of Reynolds' Number less than 1×10^6 it may even be a disadvantage to use the laminar flow type sections. An examination of several well-known sailplane designs shows that root chord Reynolds' Numbers for the airspeed giving best gliding angle are usually between $1{,}5 \times 10^6$ and 3×10^6. The corresponding wing tip Reynolds' Numbers are between about $0{,}6 \times 10^6$ and $1{,}2 \times 10^6$.

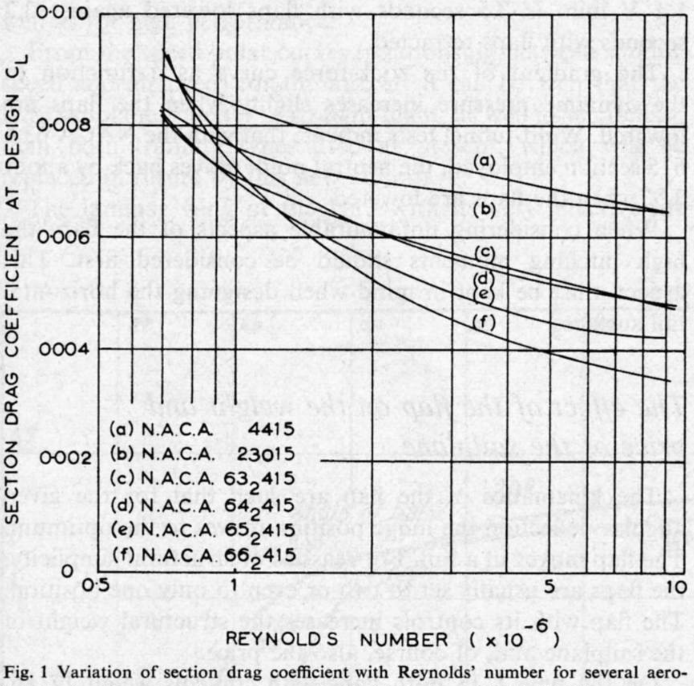


Fig. 1 Variation of section drag coefficient with Reynolds' number for several aerofoils having the same thickness-chord ratio (15 %). Sections (*c*), (*d*), (*e*), (*f*) are laminar flow type sections.

It is well known that laminar flow sections are more severely affected by surface imperfections than the non-laminar types, and in order to achieve and maintain a satisfactory surface it seems inevitable that costs should increase. Obviously, use of these sections for sailplanes is only of value if the expected gain in performance is in fact obtained.

This paper describes some tests carried out on a typical example of a "laminar flow" sailplane (the Skylark II) in order to measure the section profile drag and make a comparison with the best possible values as predicted by the N.A.C.A.

[1] Compiled from N.A.C.A. T.N. 1945

The method of making the profile drag measurements was based on the well-known momentum principle that the skin friction and form drag resistance of a body is entirely accounted for by the momentum which it imparts to the fluid through which it passes. Measurements of the dynamic and static pressures were made along a line substantially perpendicular to and passing through the wing wake just behind a typical section of the wing and the values obtained were used in the expression developed by Jones

$$C_{Dp} = \frac{2}{c} \int^{wake} \{\sqrt{g} - p\,(l - \sqrt{g}\,)\}\, dy$$

$$\text{where } g = \frac{H - P_o}{H_o - P_o} \text{ and } p = \frac{P - P_o}{H_o - P_o}$$

where C_{Dp} is the required section profile drag coefficient,

c is the chord at the required section,

H_o and P_o are the total head and static pressure respectively in the undisturbed stream and H and P the corresponding quantities in the wake at the point of measurement.

y is the position across the wake.

The computing involved in calculating the values can be considerable especially if a large number of y values is used. Much of the work is avoided if use is made of a graph giving the variation of $2\sqrt{g} - p\,(l - \sqrt{g})$ for different values of p and g. Such a graph is given in "Wind Tunnel Technique" by R. C. Pankhurst and D. W. Holder.

It was decided to use a section of wing almost exactly one metre from the centre line of the aircraft. This section is typical of the N.A.C.A. 63_{318} 620 section used for most of the wing and is clear of the influence of air brakes, inspection panels and other possible causes of premature transition of the boundary layer. It is also sufficiently close to the cockpit to allow short connecting pressure tubes, and hence reduce lag, but not close enough for the airflow to be influenced by the presence of the fuselage. In this region the greater part of the surface is of plywood, fabric being confined to the rear and covering only about 25 % of the surface area. Cellulose dope is sprayed on as a finish.

Before finally deciding on the method to be used to measure the profile drag of the aerofoil section of the Skylark II several ideas were studied. These ideas and the reasons for their rejection will be described briefly as they give a good illustration of the particular problems involved.

The "integrating pitot comb" method, in which the mean dynamic pressure along a line including the wake is measured, has been used in the past for flight trials with some measure of success. In fact a suitable comb was already available. However, a calculation based on estimates of the wake dimensions and profile drag showed that the pressure difference to be measured was only of the order of 5 mm. water even at the highest airspeeds anticipated. The difficulties of accurately measuring such small pressures in flight are quite obvious.

The "pitot comb", especially useful in the laboratory, involves having a number of pitot tubes mounted in a vertical plane behind the wing with each tube connected to a separate manometer. Whilst this has also been applied to flight tests with success, its use in this case would have been very difficult. The cockpit of the aircraft is quite small. It was considered that to attempt to read a number of manometers whilst trying to fly the aircraft at a constant speed would be unwise. The method of "freezing" the manometer levels for reading at a later stage was considered to be unlikely to give good results, especially in view of the small liquid heads expected.

The Pitot Traverse was the method used by Jones in 1936 to verify his theory. A combined pitot and static tube was traversed across the wake and the pressures recorded by photographing the manometer carried in the fuselage. A suspended static head was used to give a reference pressure. The traverse motion, along an arc of a circle centred behind the trailing edge, was made by operating a Bowden cable from the cockpit. The complete traverse took a considerable time but the pilot was only given the task of flying the aircraft at the correct speeds whilst an observer operated the experimental apparatus.

It was felt that a modified form of this method would give the best solution. However, the developed method would have to take the following points into account:

It is not easy to measure very small pressures in flight.

Since the pilot would have to fly the aircraft and read the required instruments at the same time it would be necessary to reduce the number of instruments to a minimum.

The flying time of a sailplane is limited and quite expensive.

The time during which the speed is to be kept constant should be as small as possible.

The space available for instrumentation was not very large.

The only existing power supply was an 18 volt 20 amp./hour accumulator normally used to drive an artificial horizon.

The use of a suspended static head would be inconvenient.

Major modifications to the airframe were to be avoided.

Photographic methods of recording were not considered ideal since there were no readily available developing facilities at the airfield.

The actual apparatus finally evolved is shown diagrammatically in figure 2 and discussed in principle below.

The pitot tube (A) is traversed by the electric motor (B). Pressures are transmitted to a modified airspeed indicator (C) by a length of tubing and recorded on the strip of paper (D) by passing electric sparks between the brass plate (E) and the pointer (F) of the airspeed indicator. The paper is driven from spool (G) to spool (H) by the electric motor (J). The electric sparks are produced by the induction coil (K) whenever a cam (L) is operated by the lead screw (M) carrying the pitot tube. The traverse motor (B) is controlled by the two limit switches (N), (O).

The whole apparatus is set into motion by a switch operated by the pilot. The subsequent events are then carried out automatically, the pilot being informed when the traverse has been completed by the extinction of a red light in the cockpit. The time taken to complete a traverse can be varied by changing the value of a resistor.

The "static" side of the airspeed indicator is connected to a suitable pressure tapping which supplies a pressure whose variation from free stream static pressure is known for all flying speeds. (In this case the aircraft instrument static pressure tapping.)

Static pressures in the wake are measured in the same way as the pitot pressures by interchanging pitot and static tube connections so that the variation of wake static pressure from the reference pressure is obtained.

An examination of the recorder paper shows a series of minute holes, each of which represents the pressure measured at points separated by the distance of a pitch of the lead screw. Each dot thus gives two items of information and there need be no mechanical connection between the traverse and recorder: neither is it necessary for either electric motor to run at constant speed.

The length of traverse had to be sufficient for the pitot-static head to pass through the complete wake, and to allow some margin for the displacement of the wake at different lift coefficients. Their lengths depend on the position of the measurement plane in relation to the aircraft trailing edge. It was decided that measurements should be made in a plane at about 6 inches from the trailing edge which represents about 14 % of the chord length. This was considered sufficient to avoid the region in which the Jones expression is known to disagree slightly with other theories. Furthermore the minimum value of the total head would not be too small to measure (its value of course increases with distance downstream of the point of breakaway on the aerofoil).

It was desirable to keep the traverse length, and hence time, to a reasonable minimum so that the pilot would not have to fly at constant speed for too long. This would also reduce the dimensions and weight of the traverse unit and allow the supporting structure weight to be kept small.

The dimensions and position of the wake were estimated by a method given by Silverstein and Katzoff. The traverse length was thus fixed at 5 inches with an allowance of about ¾ inches at each end.

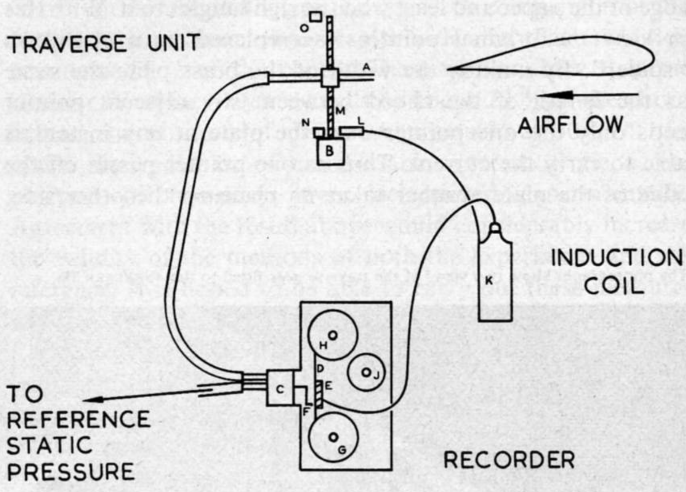


Fig. 2 Schematic diagram of apparatus

It was considered that a traverse speed of about 1 inch per second would be acceptable, the vertical component of velocity then being completely negligible and the expected lag due to the length of connecting tube being small. The pilot would then be expected to fly at constant speed for about 6½ seconds.

A normal automobile contact breaker was used to operate the induction coil. This was actuated by a suitable cam driven through a 4 : 1 ratio step down gear by the lead screw. It was felt that in order to facilitate correlation between recorder spark holes and traverse position some form of marker should note (say) every fourth spark hole. This was accomplished by using a square cam with one corner removed so that every fourth measurement was abandoned.

A very rough estimate showed that about $^1/_{100}$ h.p. would be required to operate the lead screw. In fact a 12 volt D. C. series motor rated at $^1/_{50}$ h.p. driving through a 9 : 1 ratio step-down gear was found satisfactory. Its speed could be controlled by altering a series resistor although this of course affected the power output. The motor and contact breakers were enclosed in a perspex fairing to keep them dry.

The main design consideration for the supporting structure of the traverse unit was that it should not influence the nature of the airflow over the wing. Premature transition of the boundary layer would have defeated the object of the experiment. It is known that transition caused by an isolated speck spreads at a rearwards inclosed angle of roughly 15°. In fact it was found possible to keep a region forward of the traversing plane and including an angle greater than 60° completely clear.

As described above, the experimental results were recorded by passing an electric spark through a strip of paper passing between a brass plate and the pointer of a modified airspeed indicator. This has the advantage that, since the pointer does not touch the surface of the paper, a major source of friction and backlash is removed.

The K. B. 220/02 type airspeed indicator had its glass and dial removed and was fitted with an earthing lead. It was found convenient to connect this using one of the screws previously used to hold the dial in position. (The external connecting tubes at the back of the instrument were found to be electrically insulated from the pointer spindle.)

The pressure measurement is represented by the distance of the spark hole from one edge of the paper. Clearly the greatest accuracy is obtained when the pointer is parallel to the edge of the paper and least when at right angles to it. With this in view the original pointer was replaced by a cruciform "spider". By making the width of the brass plate the same as the length of the chord between two adjacent pointer ends only the one pointer over the plate at any instant is able to carry the current. Thus as one pointer passes off the edge of the plate another takes its place on the other side.

The range of the instrument was 10—130 knots taking $1\frac{3}{4}$ turns of the dial. This meant that the pointers of the spider were spaced at intervals corresponding to just less than 20 knots. This system introduces an ambiguity since there is no distinction between pointers. However, since the traverse was to start outside the wake where the measured airspeed would be about the same as that of the aircraft itself it was possible to note the aircraft airspeed and choose the initial recorded value to correspond. After this it would be possible to follow through the other values on the assumption that no very sharp discontinuities of velocity would occur.

For the case of the static pressure measurements it was necessary to "tap" in a further pressure gauge to be read visually in the cockpit. With the aid of this the order of the static pressure at the measuring section could be estimated and thus the possible ambiguity was resolved.

The spool onto which the strip of paper was wound was driven through a 50 : 1 ratio worm gear by a small 12 volt D. C. shunt motor. The speed could be varied by altering the value of a resistor in series with the armature winding. The other spool was provided with a friction washer, made from a piece of felt cloth, to prevent overrunning.

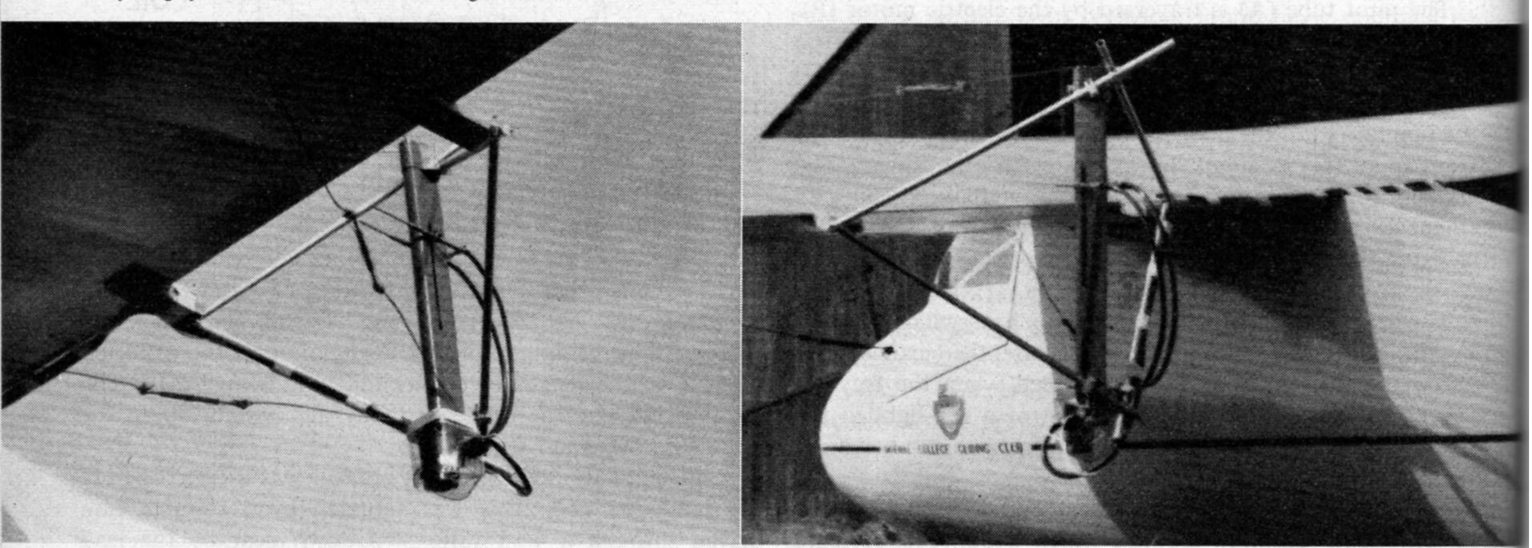
Many specimens of paper were examined before a satisfactory type was found. This had a fine texture, good electrical insulation properties, and was coated with a black glaze on one side. The spark holes could be fairly easily seen when the paper was held over a bright light with the black side uppermost.

It was found that if the paper speed was too slow a number of expected spark holes would not appear, and it was considered that the spark sometimes found its line of least resistance by passing through the previous hole again. A suitable mean paper speed was about $2\frac{1}{2}$ inches per second. This gave a space of at least 0.15 inches between adjacent spark holes.

The original airspeed indicator had been sealed so that the static pressure was applied to the whole case, whilst the pitot pressure was supplied to the inside of the brass bellows. Now that the glass had been removed it was necessary to seal up the perspex box in which the paper, spools, electric motor, and contacts were encased.

It was anticipated that although the presence of the supporting structure near the plane of measurement would

The photographs show two views of the traverse gear fitted to the «SKYLARK II»



not greatly influence the total pressure measurements it was thought that it might significantly affect the measurements of the static pressure. Experiments were therefore carried out in the Imperial College Department of Aeronautics 5 foot by 4 foot low speed wind tunnel to determine the error. The results showed that the error varied with the local dynamic pressure and with the position along the line of traverse. Since the local dynamic pressure would itself vary across the wake, the task of applying the necessary correction rigorously would have been considerable. Fortunately it was found that by applying a constant correction of 4.3 % of the free stream dynamic pressure the error in the final value of the profile drag coefficient would be quite small and would not exceed 2½ %.

All the necessary flying was carried out from Lasham Aerodrome in Hampshire where facilities for aero-tow and auto-tow launches were available. A few short flights were made initially in order to find the correct position for the traverse unit in relation to the wing and these flights also gave useful practice in keeping a reasonably constant airspeed during the traverse. In fact it was found quite practicable to reduce airspeed fluctuation during a traverse to less than ½ knot.

Measurements of the variation of total head across the wake were then made over a range of indicated airspeeds between 36 knots and 81 knots.

Initial attempts to measure the static pressure difference were not very satisfactory. Results were very inconsistent and there seemed to be insufficient data to obtain even very approximate values. It was then realised that the correction to be applied to the measured results due to the aircraft static pressure error of the standard pitot-static head was of the same order as the measured pressure itself. A calculation showed that for some speeds the corrections might be such that the pressure measured was of the opposite sign to that expected and a few flights were made with the recorder connections reversed. This again gave inconsistent results.

Fortunately, in some previous work carried out by the author in the autumn of 1955, wind tunnel experiments on a ¼ scale model of the aircraft had indicated that by suitably positioning flush static vents on the side of the fuselage the static pressure error could be considerably reduced. Accordingly the aircraft was modified and a new pressure error curve obtained. The "static" side of the recorder unit was connected to these vents leaving the aircraft airspeed indicator connected to the standard pitot-static head. A further modification was made by installing another airspeed indicator, connected to the static vents, and the traverse static tube in the same way as the recorder in order to give a direct visual indication. This was only used to obtain the order of the pressure measurements so as to identify the recorder pointer in use.

Static pressure measurements were made again, this time with considerably more consistant results. It was found more convenient to note the arbitrary speed at which a traverse was made than to try to fly at a predetermined airspeed.

In the analysis of the records it was found that it was reasonable to take a constant value of p, the ratio of the difference between the static pressure in the wake and the free stream value to the free stream dynamic pressure, for all values of the lift coefficient. The experimental value agreed with theoretical estimates quite well.

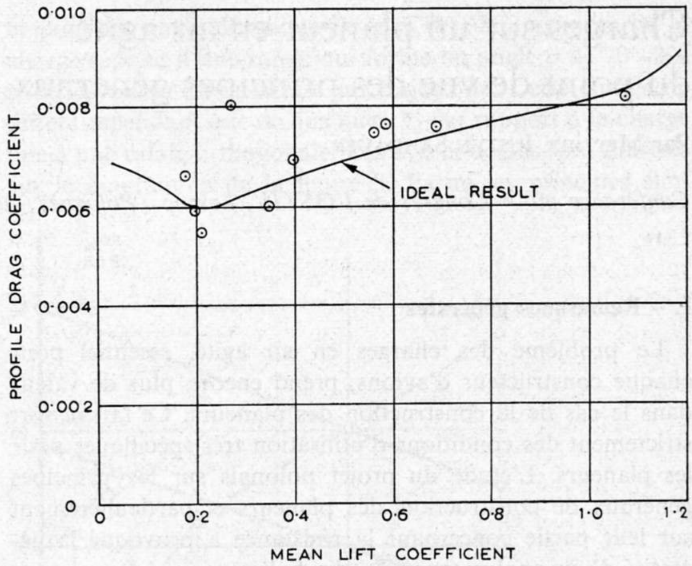


Fig. 3 Comparison of experimental results with N.A.C.A. ideal result

Figure 3 shows the measure of agreement between the experimental values of profile drag coefficient and those estimated from N.A.C.A. published results. Whilst the experimental results tend to show slightly greater values the agreement is good, although since there are fewer experimental points in the high coefficient range accuracy is less certain.

In "The Calculation of the Profile Drag of Aerofoils" H. B. Squire and A. D. Young (R and M 1838) give a further method of estimating profile drag coefficients providing the position of transition of the boundary layer is known. Theoretical calculations were made using the assumptions that the effects of section shape and life coefficient were small. The experimental results have been compared with these theoretical results in the region of small lift coefficients in order to estimate the position of transition. A slight extrapolation of the results of the reference indicates that the transition occurs at 47 % of the chord. A comparison of the N.A.C.A. and theoretical results indicates that transition occurs at 51 % of the chord. These results show that the laminar boundary layer extends to about 20 % of the chord behind the position of minimum pressure, at 30 % of the chord. It would be of considerable interest if the actual position of transition were determined experimentally. Agreement with the result above would considerably increase the validity of the methods of both the experiment and the reference. It is hoped to be able to carry out these measurements in the near future.

The technique developed for the experiment provides a very satisfactory method of determining wing profile drag, more especially of a single-seater aircraft. The close agreement of the results with the published data is an indication not only of the qualities of the actual wing, but also of the apparatus and method.

The method of recording by using sparks is very satisfactory indeed. Its use is not restricted to the type of measurements used here, and it could be used to record any property which can be represented by motion of a pointer over a circular dial, provided one value is known approximately to fix the pointer in use.

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