

# Transition-related studies on two low-drag airfoils

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**Experimental results of boundary layer transition locations on two low-drag airfoils tested in the NAL 1.5 m low speed wind tunnel are presented. Measurements made included model pressure distributions and unsteady signals from surface mounted hot-films over an incidence range of 0–6°. Chemical sublimation technique was also utilized to infer location of transition in one of the studies. The experimental results on transition location are discussed and compared with earlier data available in the literature.**

## Introduction

The last fifteen years have seen considerable interest and research in the broad topic of laminarization of flow on airfoils and wings<sup>1,2</sup>. Research has progressed in two major directions. The natural laminar flow (NLF) concept involves the stabilization of the laminar boundary layer by tailoring favourable pressure gradients on the airfoil, which is achieved by passive shaping of the airfoil geometry. On the other hand, in the laminar flow control (LFC) approach, the boundary layer is stabilized by small amounts of suction in certain regions of the airfoil. The NLF concept is particularly attractive for wing sweep angles less than about 15° and chord Reynolds numbers less than about  $15 \times 10^6$ . The application of LFC with suction is more complex, involves expenditure of energy and is suitable to delay transition beyond chord Reynolds numbers of about  $20 \times 10^6$  and wing sweep angles in excess of 20 deg. The NLF concept is now realizable and seeing applications in general aviation aircraft because of advances in material/manufacturing processes (e.g. composites), the better aerodynamic tools available for airfoil design (which include CFD codes), and improved verification criteria and modelling (based, for example, on  $e^n$  type methods).

Notwithstanding these advances, verification of NLF airfoil/wing design concepts at wind tunnel Reynolds numbers is a useful and desirable step; in particular, an assessment of the extent of laminar flow or the location of transition in wind tunnel experiments provides vital feedback on the design philosophy which includes transition modelling. It is therefore necessary that NLF experiments are carried out in relatively quiet tunnels so that the test results will be more meaningful for inter-

pretation. A freestream turbulence level better than 0.05% is often considered desirable for such studies.

Our laboratory is currently involved in the design and prototype building of two, small civil aircraft – both of these employ GAW (General Aviation) airfoils, which come under a family of low-drag airfoils. The use of an NLF type airfoil in future designs is a distinct possibility. In view of the above interest, we have recently carried out experiments on transition detection on two airfoils in our 1.5 m × 1.5 m low speed wind tunnel. In the first experiment, transition locations are determined employing hot-films on a NLF (1)-0416 airfoil and compared with NASA results, providing a broad validation of our technique and tunnel for future NLF-related research. In the second, transition locations on a 5° sweep wing (employing GAW 16% thick airfoil) are determined using both hot-films and a chemical sublimation technique. We present a brief summary of these results in this paper.

## Experiments

Experiments were conducted in the NAL 1.5 m × 1.5 m low speed wind tunnel. Study of tunnel freestream flow characteristics has shown that the mean velocity is uniform within 0.2% and the longitudinal turbulence intensity varies from 0.06% to 0.1% in the tunnel speed range of 10–50 m/s.

### Airfoil models

Studies were carried out on two models having NLF(1)-0416 and GA(W)-2 (modified) airfoil sections; both airfoil models had a thickness to chord ratio of 16%. The NLF airfoil had a chord ( $c$ ) of 500 mm and span of 750 mm, and carried two end plates in order to obtain nearly 2D end conditions (Figure 1a). The model was made of glass fibre composites using 2D templates and the surface finish was better than 25  $\mu$ m. The model was instrumented with 59 static pressure ports of 1.2 mm o.d. on the top and bottom surfaces (Figure 1a). Sixteen single-wire hot-films (WTG-50B, Micro Measurements, USA) were glued on the upper surface over a distance of 50% chord. Care was taken in locating the films to see that interference due to the thermal wake of films was minimized. The GA(W)-2 wing model having a sweep of 5° was of constant chord (500 mm) and

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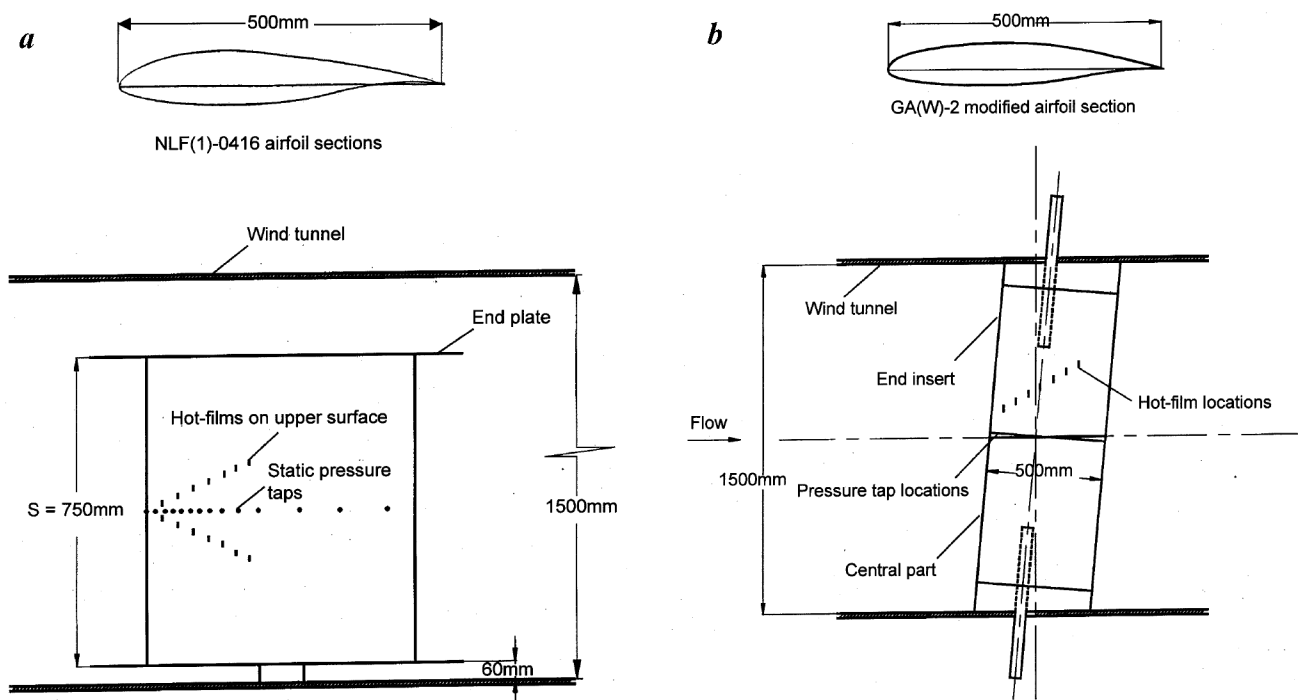


Figure 1. *a*, Sketch of the NLF model in the wind tunnel; *b*, Sketch of the swept wing model in the wind tunnel.

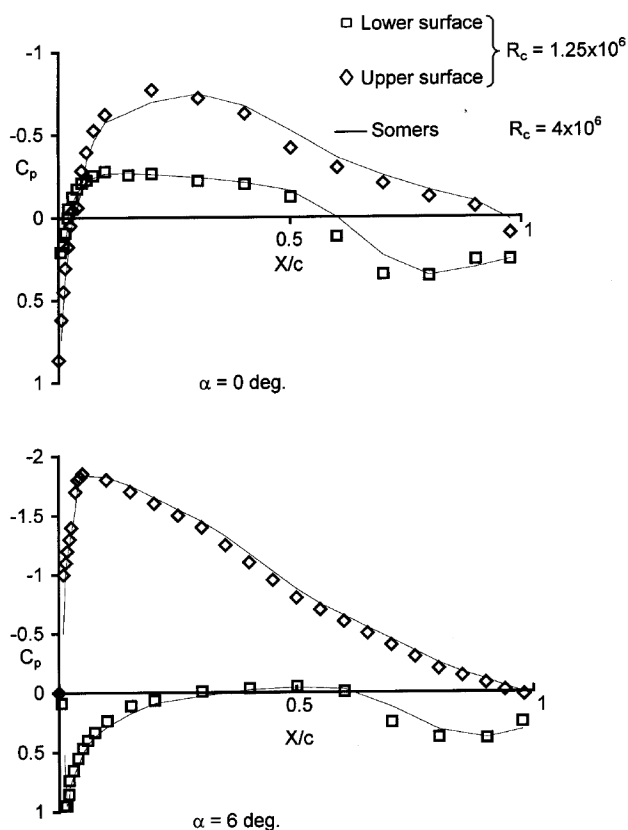


Figure 2. Surface pressure distributions on the NLF airfoil.

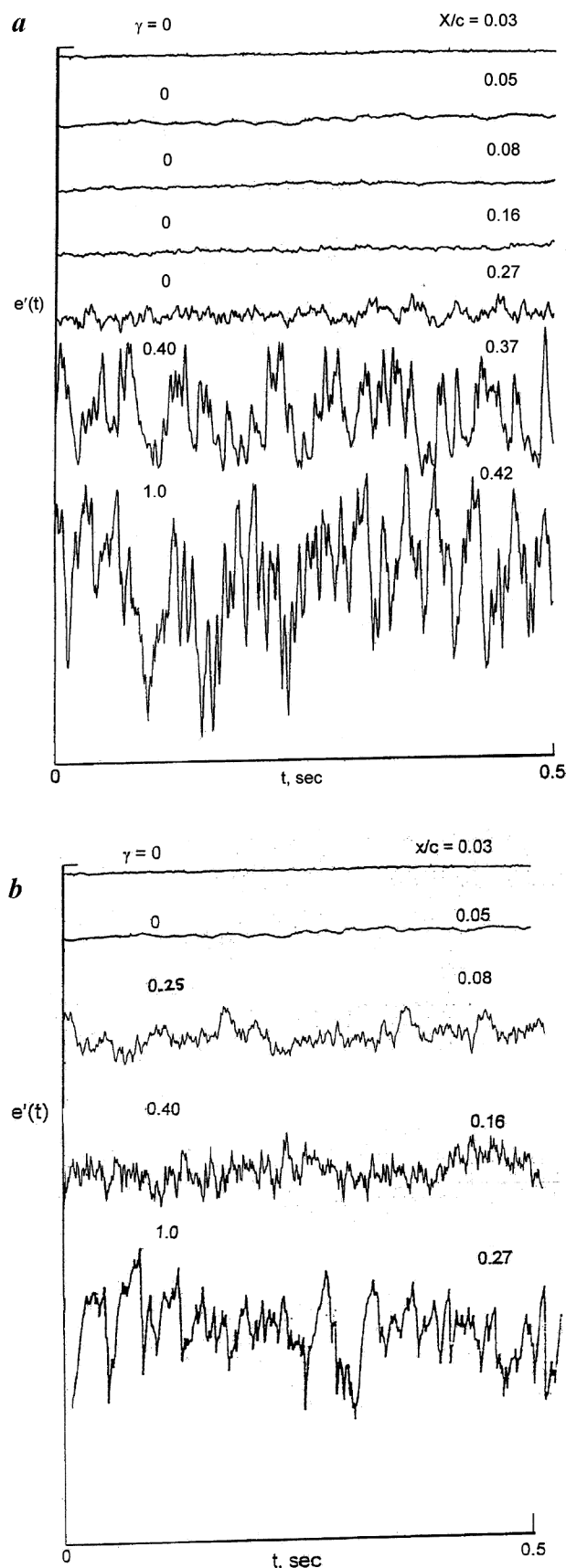
Table 1. Test conditions for experiments conducted in the NAL low speed wind tunnel

Test parameters	NLF	GA(W)
$U_\infty$ , m/s	45	35
$R_c$	$1.31 \times 10^6$	$1.02 \times 10^6$
$\alpha$ , degrees	0 to 6	-6 to 6

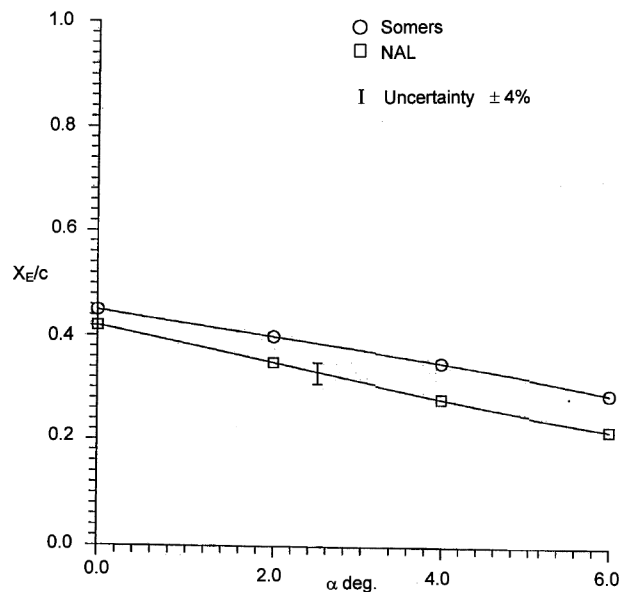
spanned the test section as shown in Figure 1 *b*; the construction was such that a variety of sweep angles of the wing leading edge could be obtained using proper end inserts. This model was also made of glass fibre composites using 2D templates. The model was instrumented with 57 static pressure ports and 14 McCrosky hot-film gauges (ET-TG-GAG-00040, Micro Measurements, USA) distributed on the upper and lower surfaces. Chemical sublimation technique using naphthalene was also employed to detect transition on the wing model. The test conditions for the above experiments are given Table 1.

### Instrumentation

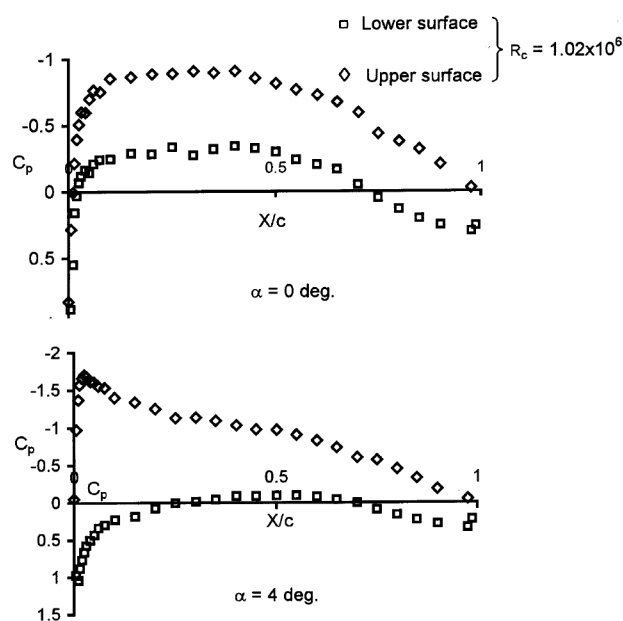
The tunnel velocity measurements were made using a 0–200 mm (water) Furness Controls digital micromanometer and the model surface pressures were measured using scanivalves integrated with appropriate Setra low pressure transducers. The hot-films were connected to a



**Figure 3.** *a*, Time series of the hot-film signal at  $\alpha = 0$  deg; *b*, Time series of the hot-film signals at  $\alpha = 6$  deg.



**Figure 4.** Variation of transition location with incidence.



**Figure 5.** Surface pressure distributions on the swept wing model.

constant temperature anemometer system (DISA 55M01) and an overheat ratio of 1.2 was used; the unsteady signals ( $e'(t)$ ) from the hot-films were amplified by a fixed gain and acquired at a frequency of 2 kHz over a duration of typically 8 s. The hot-film signals were also analysed for obtaining the intermittency factor ( $\gamma$ ) using the method described in ref. 3.

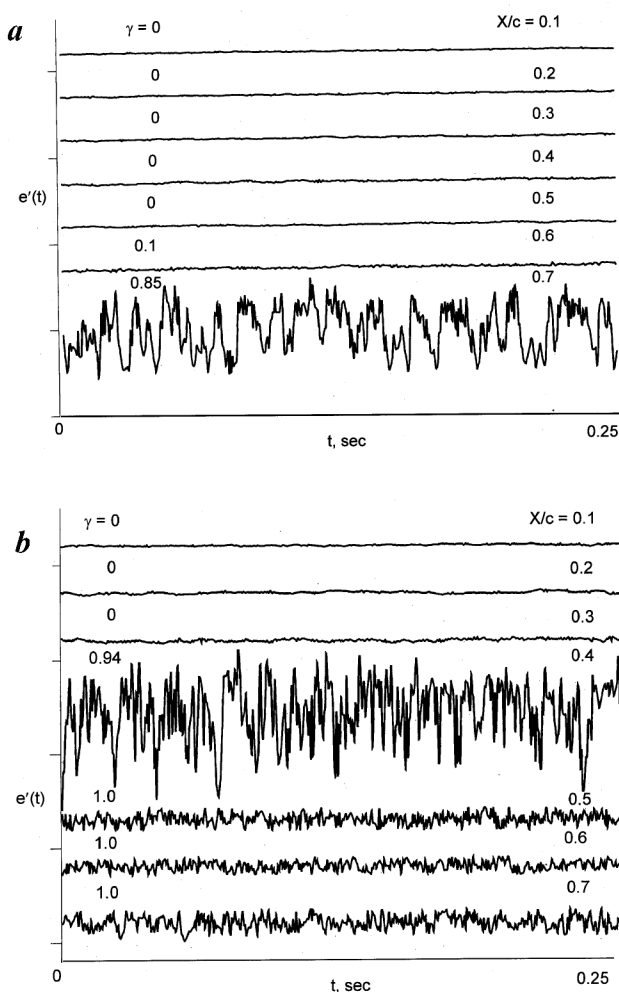


Figure 6. *a*, Time series of the hot-film signal at  $\alpha = 0$  deg; *b*, Time series of the hot-film signal at  $\alpha = 4$  deg.

## Results and discussion: NLF(1)-0416

### Surface pressure distributions

The surface pressure distributions at an incidence of 0 and 6° are shown in Figure 2. Excellent consistency in the measured pressure distributions may be seen with those of Somers<sup>4</sup> at a chord Reynolds number of  $4 \times 10^6$ .

### Transition detection

Figure 3 *a, b* show time series of hot-film signals at different streamwise locations ( $X/c$ ) on the airfoil upper surface at  $\alpha = 0$  and 6 deg. The values of laminar-turbulent intermittency factor ( $\gamma$ ) approach unity around 42% chord at  $\alpha = 0$  deg. and 27% chord for  $\alpha = 6$  deg. Figure 4 shows a comparison of streamwise locations corresponding to end of transition measured in the pre-

sent experiments with the data obtained by Somers<sup>4</sup>; the measurements<sup>4</sup> were made in the 0.9 m  $\times$  2.28 m Langley Low Turbulence Pressure Tunnel, which has a relatively low freestream turbulence of about 0.02% (in the Mach number range of 0.1 to 0.4). In Somers' experiments,  $X_E$  is defined as the beginning of a turbulent boundary layer (or end of transition), as observed from a significant increase in the noise level from the surface mounted microphones compared to the very low levels associated with a laminar boundary layer; typically the streamwise zone of transition was observed<sup>4</sup> to be around 5–6% of airfoil chord. The present data shown in Figure 4 correspond to chord locations where  $\gamma$  approaches unity. The above comparison is very encouraging, considering that the NAL 1.5 m tunnel has a slightly higher freestream turbulence level (0.1%) at the test speed of 45 m/s. The results strongly suggest that meaningful NLF research can in fact be undertaken in the NAL 1.5 m low speed facility.

## Results and discussion: Swept wing

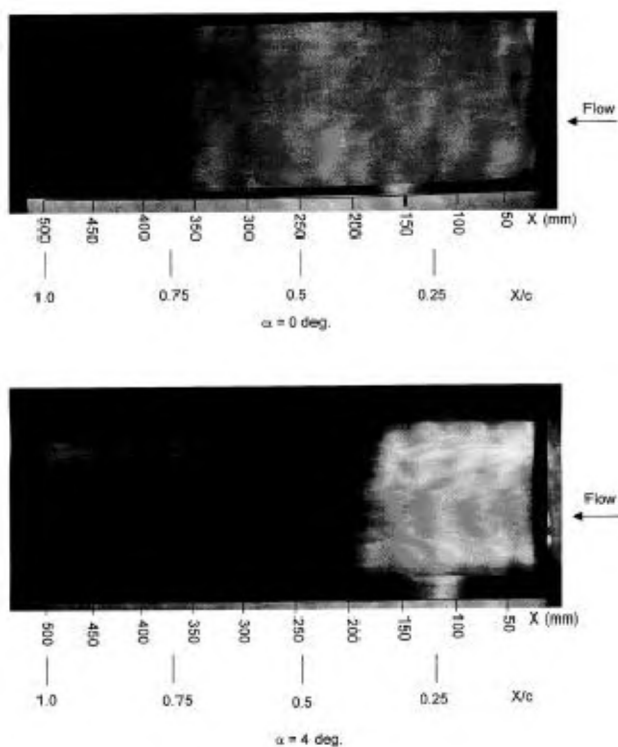
### Surface pressure distributions

Samples of pressure distributions measured in the mid-span of the wing model at an incidence of 0 and 4 deg. are presented in Figure 5. No direct comparison of these measurements can be made with results available in the literature since data on 16% thick GA(W) airfoil does not appear to be available. However, these pressure distributions show broad similarity with those measured on other GA(W) airfoils<sup>5,6</sup>.

### Transition detection

Typical examples of hot-film traces from one of the sensors of each McCrosky gauge on the airfoil upper surface at  $\alpha = 0$  and 4 deg. are shown in Figure 6. Signals from both the sensors of each hot-film gauge were very similar since the local flow direction (as observed from surface flow visualization studies) was nearly parallel to the freestream. At  $\alpha = 0$  deg. the signals have very low magnitude up to about 60% chord indicating laminar flow, and the value  $\gamma = 0.85$  at 70% chord indicates that the flow is undergoing transition; it is likely that transition is completed slightly further downstream. At  $\alpha = 4$  deg. transition moved upstream and was completed around 40% chord. The hot-film signals at 50, 60 and 70% chord positions (Figure 6 *b*) indicate turbulent flow.

Two samples of the chemical sublimation pattern on the upper surface, at  $\alpha = 0$  and 4 deg. are shown in Figure 7. These patterns suggest beginning of transition around 70% and 35% chord at  $\alpha = 0$  and 4 deg. respec-



**Figure 7.** Chemical sublimation patterns on swept wing model.

tively. Considering the fact that hot-films were not closely spaced on the airfoil, the agreement of transition indication by sublimation technique with hot-films can be regarded as good. It was found that transition location moved upstream to about 25% chord at  $\alpha = 6$  deg.

## Conclusions

We have reported results from two experimental investigations on airfoil boundary layer transition in the NAL 1.5 m low speed wind tunnel. The calibration tests involving measurements on the NLF(1)-0416 airfoil suggest that the 1.5 m wind tunnel can be employed for meaningful NLF research in the future, although the freestream turbulence levels are not very low. The results on the swept wing show very satisfactory comparison of transition inferred from hot-films and the chemical sublimation technique – these experimental tools can now be routinely utilized in airfoil development programmes at NAL.

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