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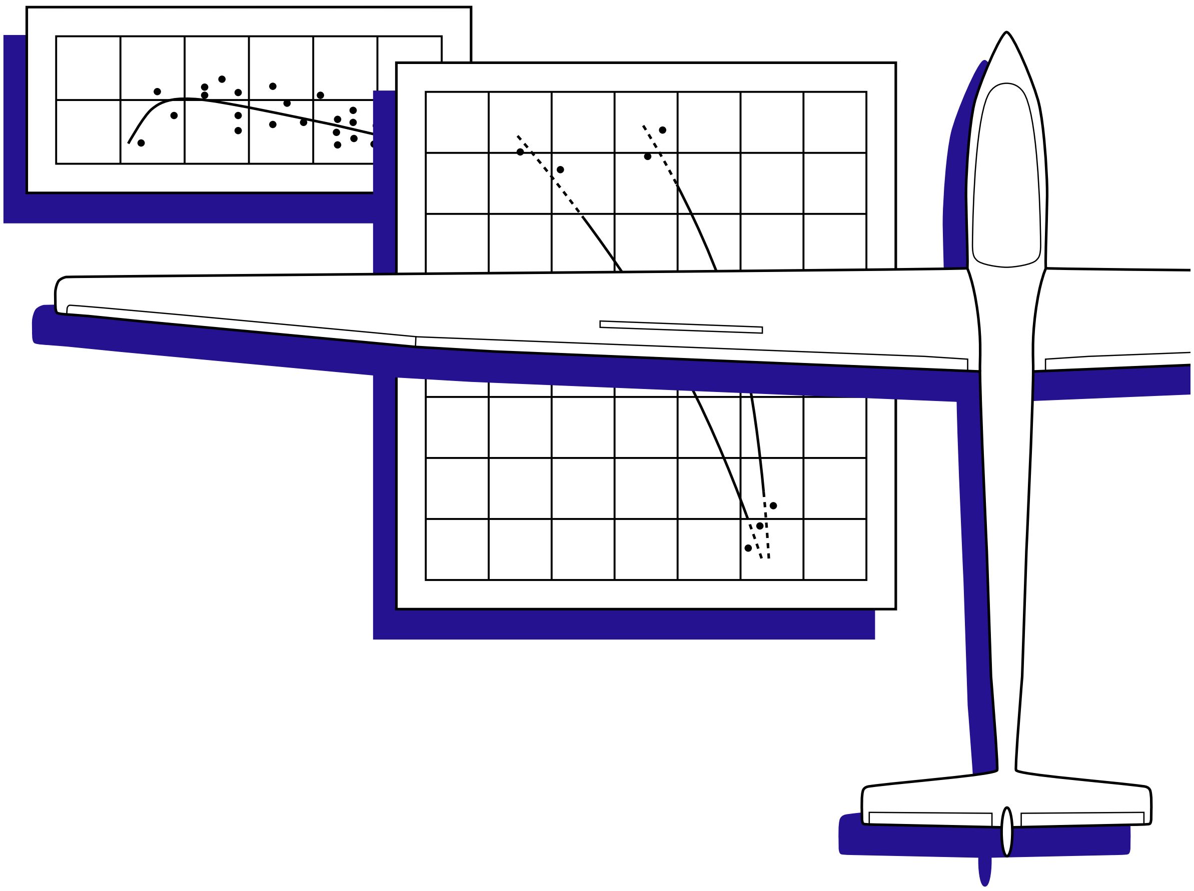

- **Wind Tunnel Measurements on Details of Laminar Wings**

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(International Scientific and Technical Organization for Gliding)
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Technical Soaring (*TS*) documents recent advances in the science, technology and operations of motorless aviation.
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From the Editor

OSTIV Congress XXXIII

OSTIV Congress XXXIII will be held in conjunction with the 34th World Gliding Championships in Benalla, Australia, 8–13 January, 2017. We encourage everybody to attend and present their latest work. The call for papers appeared in *TS* 39:1 and may be obtained from OSTIV — contact `admin@ostiv.org`.

Open-Access, continued

In the last issue of *Technical Soaring* (Vol. 39 No. 1), we announced a new Open-Access Policy clarifying OSTIV's policies concerning use of articles appearing in *TS*. This policy now appears on the Table of Contents page. One minor revision addresses the question of authors self-archiving their material to open-access websites:

> **Archiving.** Authors may archive their own papers on the web and in Open-Access archives as follows. The version of the paper as first submitted to Technical Soaring may be archived at any time. The version as published may be archived in Open-Access archives starting 12 months following publication. OSTIV may archive papers as published at any time.

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Publication Date

This issue is the second of Volume 39 of *TS*, corresponding to April-June 2015. For the record, the issue was published in March, 2016.

Acknowledgments

We gratefully acknowledge Associate Editor Mark Maughmer, who oversaw the review of the Frey paper in this issue.

Respectfully,

Judah Milgram
Editor-in-Chief, *Technical Soaring*
`ts-editor@ostiv.org`

Wind Tunnel Measurements on Details of Laminar Wings

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Abstract

Flow visualization using oil in wind tunnel as well as in free flight have been conducted to show whether or not the pressure field of the fuselage does influence the position of laminar-turbulent transition on a glider wing. Within the wind tunnel campaign, valuable experience could be gained in visualization of laminar separation bubbles under free flight Reynolds numbers. In free flight, it could be shown that the fuselage does not influence the boundary layer of the wing to a significant spanwise extent. Moreover, winch launch is an appropriate way to conduct oil visualization in free flight. It even shows some significant and unexpected advantages. Moreover, the effect of details like fences and aileron linkage fairings on parasite drag has been investigated under laboratory conditions. Fairings have been applied in closed, open and even cut configuration on the suction as well as on the pressure side of the airfoil. All details are clearly visible in the wake bucket, however, their effect on total drag can be considered rather small.

Introduction

Recent transition experiments on an Eppler 603 laminar airfoil showed that in free flight, a turbulent boundary layer occurred upstream from the position where it did in the wind tunnel. This is in opposite to what could be expected concerning free stream turbulence. The obvious reason for that is the dominant effect of the pressure gradient on the stability of a laminar boundary layer. There are significant differences in pressure distribution between wind tunnel and free flight caused by blockage effects in the open test section and perhaps also by displacement of the fuselage. Flow visualization using paint was intended to show whether there is a significant influence on the spanwise transition line caused by the body's pressure field. Prior to that, some "training" was intended in the tunnel.

A second topic that has been discussed in Idaflieg circles for several years now is the effect of details such as fences on total drag. In 2006, a project had been initiated to measure the loss in overall performance by applying for example four additional pairs of fences on the wings of an ASW 28 (Fig. 1). The result was a decrease in maximum L/D of about 0.25 points for a single pair of fences [1]. Extensive efforts have been made to visualize the airflow around aileron linkage fairings.

Generally it has to be stated that a detailed investigation of these topics is best done under laboratory conditions. TU Dresden has a low speed wind tunnel (Fig. 2) that can be used for Akaflieg projects to a certain extent. The wind tunnel department has at its disposal a wing section cut from a damaged Twin-Astir wing that can be installed in the open test section between two endplates. It has been used in the experiments described below. In February 2012, there was some free wind tunnel time available for visualization "training" as well as detailed flow investigations. Two years later, another wind tunnel campaign could be conducted to clarify some open questions resulting from the previous measurements.

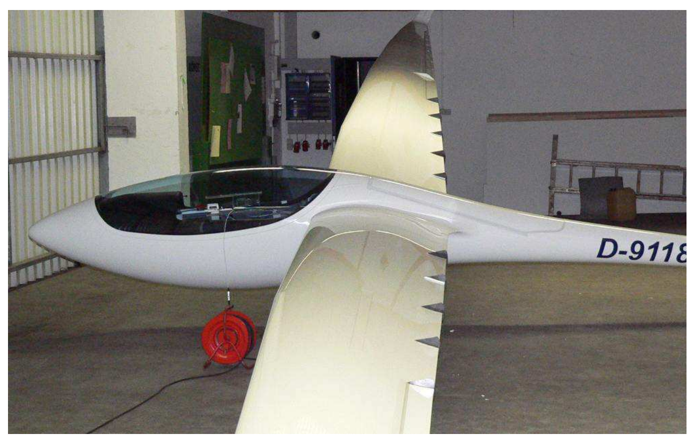


Fig. 1: ASW 28 carrying 5 pairs of fences

Transition on a Laminar Airfoil

Comparing the pressure distribution on the E-603 wing glove used for transition experiments in wind tunnel and free flight, a distinct suction peak at the nose can only be observed in flight,

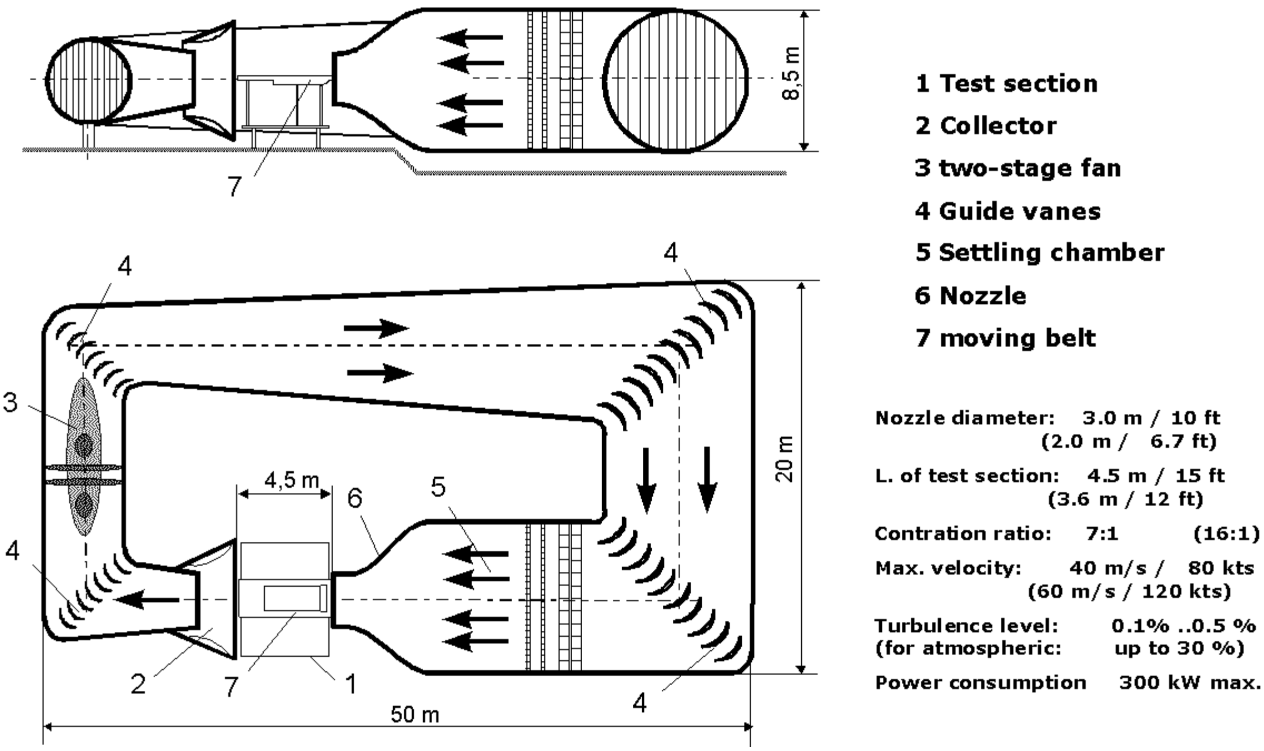


Fig. 2: Low speed wind tunnel of TU-DD

probably increased by the fact that the fuselage's maximum diameter and therefore pressure minimum is slightly upstream from the wing. In the tunnel however the pressure distribution is flattened by the closeness of the airfoil nose to the edge of the open jet. But most important is that the position of the main pressure gradient moves, which is responsible for laminar separation and turbulent reattachment (Fig. 3).

The laminar separation bubble is also evident in the pressure distribution. Applying a turbulator at 10% cord causes the bubble to vanish, in turn causing higher pressure between 50 and 55% chord (Fig. 4).

The aim of the intended experiment was to investigate whether the pressure distribution on the wing is significantly influenced by the fuselage. If this was true, an effect on transition point should be visible by its spanwise decay. Doing so, the gap was to be closed between the turbulent wedge at the wing root and undisturbed flow further outboard. Both have been investigated before using infrared thermography. However, flow visualization using paint requires much less instrumentation and is the only way to detect laminar separation in free flight.

Within the described experiments, the most classical mixture of soot, oil and kerosene has been applied. This worked surprisingly well, whereby a hint from the Akaflieg Braunschweig ("make it as wet as possible") proved to be very helpful. Turbulent wedges could be observed, originating from agglomerated soot.

Good agreement has been achieved between flow visualization and pressure distribution concerning position and dimension of the separation bubble, proving that the wing glove used for quantitative measurements does not significantly influence the boundary layer (Fig. 4).

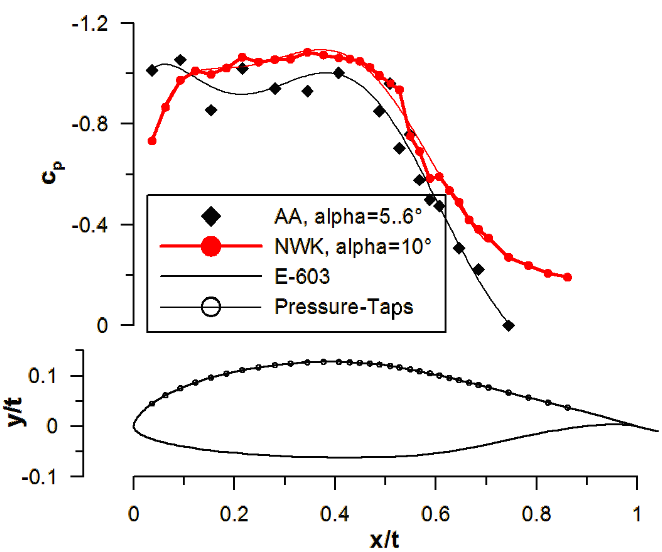


Fig. 3: Pressure distribution in wind tunnel and free flight, Eppler 603

A single trial has been made on the pressure side, which is in general the more interesting area for investigation and control

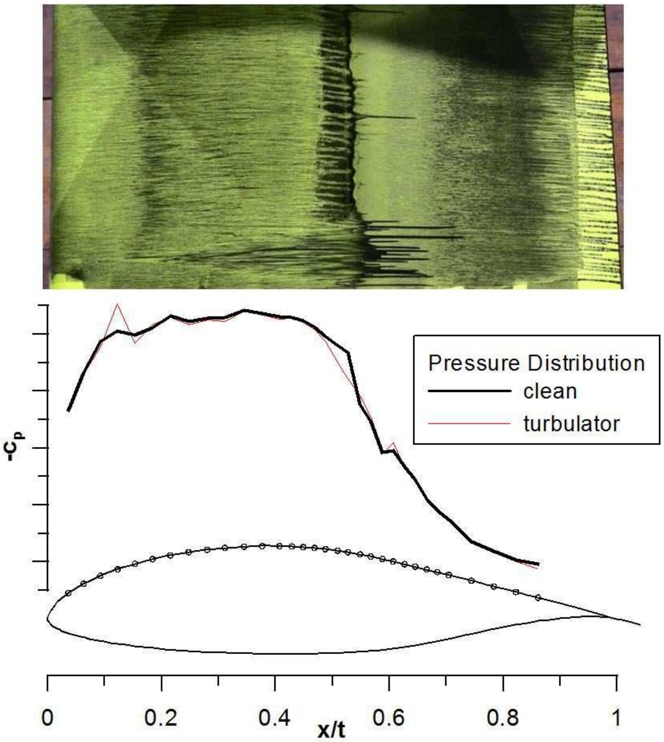


Fig. 4: Flow visualization and pressure distribution in wind tunnel, Eppler 603. Flow is from the left.

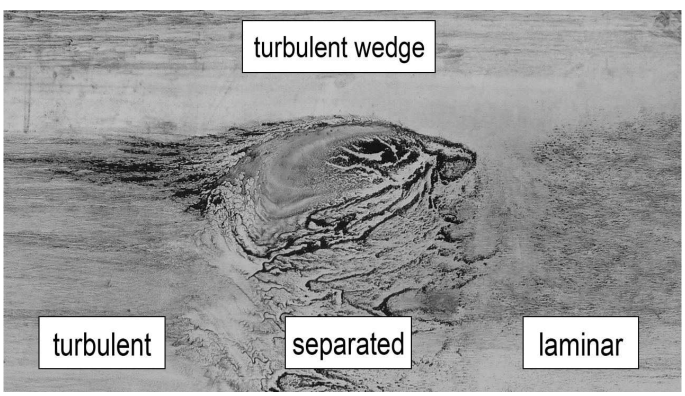


Fig. 5: Laminar separation on pressure side and turbulent wedge, Eppler 603. Flow is from the right.

of laminar separation bubbles. A big turbulent wedge occurred near the center line, painting interesting figures into the separated area. There may be doubt whether all the paintings found in caves are really made by our ancestors (Fig. 5).

In October, 2013, the intended free flight experiment could be conducted. Paint has been applied to the wing of Akaflieg Dresden's Twin Astir for six minute flights taking off with the winch. This kind of launch has even some advantages compared to an air tow. During climb, angle of attack and lift coefficient can be kept close to the values in untethered flight using a simple

Fig. 6: Flow visualization in free flight, Twin-Astir with Eppler 603 airfoil.

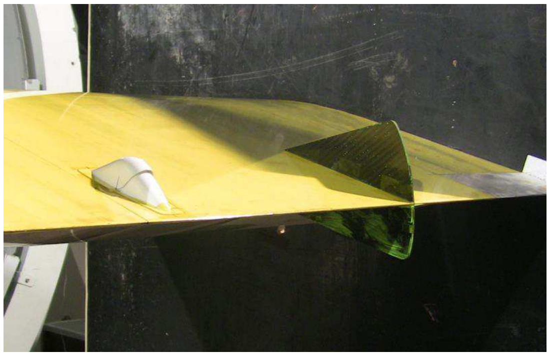
wool tuft sideways of the canopy, just leading to slightly higher airspeeds than normal. In opposite, the tow aircraft dictates the speed for take off and its wake strongly distorts the glider's lift distribution. Hence, there is no need to cover the area of interest for takeoff. Finally, turn around time is shorter with the winch, as only one test case can be investigated during a single flight anyway.

Within two tests, a significant camber in the transition line, which would prove the fuselage's influence, could not be found (Fig. 6). In consequence, wind tunnel blockage is probably the main guilty effect.

Fences and Fairings

Besides more visualization to get an overview, the wing segment's wake has been extensively investigated using pitot-tubes to detect total pressure loss.

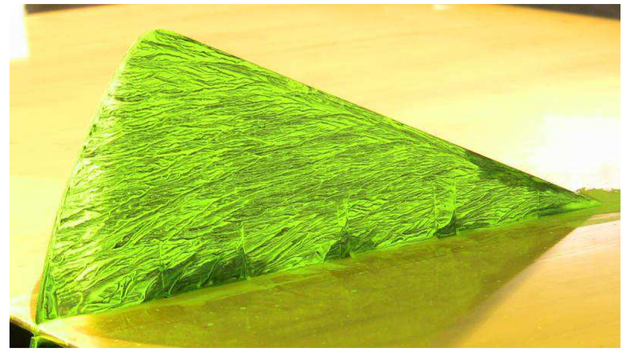
Michael Greiner (Schleicher) had provided a drawing of a fence used with the ASW 28 and Andreas Lutz (Schempp-Hirth) sent two Arcus fairings as well as the prepared ASW 28 fairing he once had used for free flight investigation. Considering the



(a)

(b)

Fig. 7: Experimental setup for wake measurements. (a) Arcus-fairing on suction side and fence; (b) fairings on both sides, Arcus (suction side) ASW-28 and Arcus (pressure side)



(a)

(b)

Fig. 8: Flow visualization on fence (a) and aileron fairing (b). View of wing upper surface from above, corresponding to configuration in Fig. 7(a).

ratio between the chord length of the Twin-Astir's wing root and that of the ASW's outer wing, the fence has been scaled by a factor of two for similarity (Fig. 7(a)). Moreover, the Reynolds number could be kept high without running the tunnel at its limit for longer times.

In contrast, the aileron linkage fairings could only be applied in their actual size. However, there is no reason to scale them because these fairings naturally tend to be smaller for double seaters, as thicker wings provide more space inside.

The fairings have been applied on the suction side as well as on the pressure side of the wing (Arcus). In the case of the ASW 28 a single fairing only is applied to the pressure side for practical reasons. Application on the lower side is of interest as being representative of negative flap settings, when the airfoil develops a concave shape on its upper surface (Fig. 7(b)).

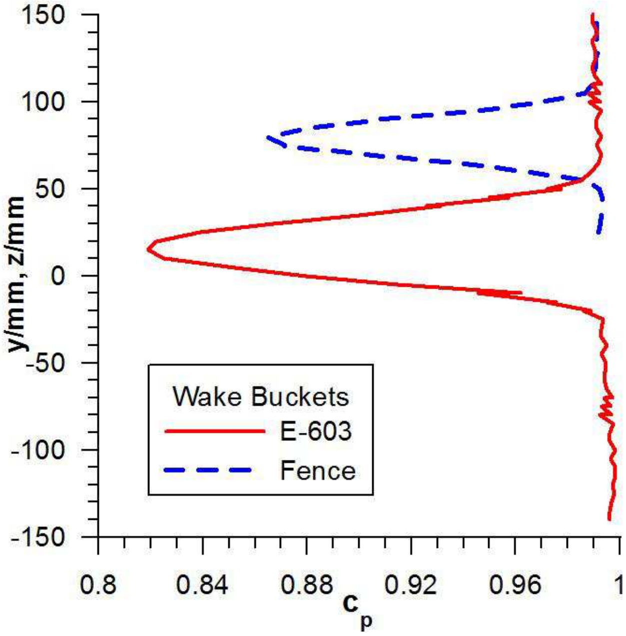
At first, some more modern art has been created that leaves quite a lot of room for interpretation (Fig. 8).

In the contour plot of total pressure, the fence is clearly visible (Fig. 9(b)). The height of its wake is about 150mm, which is, considering the scale factor, 1% of the half span for a standard class glider. The magnitude of the wake bucket is, compared to that of the airfoil, clearly less than half. So the total drag increase should be less then 0.5% of the profile drag. Further estimation leads to an extra sink rate of only several millimeters per second, which should be considered as fairly negligible.

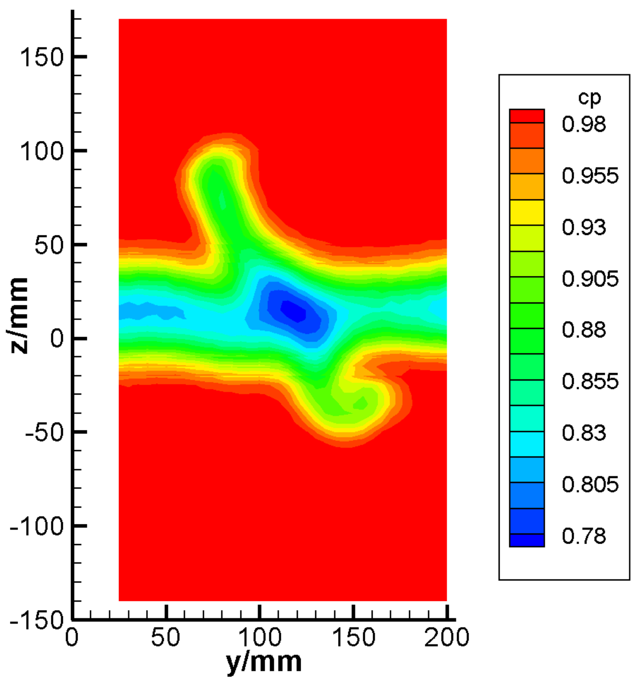
The only slightly tapered wing already causes a vortex sheet strong enough to distort the fence's wake by an angle of almost 45 degrees from trailing edge to pitot probe. Aileron linkage fairings instead did not lead to any recognizable change in the magnitude of the wake, but made its position move (Fig. 10). With a fairing on the upper side, the wake moved downward, indicating a local aerodynamic twist, due to the additional camber caused by the fairing. Increased circulation and a pair of free vortices induce additional downwash. Given this, the covers should cause induced drag rather than parasite drag. Nonetheless, this effect had to be added to C_{D_0}, as the lift distortion is independent from the over all angle of attack. On the pressure side, obviously the boundary layer is so thick, not even an effect on induced velocities can be proved.

Some discussion occurred about the question whether the most practical solution has been carried out by SZD with the Puchacz: Fairings are only attached to the fixed part of the wing, from which the push rod protrudes and the joint is open for assembly and maintenance. This is, of course, only applicable on the pressure side, but then provides quite a good opening for drainage (Fig. 11(a)).

Within an additional test campaign in February 2014, the ef-

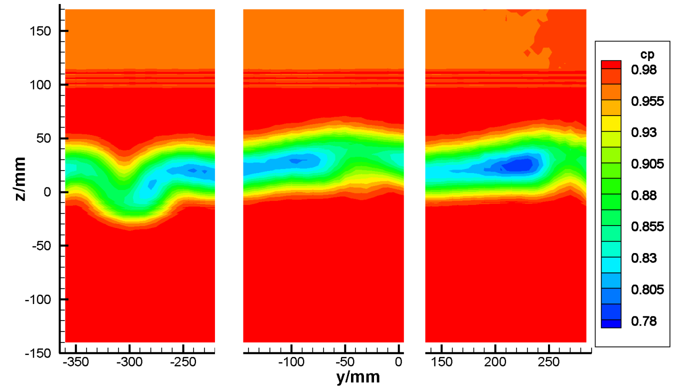


(a)



(b)

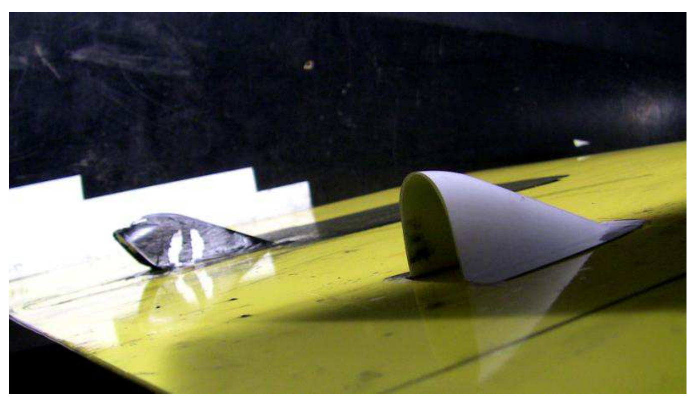
Fig. 9: (a) Wake bucket of fence compared to that of airfoil; (b) vortex sheet downstream of the slightly tapered wing showing distortion of wake flow



(a) (b) (c)

Fig. 10: Wake of covers (closed) on suction (a) and pressure side (b and c)

(a)

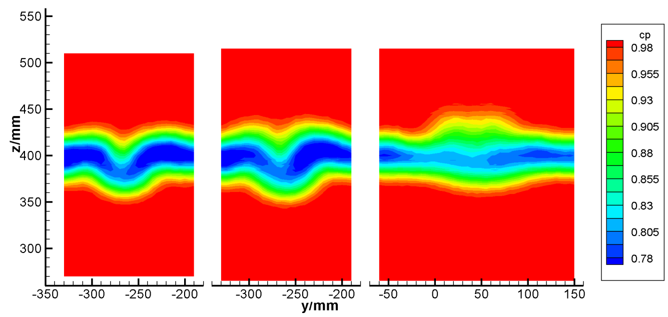


(b)

Fig. 11: Open fairings on Puchacz wing (a) and wind tunnel model (b)

fect of open fairings has been investigated. Only the upstream parts of the covers remained on the wing, the rear parts, which should be on the flap or aileron, respectively, have been removed (Fig. 11(b)).

As the wake measurement did not show any difference to the previous case, one of the fairings was cut at its maximum cross section to copy the Puchacz as close as possible. A slight increase of the width of the wake was to be observed, however, the circulation jump vanished (Fig. 12). The question of which ef-



(a) (b) (c)

Fig. 12: Wake of covers on suction side: (a) closed; (b) open; (c) cut

fect is stronger warrants further discussion. Most probably, both are too weak to make any significant difference in total drag.

Tracking the downstream propagation of the wake bucket behind a full fairing, a slight increase of the sagging can be observed (Fig. 13). This indicates the presence of a pair of free vortices, even though these have to be very weak.

Conclusions

Oil visualization shows no significant influence of the fuselage's pressure field on transition and turbulent re-attachment on the wing. Good agreement between pressure measurement and flow visualization has been achieved in the wind tunnel.

Make oil paintings as wet as possible.

The wake of fences is clearly detectable, but they have only a very small influence on total drag.

The aileron linkage fairings' effect on viscous drag is barely recognizable, a remarkable effect on induced velocities is to be observed instead. Open fairings show no change, as long as the downstream opening does not exceed the boundary layer too far; big openings produce some viscous drag but make the induced velocity effect vanish. Both effects are probably negligible with respect to total drag.

Acknowledgments

The author would in particular like to thank Michael Greiner and Andreas Lutz who provided data and material out of the production line of sailplane manufacturers making these investigations possible. Special thanks is also due to Akaflieg Dresden who allowed me to pollute their Twin Astir with soot and oil.

The results presented here appeared previously in an Idaflieg report [2] and a TU Dresden internal research report [3].

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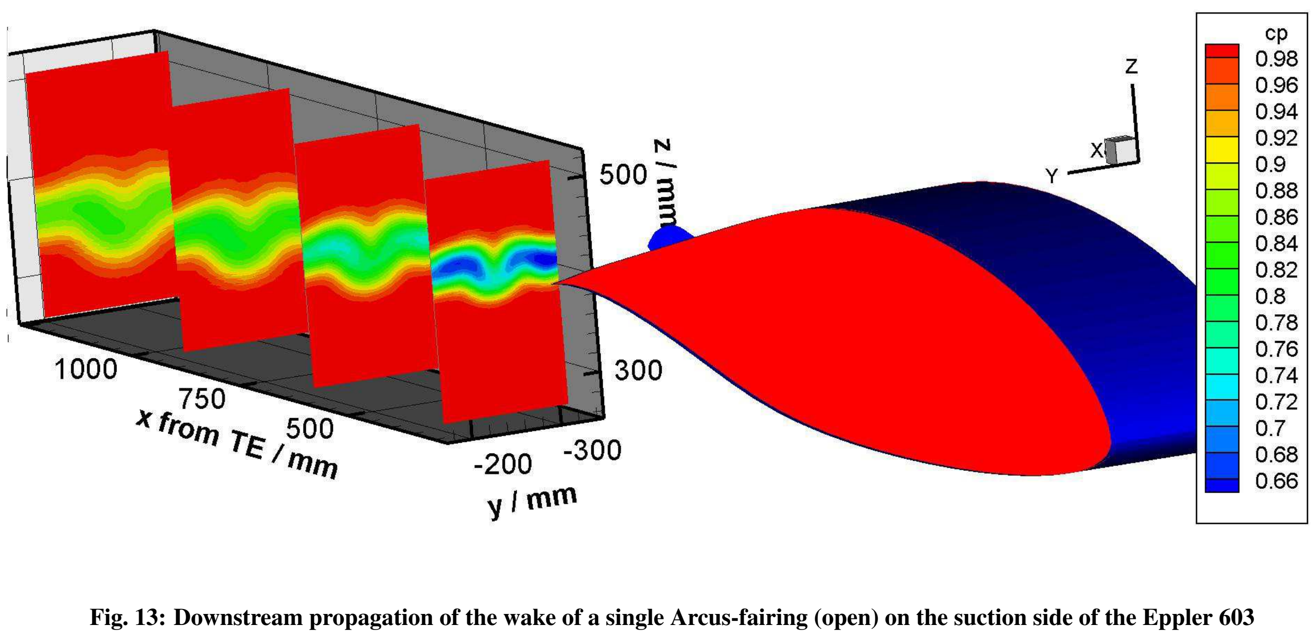

Fig. 13: Downstream propagation of the wake of a single Arcus-fairing (open) on the suction side of the Eppler 603