Measurement of different down tube sections
for the
Company Wills Wing / USA

1. Test arrangement

All measurements were made at the Model Wind Tunnel of the University of Stuttgart. The angle of attack is measured with a high precision potentiometer, the lift by a load cell and the drag with the help of a wake rake. While the angle of attack and the lift coefficient are measured directly, the evaluation of the drag requires a measurement of different pressures. The whole measurement set-up is controlled by a PC.

The following values are needed for the determination of the airfoil drag:

- (free stream-) dynamic pressure head upstream the airfoil $q_\infty = g_\infty - p_\infty$
- maximum total pressure loss in the center of the wake $\Delta g_{\max} = g_\infty - g_{\max}$
- integrated total pressure (mean value) across the width of the rake $\overline{\Delta g} = g_\infty - \overline{g_D}$
- static pressure difference between the wake and the free stream $\Delta p_D = p_\infty - p_D$

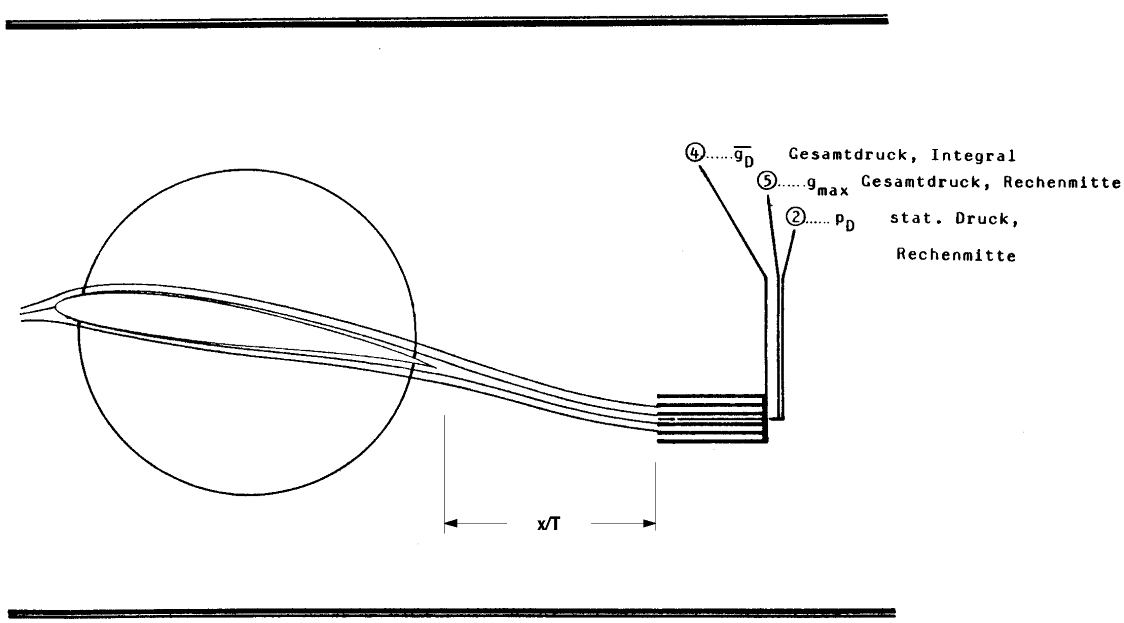

Figure 1: Sketch of the measurement set-up

For this kind of drag measurement it is important to pay attention to the fact that the wake rake width fits to the width of the wake to achieve a good resolution which minimizes the discretisation error.

Geometrical definitions

For the wind tunnel measurements, different airfoils of the Company Wills Wing and other commonly used down tubes were available. In addition the influence of different trips (turbulators) was investigated. The numbering of the airfoils is equivalent to the numbering used in the purchase order (see appendix).

1.1 Wills Wing Carbon in original configuration (chord length 76.5mm, thickness 19.9mm, relative thickness 26%) with trip (approximately 1x1mm) at 25% chord length

1.2 Wills Wing Carbon with 3D-turbulator (thickness 0.5mm, width 10.5mm, wedge angle 60°) with its rear end at 25% chord length

1.3 Wills Wing Carbon with V-form stamped vinyl tape, thickness of the stamping 0,6mm, depth of stamp tape 9.5mm, depth of V-stamping 4mm, with its rear end at 25% chord length

1.4 Wills Wing Carbon without trip

2.1 Seedwings down tube airfoil section out of aluminum (chord length 62.4mm, thickness 25.2mm, relative thickness 40.38%) with trip (approximately 0.5x0.5mm) at 8% chord length

3.1 Aluminum round tube as a section for reference measurements (diameter 28.575mm)

3.2 Aluminum round as tube section with 3D-trip (thickness 0.5mm, width 10.5mm, wedge angle 60°) at 30% chord length

4.1 Finsterwalder aluminum down tube airfoil section out of aluminum (chord length 49.2mm, thickness 25.9mm, relative thickness 52.64%) with trip (approximately 0.5x0.5mm) at 5% chord length and dip (approximately 0.3x0.3mm) at 44% chord length

4.2 Wills Wing aluminum standard section (chord length 50.5mm, thickness 26.2mm, relative thickness 51.88%) with trip (ca. 0.5x0.5mm) at 33% chord length and dip (approximately 0.3x0.3mm) at 50% chord length

5.1 Wills Wing new aluminum in original configuration (chord length 76.6mm, thickness 20.2mm, relative thickness 26.37%) with trip (approximately 0.5x0.5mm) at 10% chord length

5.2 Wills Wing new aluminum with V-form stamped vinyl tape, thickness of the stamping 0.6mm, depth of stamp tape 9.5mm, depth of V-stamping 4mm, with its front end at 10% chord length

1. Test conditions

All sections were measured at the same free stream velocities (10m/s, 15m/s, 20m/s and 30m/s), while the angle of attack was changed from –15degrees to +15degrees. Here the measurements were always started at –15degrees and than the angle of attack was increased by 1 degree steps. Because all of the measured sections are symmetrically (and therefore the polar should be symmetric), effects of hysteresis can be observed by this procedure.
The drag measurements were made in a region of 100mm in spanwise direction (50mm of the middle of the models to each side) with step size of 1.5mm. This procedure is used to determine a reliable mean value of the drag from approximately 67 single measurements.
The lift coefficient was averaged during the whole time needed for the drag measurement.

2. Measure arrangement

Because of partly large turbulent separations at some of the airfoil sections the drag measurement with a wake rake (instead of a balance) is problematic. The large sized vortices which occur in the wake cause local unstationary oblique flow at the tubes of the rake and in addition the energy of these vortices is not recorded by the wake rake.
During the measurements another problem turned out. Mainly for the round sections and sections with very blunt trailing edge the static pressure in the wake also very far behind the models was significantly different to the level of the undisturbed static pressure of the free stream flow.
For small static pressure differences, which are usual, a standard wind tunnel correction is used. The large pressure difference occurring at the measurement of e.g. the round cylinder (round tube) could not be corrected in a reliable manner. Therefore, in this cases only rough values are declared which are based on the measured values and the applied wind tunnel corrections.
During the measurements the same rake distance was used for down tube sections with similar expected results. For the measurements 1.1 -1.4, 2.1 and 5.1 a rake distance of x/c = 2 (means 2 times chord length) was chosen, for the measurements 4.1 and 4.2 a distance of 3 times the chord length. The correctness of these distances was verified by comparative measurements.

5. The investigated turbulators (trips)

During the measurements different turbulators (trips) were used which were partly manufactured at the time of production of the tube. The following types of turbulators were tested:

- Stumble edge turbulators, i.e. cast moulded (at the aluminum sections) e.g. laminated into the form (at the carbon section) 2D-turbulators with rectangular cross-sections of the sizes 0.3x0.3mm, 0.5x0.5mm and 1x1mm (measures are approximately-measures)
- Zig-zag tape turbulators, like they are used in the manned gliding. Sizes see sketch, thickness approximately 0.5mm
- Stamped tape turbulators, out of stamped tape indicated vortex generators. Sizes see sketch too, thickness of stamped tape approximately 0.1mm, thickness of stamping approximately 0.6mm

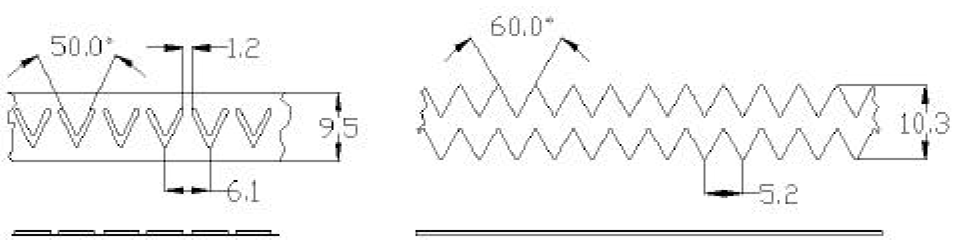

Figure 2: Stamped e.g. zig-zag tape turbulators

1.1 Wills Wing Carbon, standard trip

The carbon down tube in the original configuration shows a normal behavior over an angle of attack range of ±5degrees. At higher angles of attack a turbulent separation occurs on the suction side and causes an immediate increase of drag up to values between 0.1 and 0.2. This increase varied with velocity and angle of attack.

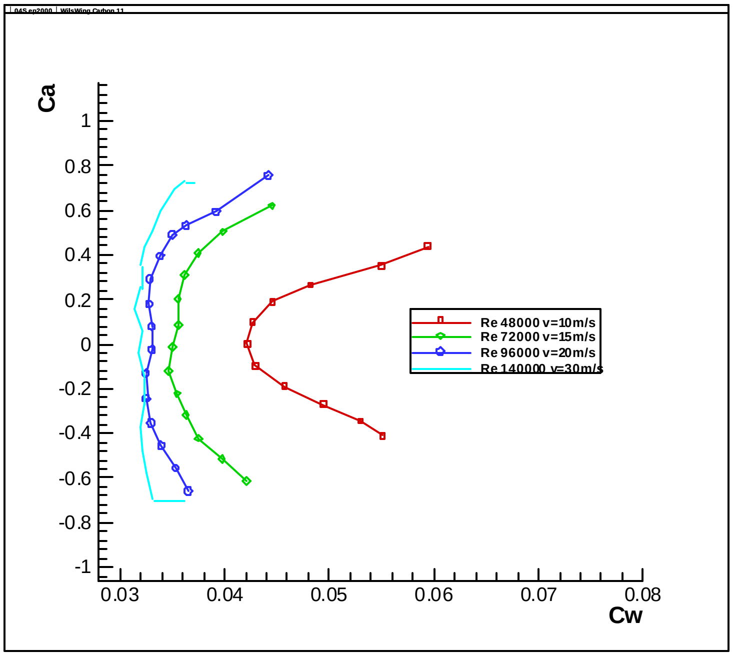

Figure 1.1-1: Cl-Cd diagram WillsWing Carbon 1.1

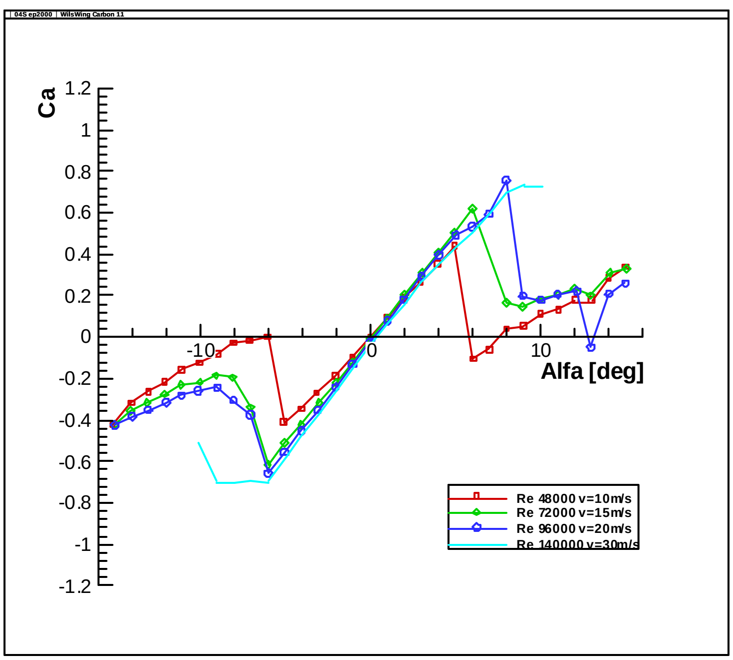

Figure 1.1-2: Cl-Alpha diagram WillsWing Carbon 1.1

1.2 Wills Wing Carbon, zig-zag trip

By attaching the relatively thick (0.5mm) 3D-turbulator the separation and the accompanying abrupt increase in drag can be delayed to an angle of attack range of ±8degrees. The drag coefficients in the separated case are equal to the former ones (see 1.1). Due to the turbulator the drag at zero angle of attack Cd_0 is increased by approximately 50%.

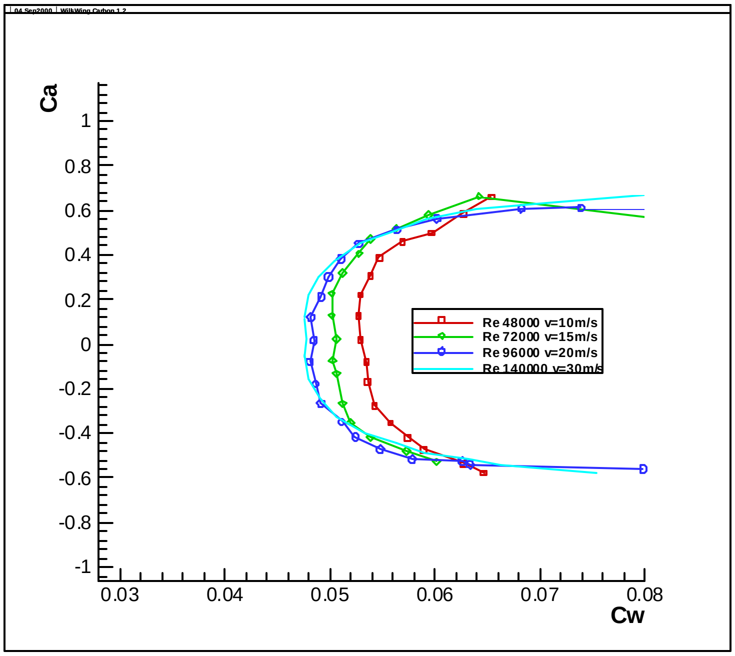

Figure 1.2-1: Cl-Cd diagram WillsWing Carbon 1.2

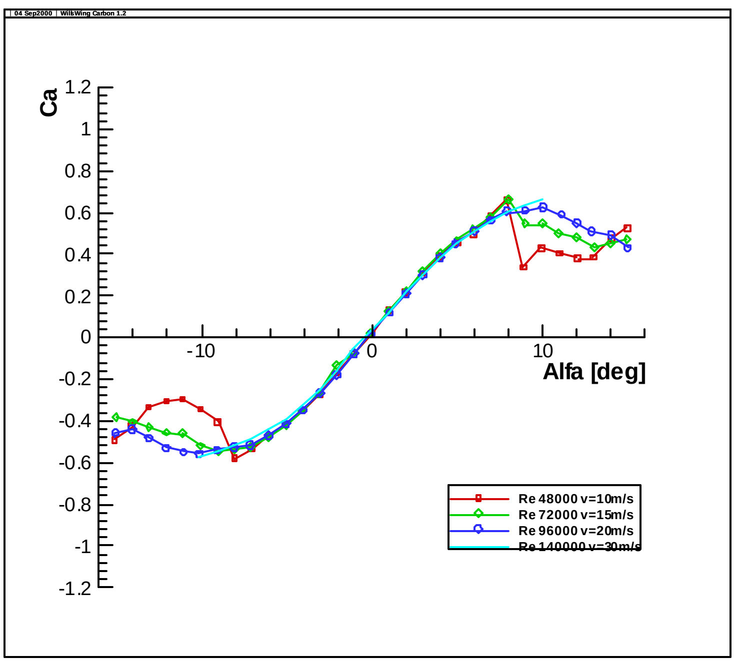

Figure 1.2-2: Cl-Alpha diagram WillsWing Carbon 1.2

1.3 Wills Wing Carbon, vinyl V-trip

The use of an simulated vortex generator expands the angle of attack range of the airfoil, for which no turbulent separation is observed, up to ±10degrees. The drag coefficient Cd_0 is increased about 15%. However this configuration caused a very high noise emission (single tone) at a velocity of 30m/s at angles of attack of ±2 degrees.

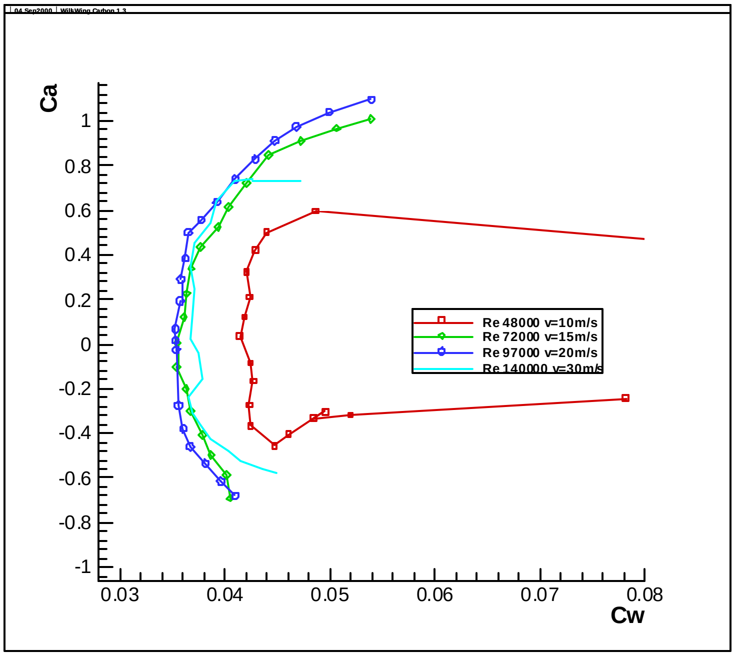

Figure 1.3-1: Cl-Cd diagram WillsWing Carbon 1.3

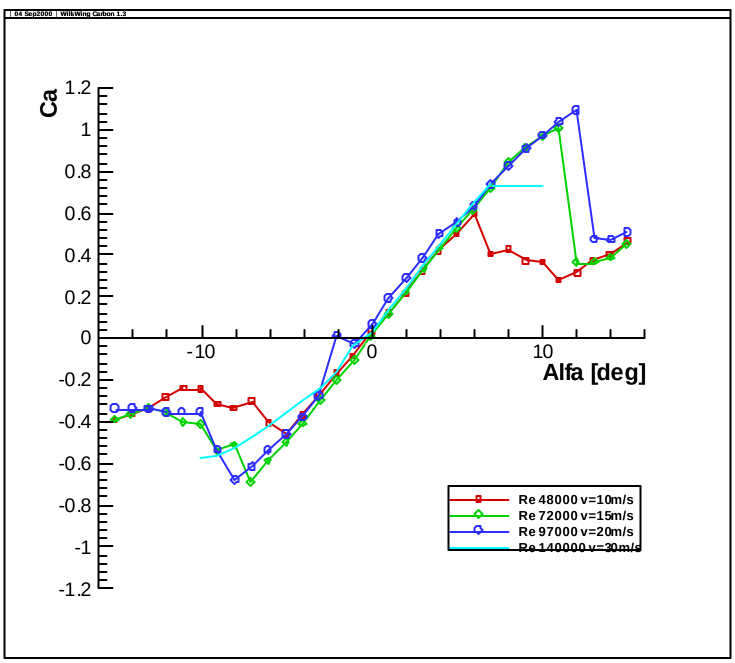

Figure 1.3-2: Cl-Alpha diagram WillsWing Carbon 1.3

1.4 Wills Wing Carbon, no trip

Omitting the standard trip reduces the operation range of the airfoil to angle of attack ranges of ±4degrees at 20m/s. At lower velocities, separation exists practically permanently. The drag coefficients measured here are similar as reported under 1.1.

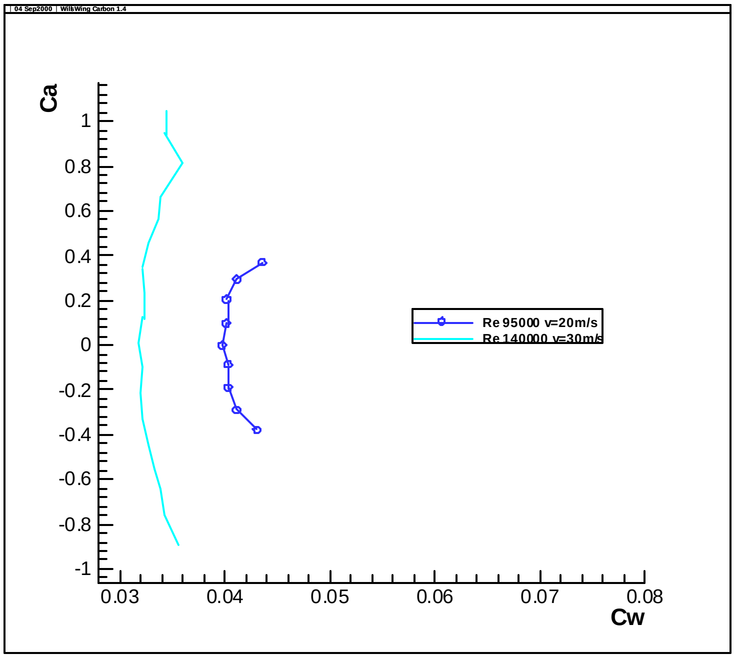

Figure 1.4-1: Cl-Cd diagram WillsWing Carbon 1.4

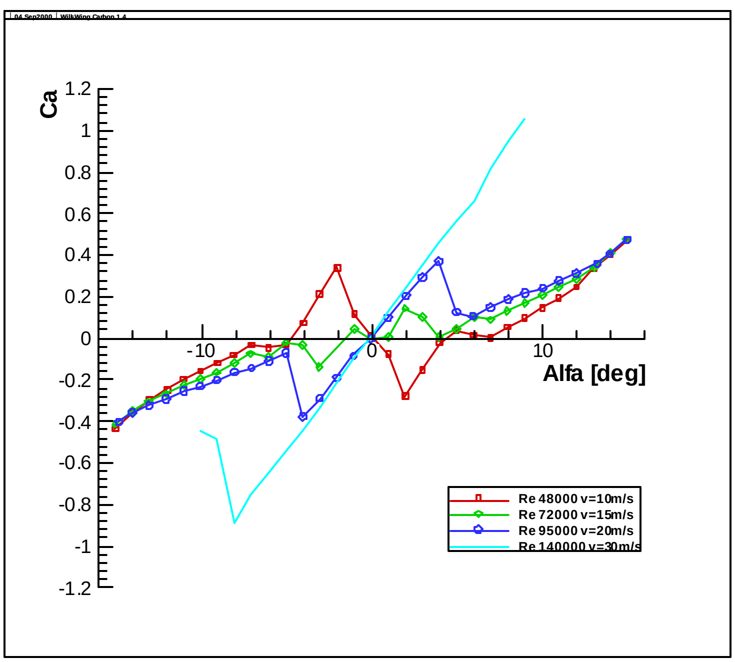

Figure 1.4-2: Cl-Alpha diagram WillsWing Carbon 1.4

2.1 Seedwings aluminum down tube

Separation occurs at the Seedwing section at approximately 5degrees. This is caused by its relative thickness of 40.38%. At a velocity of 10m/s the separation is permanent. Because of the large static pressure difference between wake and undisturbed free stream flow no exact specification can be made about the drag coefficient at 10m/s. However, the drag coefficient is expected to be in the range of $Cd_0 = 0.14 - 0.16$.

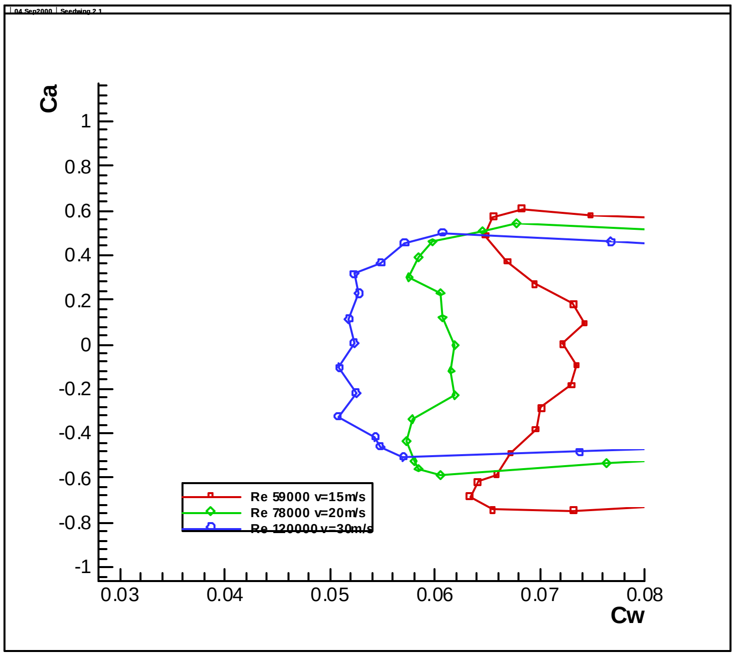

Figure 2.1-1: Cl-Cd diagram Seedwings 2.1

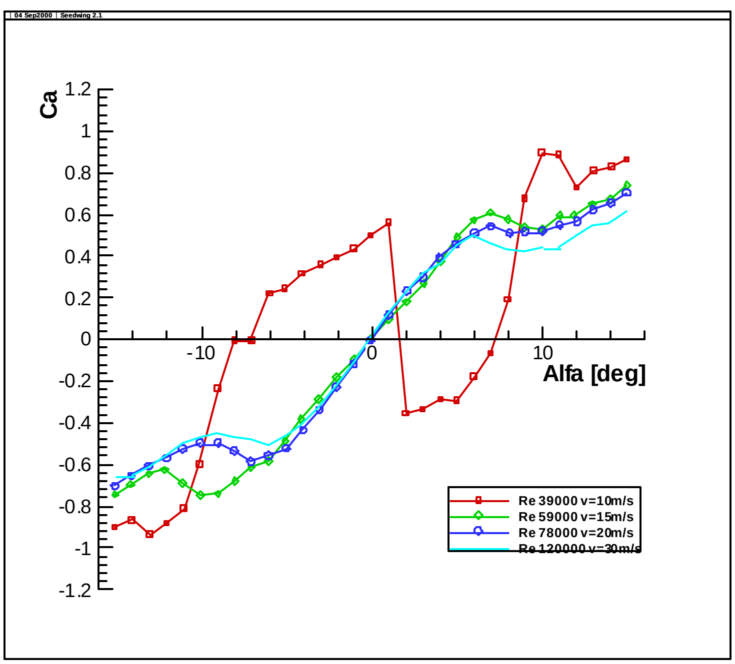

Figure 2.1-2: Cl-Alpha diagram Seedwings 2.1

3.1 Aluminum round tube

An exact measurement of the round cylinder was not possible because the static pressure of the wake increased only slowly to the value of the undisturbed free stream. Therefore a smaller tube with diameter d=14mm was manufactured. But even with this tube and rake distances of 10 times the chord length large static pressure differences were observed. Further shifting of the rake was not possible because of the length of the measurement chamber. The estimated values of the drag coefficients (for the 14mm tube) were in the order of 0.75 (20m/s) to 0.81 (30m/s). This is below the value of approximately 1.1 to 1.2 reported in literature. Nevertheless, this very inferior case shows that the magnitude of the drag coefficient can be evaluated.

3.2 Aluminum round tube with turbulator

Because of the results obtained in 3.1 the tests of the round tube with turbulator were skipped.

4.1 Finsterwalder aluminum down tube

This very thick airfoil (52.64%) was practically throughout the whole measured (alpha) range in a separated condition. The turbulent separation could be observed with a tuft probe at 39% - 42% chord. The position of the separation was almost independent from angle of attack. (±15degrees).
Because of the large static pressure difference caused by the separation the exact drag coefficient can not be specified for this airfoil. The estimated drag is listed below.

- Free stream velocity 10m/s → Cd_0 approximately 0.28 – 0.35
- Free stream velocity 15m/s → Cd_0 approximately 0.28 – 0.35
- Free stream velocity 20m/s → Cd_0 approximately 0.27 – 0.34
- Free stream velocity 30m/s → Cd_0 approximately 0.11 – 0.20

It is possible to approximately determine the shape of the drag curve from the geometry of the Cl-Alpha curve because every erratic change of the lift coefficient goes along with an intense increase of drag.

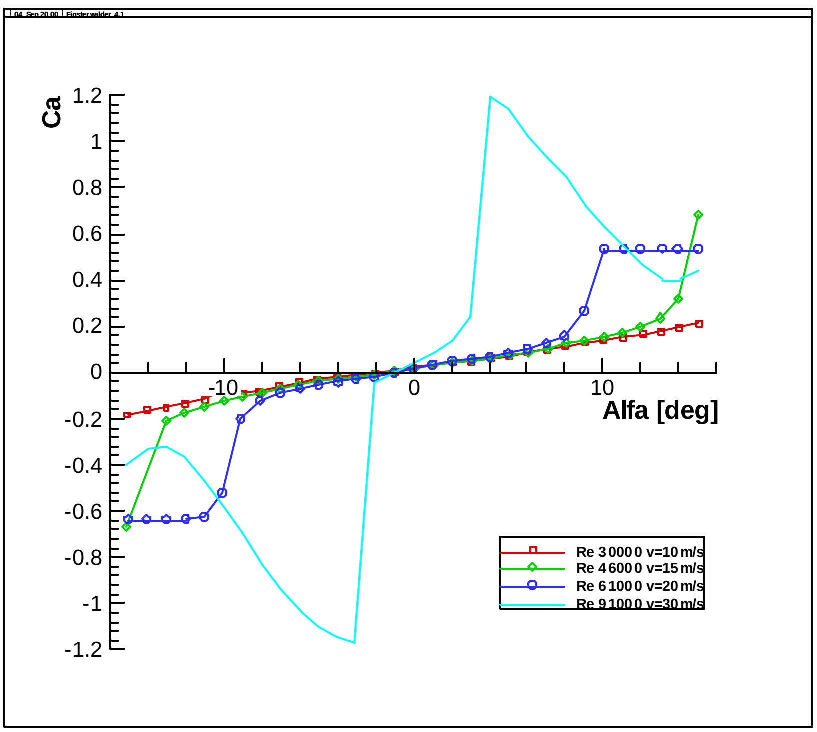

Figure 4.1-2: Cl-Alpha diagram Finsterwalder down tube 4.1

4.2 Wills Wing standard aluminum

The behavior of this very thick airfoil (51.88%) was similar to the Finsterwalder (4.1) one. Large turbulent separation was present over the whole range of angle of attack. Because of the large static pressure difference caused by the separation the exact drag coefficient can not be specified. The estimated drag is listed below.

- Free stream velocity 10m/s → Cd_0 approximately 0,28 – 0,35
- Free stream velocity 15m/s → Cd_0 approximately 0,18 – 0,25
- Free stream velocity 20m/s → Cd_0 approximately 0,13 – 0,20
- Free stream velocity 30m/s → Cd_0 approximately 0,08 – 0,12

It is possible to approximately determine the shape of the drag curve from the geometry of the Cl-Alpha curve because every erratic change of the lift coefficient goes along with an intense increase of drag. Conspicuous at this airfoil is its tendency to separate abrupt on the suction side if the angle of attack is slightly increased. This effect occurred mainly at higher velocities.

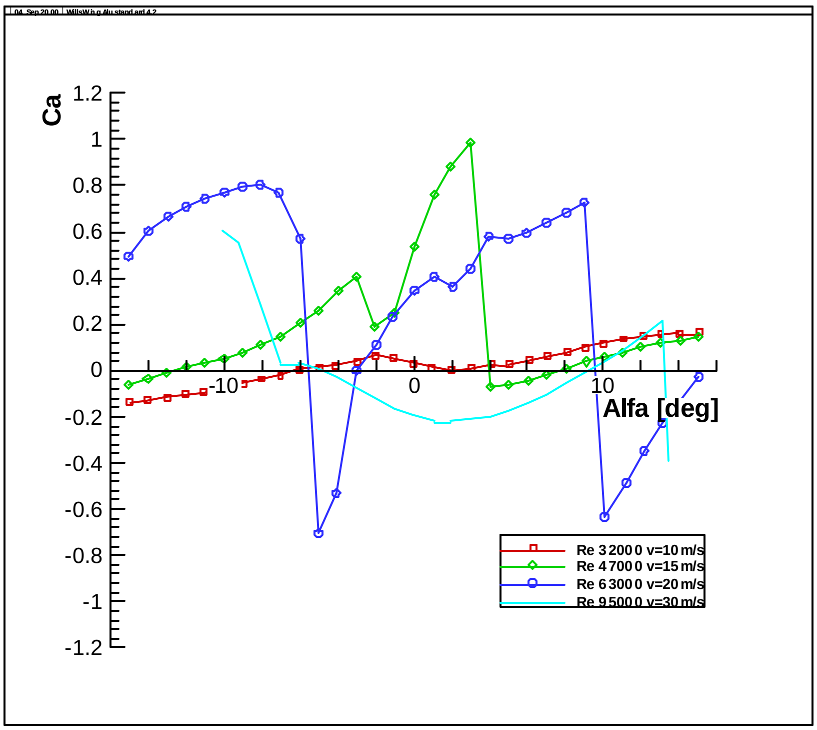

Figure 4.2-2: Cl-Alpha diagram WillsWing standard aluminum 4.2

5.1 Wills Wing new aluminum

The most essential difference of this model compared to the Carbon airfoil of 1.1 is the turbulator at 10% chord. This turbulator is produced during the manufacturing process. This trip extends the angle of attack range of the airfoil up to about ±10degrees. For larger angles of attack the drag increases up to a factor of 4 - 5 with respect to Cd_0. It was not examined if the waves (dip) in the rear part of the wind tunnel model created by production and transport influenced the aerodynamic characteristics of the airfoil.

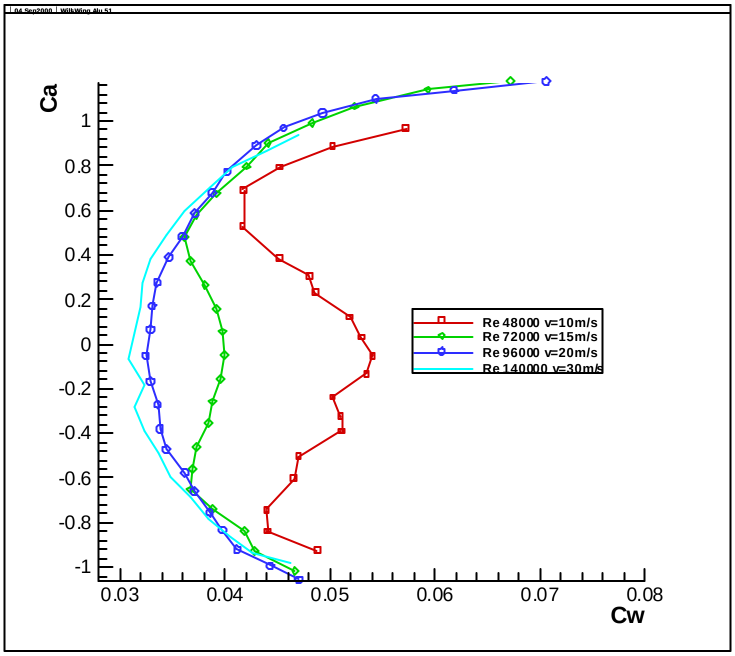

Figure 5.1-1: Cl-Cd diagram WillsWing new aluminum 5.1

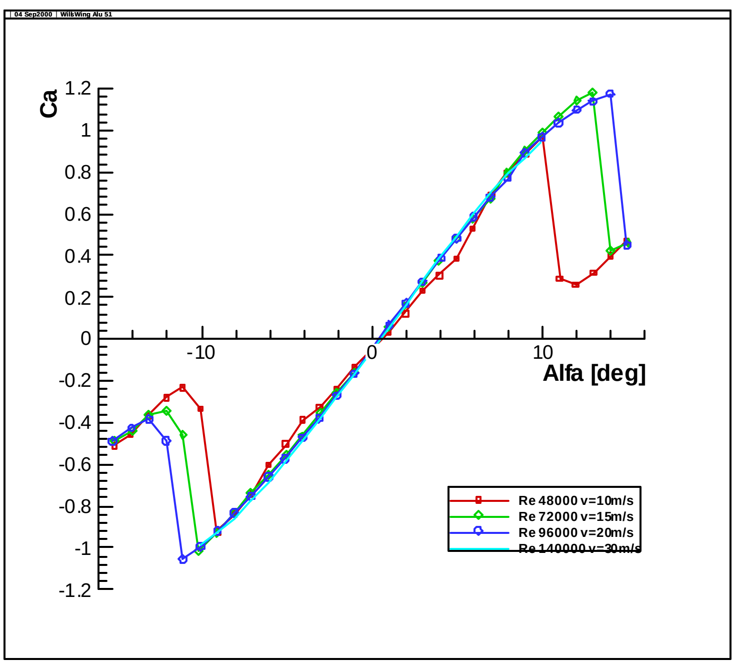

Figure 5.1-2: Cl-Alpha diagram WillsWing new aluminum 5.1

5.2 Wills Wing new aluminum with vinyl V-trip

Because of the good measurement results with the original configuration only single checks were carried out with the turbulators (listed above) placed at different positions. No further improvement of performance could be made. Therefore no diagrams are given here.

Appendix 1

List of sections to test and general instructions

Test sections (altogether 11):

1.1 Wills Wing Carbon down tube, standard trip (76.2 x 19.5mm)
1.2 Wills Wing Carbon down tube (76.2 x 19.5mm) with sailplane zig-zag trip
1.3 Wills Wing Carbon down tube (76.2 x 19.5mm) with vinyl V trip
1.4 Wills Wing Carbon down tube (76.2 x 19.5mm) with no trip

2.1 Seedwings down tube (62.2 x 25mm)

3.1 Aluminum round down tube (28.575mm)
- as a reference to analytical and other tunnel data
3.2 Aluminum round down tube (28. 575mm) with trip

4.1 Finsterwalder down tube (as an industry standard reference)
4.2 Wills Wing aluminum standard down tube (50.8 x 25.4mm)

5.1 Wills Wing aluminum streamlined down tube (76.2 x 22mm)
5.2 Wills Wing aluminum streamlined down tube (76.2 x 22mm) with vinyl V trip
- if a testing is indicated by the previous testing with the carbon standard down tube (76.2 x 19.5mm) with vinyl V trip

General instructions:

The test velocities are 10m/s, 15m/s, 20m/s and 30m/s

For all tests, except #3.1

The angle of attack range from –15° to +15° should be tested. If no hysteresis is observed in the lift/drag curve when approaching compared to departing 0 angle of attack at the 10m/s test speed, testing at higher speeds may be limited to 0° to +15°

Appendix 2

Overview of the data files

- Alu51.dat — Summary of the measure results of the airfoil Wills Wing aluminum streamlined down tube #5.1
- Carbon11.dat — Summary of the measure results of the airfoil Wills Wing carbon down tube #1.1
- Carbon12.dat — Summary of the measure results of the airfoil Wills Wing carbon down tube #1.2
- Carbon13.dat — Summary of the measure results of the airfoil Wills Wing carbon down tube #1.3
- Carbon14.dat — Summary of the measure results of the airfoil Wills Wing carbon down tube #1.4
- Finsterw.dat — Summary of the measure results of the airfoil Finsterwalder down tube #4.1
- Seedwing.dat — Summary of the measure results of the airfoil Seedwings down tube #2.1
- Standard.dat — Summary of the measure results of the airfoil Wills Wing aluminum standard down tube #4.2
- CaAlfa11.wmf — Cl-Alpha diagram of the airfoil Wills Wing carbon down tube #1.1
- CaCw11.wmf — Cl-Cd diagram of the airfoil Wills Wing carbon down tube #1.1
- CaAlfa12.wmf — Cl-Alpha diagram of the airfoil Wills Wing carbon down tube #1.2
- CaCw12.wmf — Cl- Cd diagram of the airfoil Wills Wing carbon down tube #1.2
- CaAlfa13.wmf — Cl-Alpha diagram of the airfoil Wills Wing carbon down tube #1.3
- CaCw13.wmf — Cl- Cd diagram of the airfoil Wills Wing carbon down tube #1.3
- CaAlfa14.wmf — Cl-Alpha diagram of the airfoil Wills Wing carbon down tube #1.4
- CaCw14.wmf — Cl- Cd diagram of the airfoil Wills Wing carbon down tube #1.4

- CaAlfa21.wmf — Cl-Alpha diagram of the airfoil Seedwings aluminum down tube #2.1
- CaCw21.wmf — Cl-Alpha diagram of the airfoil Seedwings alumin um down tube #2.1
- CaAlfa41.wmf — Cl-Alpha diagram of the airfoil Finsterwalder aluminum down tube #4.1
- CaAlfa42.wmf — Cl-Alpha diagram of the airfoil Wills Wing standard aluminum down tube #4.2
- CaAlfa51.wmf — Cl-Alpha diagram of the airfoil Wills Wing new aluminum streamlined down tube #5.1
- CaCw51.wmf — Cl- Cd diagram of the airfoil Wills Wing new aluminum down tube #5.1

Explanation of the measurement results

TITLE = "WillsWing Carbon 1.1" — **Name of the examined airfoil**
VARIABLES = "Alpha","Cl","Cd","q" — **Variables subdivided into columns**
Zone T="Re 48000 v=10m/s" — **Test velocity and Re-number**

```
-15.103   -.4315  ******   5.9090
-14.008   -.3279  ******   5.9650
-5.998    -.0100  ******   6.0070
                - - -
                - - -
                - - -
-5.035    -.4201  .05523   6.0030
-4.040    -.3551  .05315   6.0080
-3.105    -.2789  .04958   6.0080
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1. column: angle of attack α in degrees
2. column: lift coefficient Cl
3. column: drag coefficient Cd
4. column: free stream pressure q in mmWS (1mmWS $\approx$ 9.81Pa)