Preliminary Results of Flight Performance Determination of Cirrus75 D-6607 S/N 633

at the IDAFLIEG Sommertreffen 2011
in clean configuration and modified with leading edge tapes on wings by Jim Hendrix

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Overview

Comparison flights using a reference glider to determine the flight performance of gliders is a common method since more than 40 years at the IDAFLIEG Sommertreffen. More than 330 flight performance investigations were carried out in the last four decades.

Repeating flight performance investigations of older gliders with the current technologies provides the basis for considerations of accuracy and comparability of flight performance determination results in the change of metrological facilities and analysis possibilities over the last decades. Before the current investigation the *Standard Cirrus* was investigated in 1971, 1972 and 1974, see summation in [8].

The occasion for the re-investigation of a *Standard Cirrus* was the question concerning the influence of tapes on the wing surface that are intend to improve the flight performance very clearly. The so-called *deturbulation tape* was developed by Dr. Sinha [1] but was not investigated in this study. Different kinds of *leading edge tapes* were introduced by Jim Hendrix, first for augmenting the *deturbulation tape*, later as stand alone measure, see [2]. These airfoil modifying tapes were tested on a *Standard Cirrus*. Flight performance investigations were done by Richard Johnson [3] and Jim Hendrix [2]. This investigation focused on the effectivity of *leading edge tapes*.

In this survey three flights for determining the basic aircraft flight performance and two flights each with different configuration of adhesive tapes on the leading edge of the wings were carried out.

Figure 1: Comparison flight formation, in the background the Alps about 100km southward

1. Description of flight trials

The Cirrus 75 D-6607 was investigated on August 11th and 12th 2011 at the annual IDAFLIEG Sommertreffen. As usual the DG-300/17 D-1633 was used as reference glider for the flight performance determination applying the comparison flight method. The five comparison flights of this investigation took place at the airfield Aalen-Heidenheim-Elchingen (EDPA) in southern Germany.

Basic data of Cirrus 75

	value	source
flight weight during investigation	355.6kg (784lb)	measured
center of gravity during investigation	336 mm aft reference datum certified: 250 – 400mm aft reference datum	measured AFM
wing span b	15.009m (49.242ft)	measured
wing area S	$10.0m^2$ ($107.64ft^2$)	AFM

Table 1: Basic data of Cirrus75 D-6607

Investigated configurations

1. Configuration „**clean**“: The performance is investigated in quasi steady wings level flight with out sideslip and with closed ventilation.
2. Configuration „**vent open**“: The same as configuration „clean“, but with open cockpit ventilation.

In two flights the effectivity of two configurations of the *leading edge tapes* as suggested in [4] were investigated:

3. Configuration „**small tape**“: Compared to the "clean" configuration, a narrow tape was applied to the leading edge of the wings. This corresponds to „1. Lower-Surface 12mm wide configuration“ in [4]. The adhesive tape Tesa 4104 (12 mm wide, 70-76µm thick, clear) was applied at an angle of 45 ° to the leading edge, relative to the normal level of gravity in weighing reference attitude.

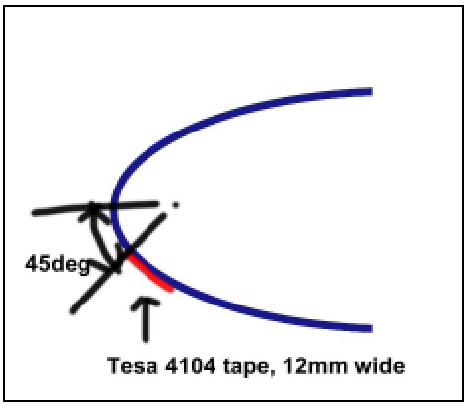

Figure 2: Position of „small tape“ according [4]

Figure 3: „small tape“ on right wing leading edge

4. Configuration „**wide tape**“: Compared to the "small tape" configuration, a wider tape was applied to the leading edge of the wings. This corresponds to „6. Original Two-Surface configuration“ in [4]. The 50mm wide adhesive tape (Tesa, 76µm thick, clear) was applied on the inner wing as shown in Figure 4. Applying the tape on the outer wing according Figure 5 failed several times, so this part of modification had to be abandoned.

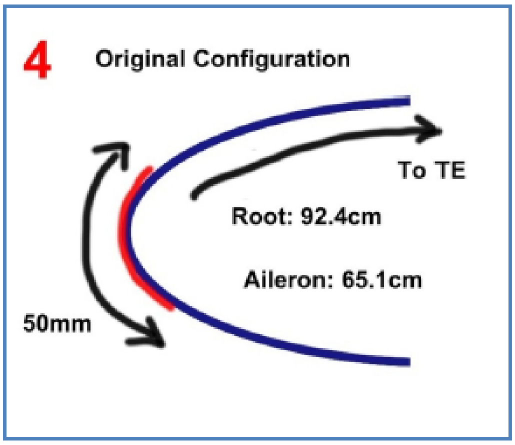

Figure 4: Position of „wide tape“ on inner wing leading edge according [4]

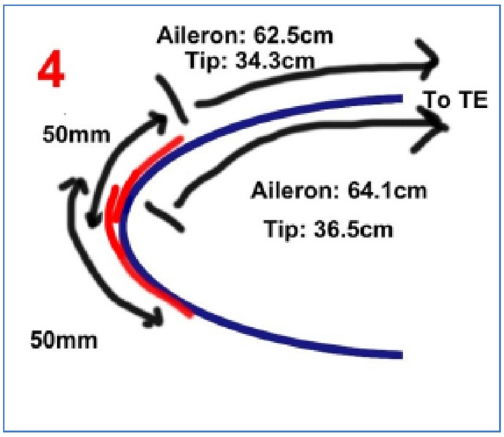

Figure 5: Position of „wide tape“ on outboard wing leading edge according [4]

The *leading edge tapes* were applied on the eve of each flight test day and removed without leaving any residue after the first flight of the day.

Overview of flights

If the weather conditions are appropriate for flight performance investigations three comparison flights are normally carried out from sunrise. The airfield altitude is located at 586m above sea level and the maximum altitude in all flights was about FL95. Depending on the measuring program each flight lasts about one hour with a gross measuring time of about 30 to 40 minutes.

A cost benefit discussion resulted in establishing measurement sections of one-minute duration with constant airspeed. Using shorter measuring sections instead of the usual two minutes duration of the measuring section may reduce the accuracy of the results compared to the accuracy stated in [5] (relative error $\varepsilon_{L/D}$<0.3 up to 160km/h). However analyses have shown only very little degradation and quantifying this influence is still in progress. No restrictions of the investigation in relation to the objectives are expected from this change in procedure.

The measured meteorological quantities as shown in annex 7.1 do indicate not optimal but at least suitable weather conditions for August 11th 2011. The determined vertical wind reveals a significant tendency for wave formation. On August 12th 2011 thermals started unusual early during the second flight at about 1000m above ground hence no other usable measuring sections could be flown that day.

Flight - No.	Date	Configuration(s)	Number of usable measurement sections á 1min
1	Aug 11th 2011	Small tape	25
2	Aug 11th 2011	Clean	19
3	Aug 11th 2011	Clean, vent open	20
4	Aug 12th 2011	Wide tape	21
5	Aug 12th 2011	Clean, vent open	14

Table 2: Overview of flights

2. Preliminary results

Processing and analysis of the measured data follows the principles published in [6]. Several minor changes are implemented in the used software version (release Aug2011).

As Jim Hendrix and Richard Johnson used the partial glide method in his investigation, see [2] and [3], the results of the partial glide analysis of the one minute sections are added in appendix 8.2.

The airspeed calibration is presented as the quotient of the calibrated airspeed (Calibrated Airspeed – CAS) to measured airspeed (Basic Airspeed – BAS) vs. BAS. The shown graph is very characteristic for the arrangement of the static pressure port at the fuselage as Schempp-Hirth implements it.

With the open ventilation a slight deviation from the other configurations can be found at airspeeds above 70kts. Probably this result from the position of the total pressure tube inside the ventilation air intake fitted at the nose of the fuselage.

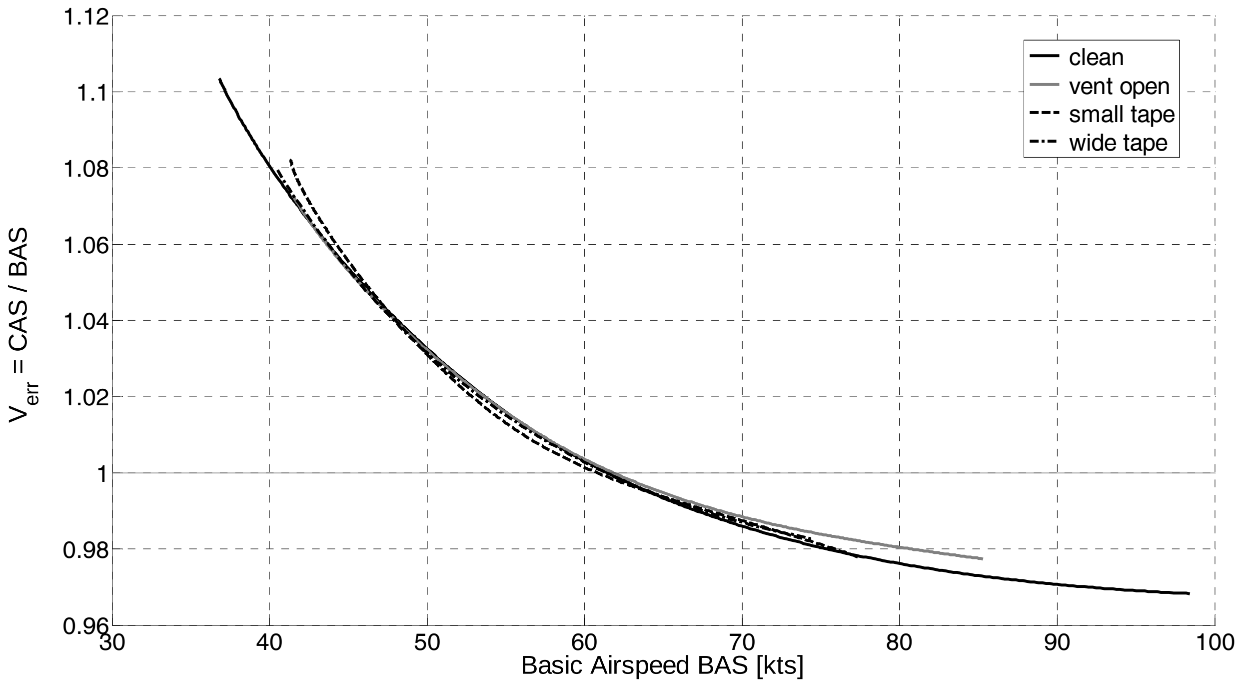

Figure 6: Airspeed calibration, CAS/BAS-BAS-depiction

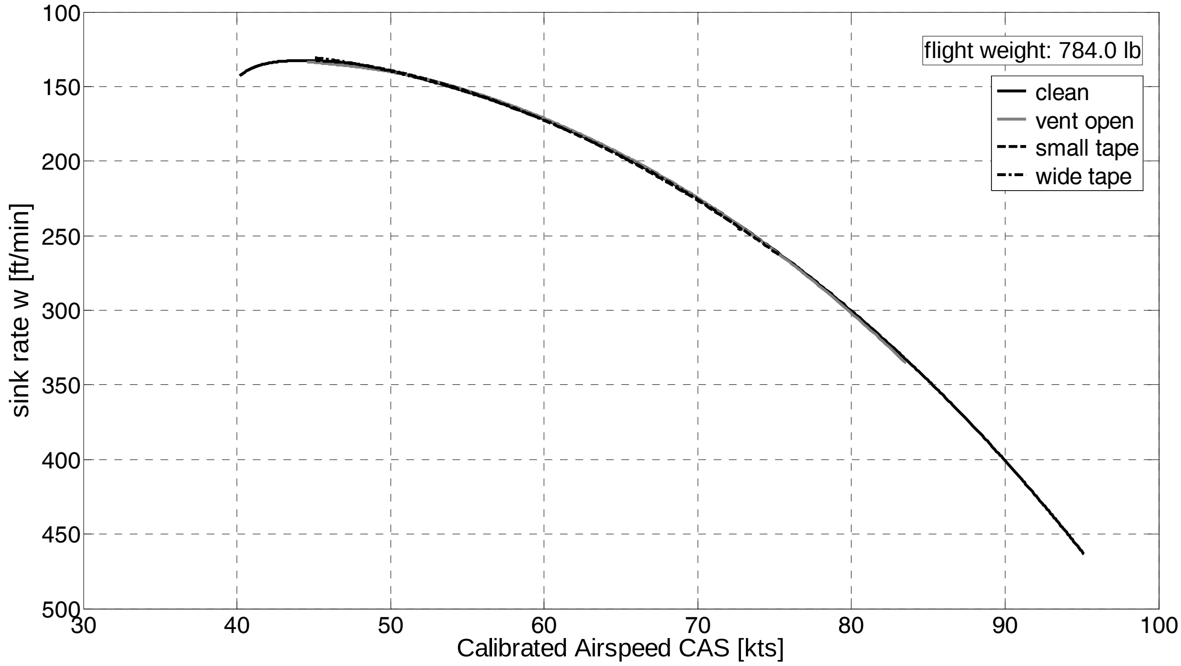

Figure 7: Sink rate vs. Calibrated Airspeed at reference weight

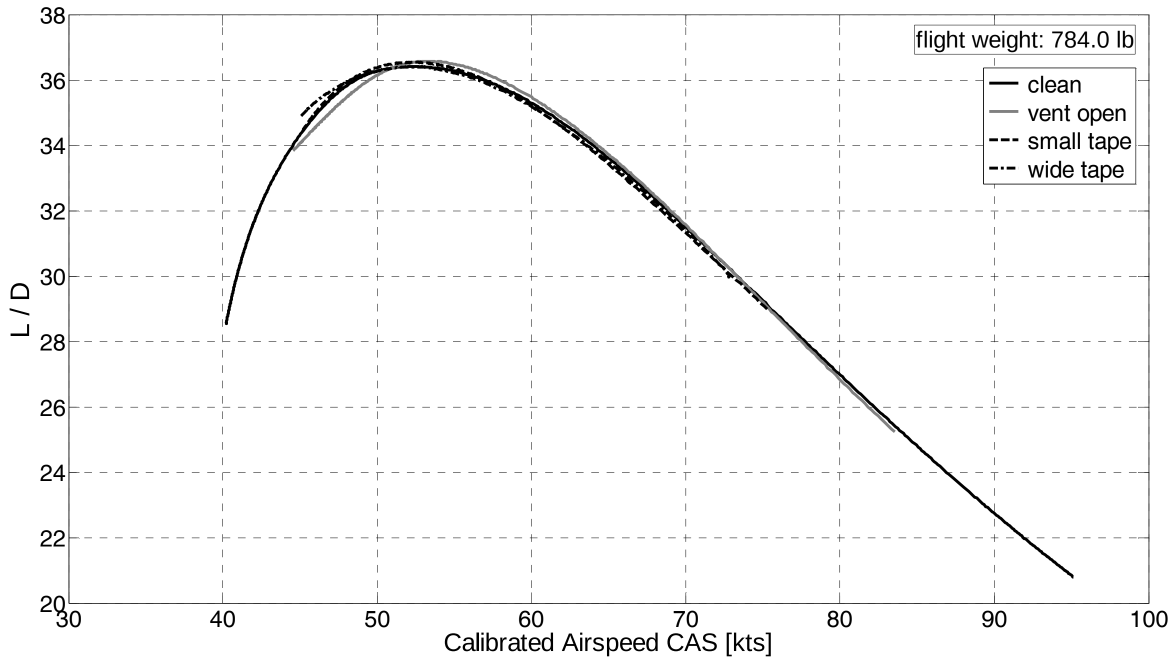

Figure 8: L/D vs. Calibrated Airspeed at reference weight

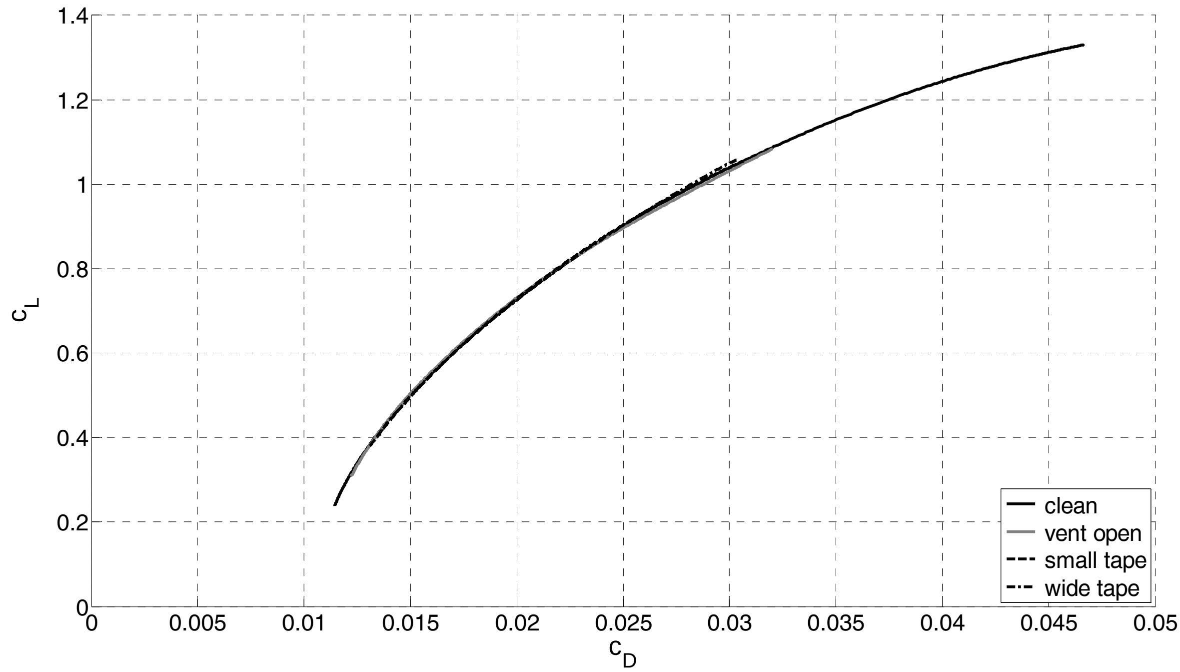

Figure 9: c_L-c_D-diagram

In the following figure the drag coefficient is reduced by the coefficient of the induced drag assuming an elliptical lift distribution according the following formula:

$$c_{Di} = \frac{c_L^{\ 2}}{\pi \cdot \Lambda} = \frac{c_L^{\ 2}}{\pi \cdot \frac{b^2}{S}} \qquad \{1\}$$

This results in a more sensitive depiction of differences between the configurations:

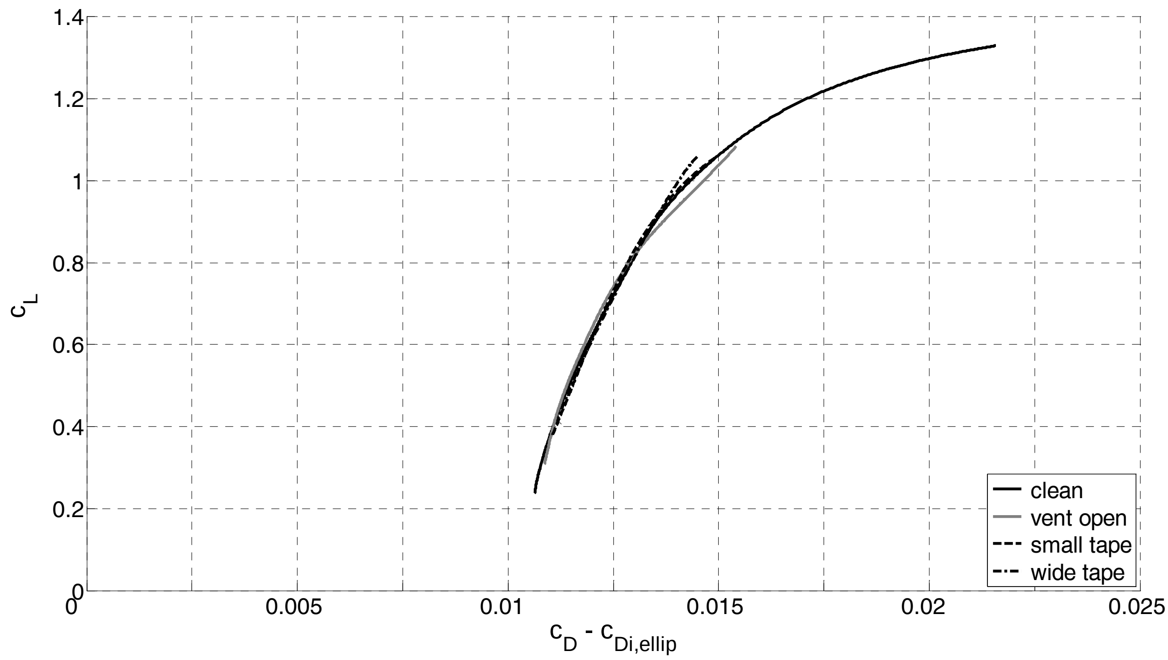

Figure 10: c_L-(c_D- $c_{Di,ellip}$)-diagram

The Angel of Attack (AOA) in Figure 11 is related to horizontal plane with glider in weighing reference attitude.

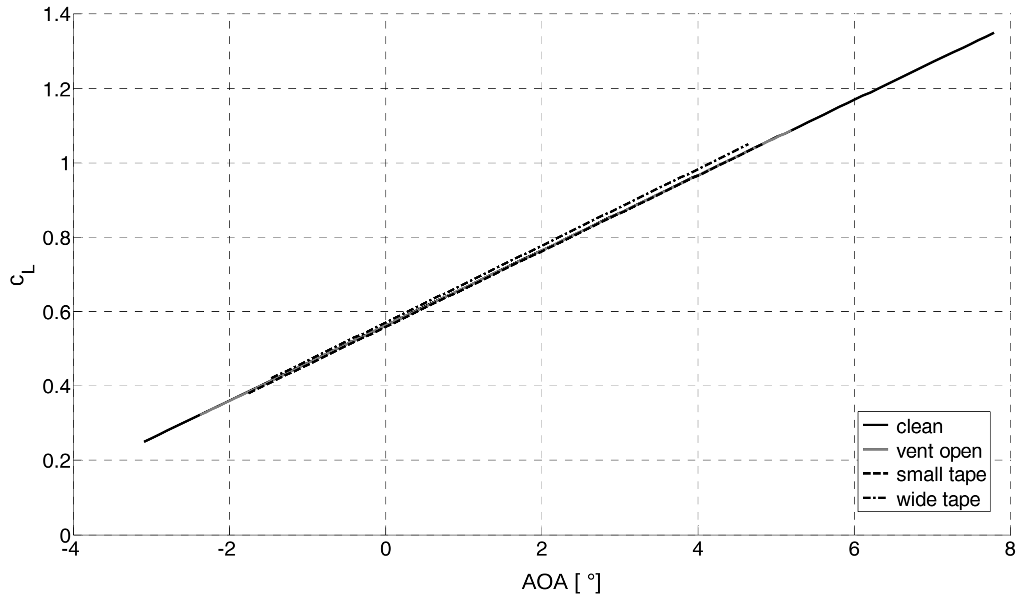

Figure 11: c_L-AOA-diagram

Cabin pressure

The measurement equipment for the flight performance determination includes a differential pressure sensor that measures the pressure difference between the cabin behind the pilot and the static pressure of the onboard system.

It is assumed that the airspeed error is solely caused by the error of the onboard static pressure. This assumption is based on the widespread knowledge about flow probes that the static pressure is primarily error-prone. Mostly this assumption leads to plausible results.

So the pressure difference can be corrected by the static pressure error and is related to the corrected dynamic pressure:

$$c_{p,cabin,corr} = \frac{\left(p_{cabin} - p_{stat,onboard}\right)_{measured} - p_{stat,onboard,error}}{q_{calibrated}} \qquad \{2\}$$

At a pressure coefficient of zero the cabin pressure is the same as the undisturbed static pressure at this altitude.

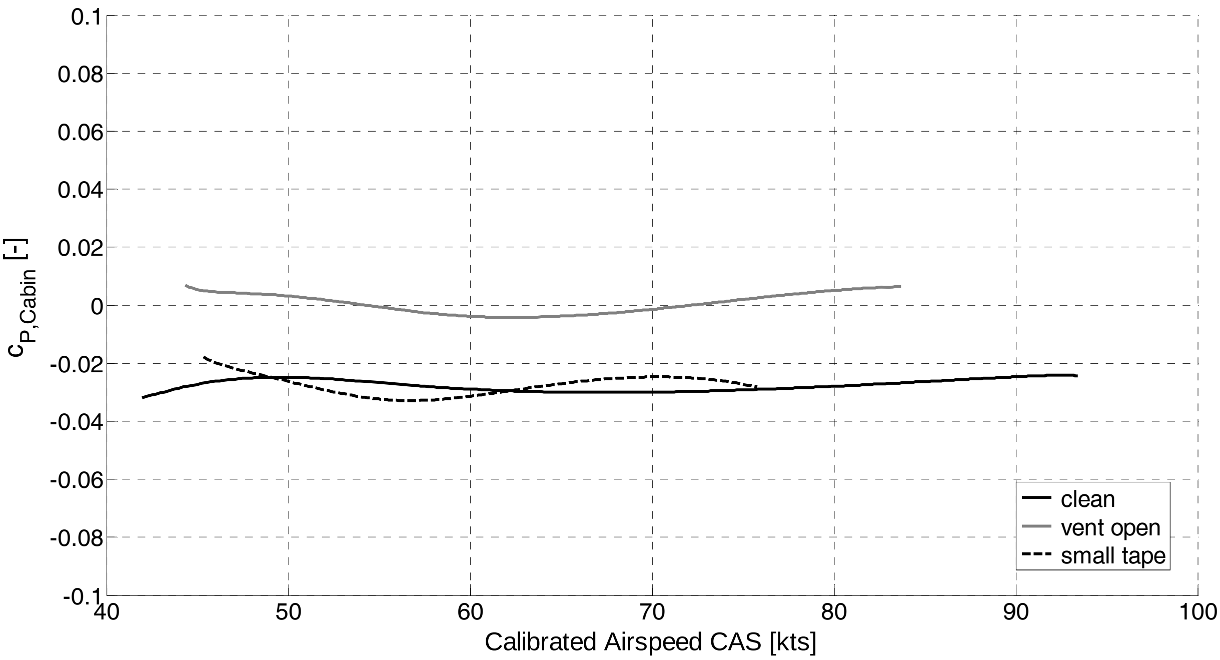

Figure 12: Coefficient of corrected cabin pressure vs. Calibrated Airspeed

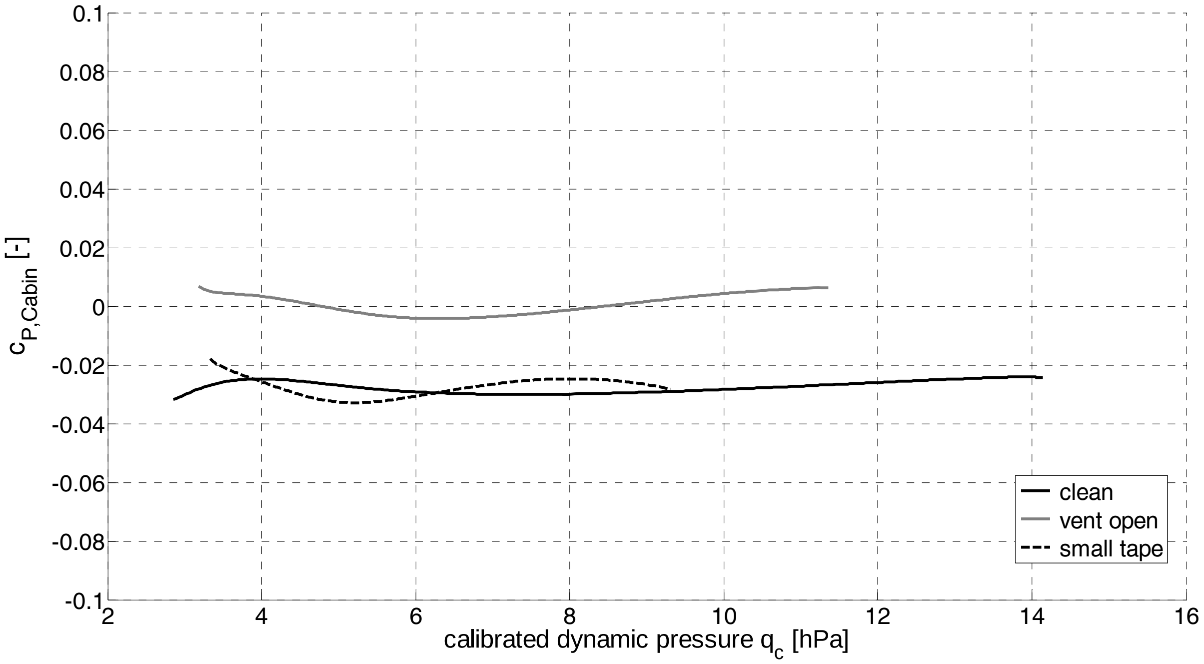

Figure 13: Coefficient of corrected cabin pressure vs. dynamic pressure

3. Comparison of 2011 results with former IDAFLIEG results

Comparing results from flight performance it must be in general considered that the flight performance of one certain specimen is determined at a certain time with certain external conditions. Generalizing these results for other specimen of the glider type and even the same specimen for the future must be done with appropriate attention.

It is contrary to the experience of flight performance measurement of the last 13 years that "large" differences arise between comparable specimens of a gilder type. The mostly anecdotal circulating stories about large differences within a type series should be analyzed differentiated to work out suitable setups for future in-flight investigations.

Following major differences between the surveys in 1971-1974 (see [7] and [8]) and in 2011 can be figured out:

- Serial number of investigated gliders
- Used reference glider (1971-1974: Cirrus D-0471, 2011: DG-300/17 D-1633)
- Execution of comparison flights
- Measuring method and data analysis

In this section the airspeed calibration of a Standard Cirrus (D-0483) in 1971/72 [7] and the flight performance of the Standard Cirrus obtained from several surveys [8] is compared with the results of the 2011 investigation.

<u>Comparison of airspeed calibration</u>

For this comparison the airspeed calibration in Figure 6 is transformed to the following depiction and is overlaid the 1971/72 [7] results:

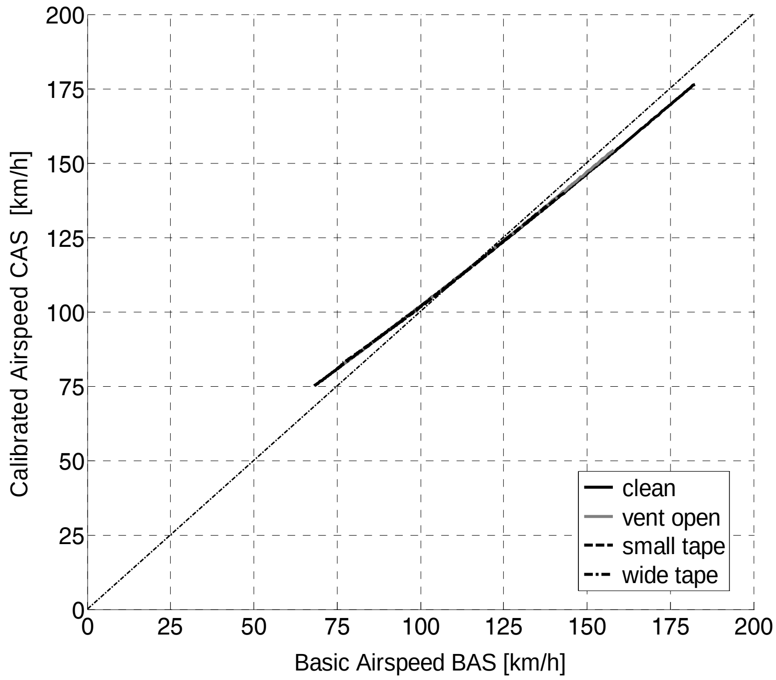

Figure 14: Airspeed calibration, CAS-BAS-depiction

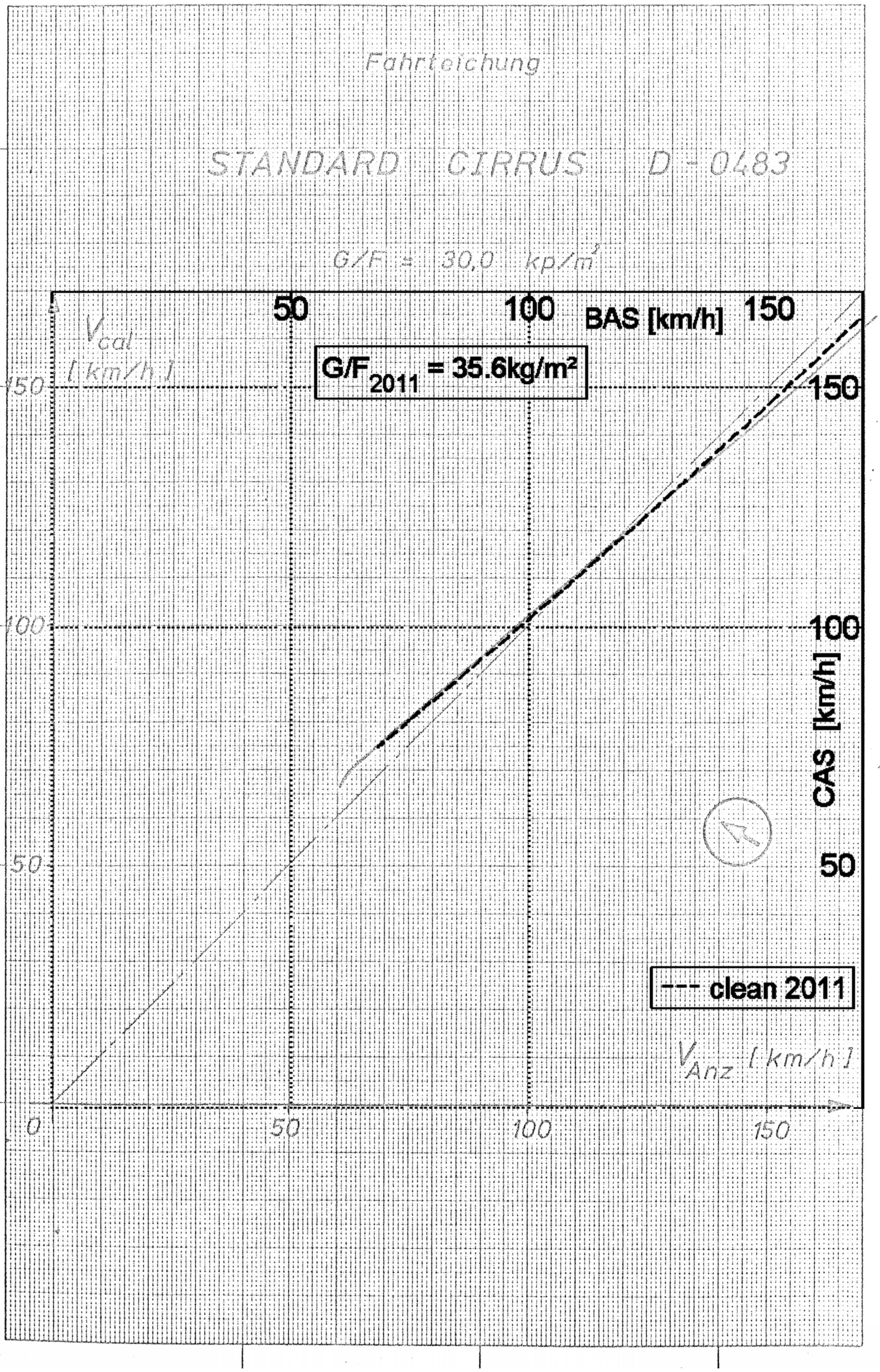

Figure 15: Comparison of airspeed calibration in 1971/72 [7] and 2011

The types of pressure ports on the *Standard Cirrus* D-0483 (1971/72) were not documented. Both airspeed calibrations are derived from comparison flights. The difference of the glider weight at the time of the investigations of about 18% must be kept in mind.

In contrast to the many uncertainties, the two airspeed calibrations agree very well.

Comparison of flight performance

The *Standard Cirrus* flight performance presented in [8] is derived in a not documented manner from measurements in 1971, 1972 and 1974 using two different gliders. The conditions of the two gliders were not documented.

For this comparison the 2011 result is computed from a flight weight of 335.6kg to 306.0kg without considering Reynolds number effects.

The comparison is depicted in Figure 16. The maximum difference between the 1974 and the 2011 result is about 6cm/s at 140km/h (about 12ft/min @76kts CAS) what is about 1 L/D. The difference at best L/D is merely about 0.6. The speed of best L/D can be appraised from 1974 result with about 94km/h (51kts CAS) which is very close to the 2011 result.

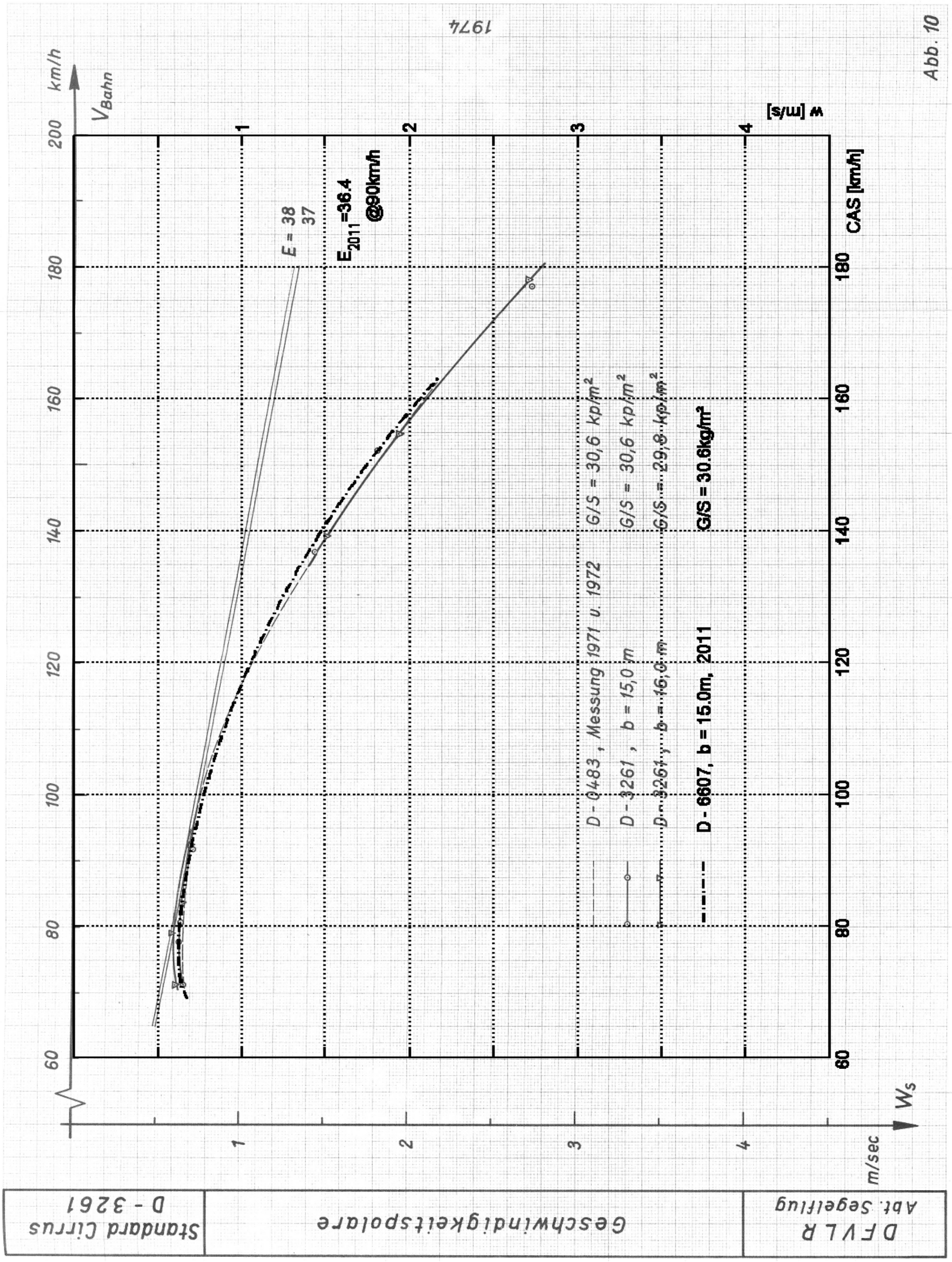

Figure 16: Comparison of flight performance determined in 1974 [8] and 2011

4. Summary

In five flights on two consecutive days with suitable weather conditions the flight performance of the Cirrus75 D-6607 was determined for four configurations with satisfactory quality. An influence of the *leading edge tapes* on the flight performance is not recognizable in the context of the accuracy of the measuring procedure.

The comparison of the clean configuration with the measurements on two other exemplars of the *Standard Cirrus* in the years 1971 to 1974 shows surprisingly good matches. For more general statements regarding the comparability of the flight performance measurement results over the decades, further measurements must be carried.

5. Acknowledgements

Thanks to Hans-Joachim "Joe" Riedelsheimer for providing the Cirrus75 D-6607 and Jim Hendrix for his cooperation in the transatlantic preparation of the flight tests.

The flight performance investigation of gliders at the IDAFLIEG-summer meeting is a joint effort of the *Interessengemeinschaft deutscher Akademischer Fliegergruppen IDAFLIEG e.V.*, the participating institutes of the *Deutsches Zentrum für Luft- und Raumfahrt DLR e.V.* and the *Institute of Flight Guidance* at *Technische Universität Braunschweig*. Sincere thanks are given to all!

6. Contact

In case of any questions, comments and suggestions don't hesitate to contact me via email: f.paetzold@tu-braunschweig.de

7. Literature

[1] http://www.sinhatech.com/, Oct 22th 2012

[2] http://www.deturbulator.org/, Oct 22th 2012

[3] Johnson , R. H.: A FLIGHT TEST EVALUATION OF THE SINHA WING PERFORMANCE ENHANCING DETURBULATORS, 1/2/07

[4] Hendrix, J.: Tape Configurations and Installation Instructions, 21. Jul 2011

[5] Pätzold, F.: Zur Genauigkeit der Flugleistungsvermessung beim IDAFLIEG-Sommertreffen, IDAFLIEG-Berichtsheft 2011, April 2011

[6] Wende, G.: Flugleistungsvermessung von Segelflugzeugen, TU Braunschweig, Institut für Flugführung, Dissertation, 2003

[7] Magyar, T.: Fahrtanzeigen von Segelflugzeugen und Motorseglern, DFVLR report IB 151-73/54, 1973

[8] Laurson, H.: Leistungsmessung an 8 Segelflugzeugen, Idaflieg-Vergleichsfliegen 1974, DFVLR, IB151-74/55, 1974

This report is published in a similar form in German language:

[9] Pätzold, F.: Vorläufige Ergebnisse der Flugleistungsvermessung des Cirrus75 D-6607 Werk-Nr. 633, Technische Universität Braunschweig, Institut für Flugführung, 06. Januar 2012

8. Appendixes

8.1 Measured meteorological data: wind vector und air temperature

Air temperature T_{stat}, wind direction χ_W, horizontal and vertical wind speed component V_W and w_{Wg} are shown related to barometric altitude.

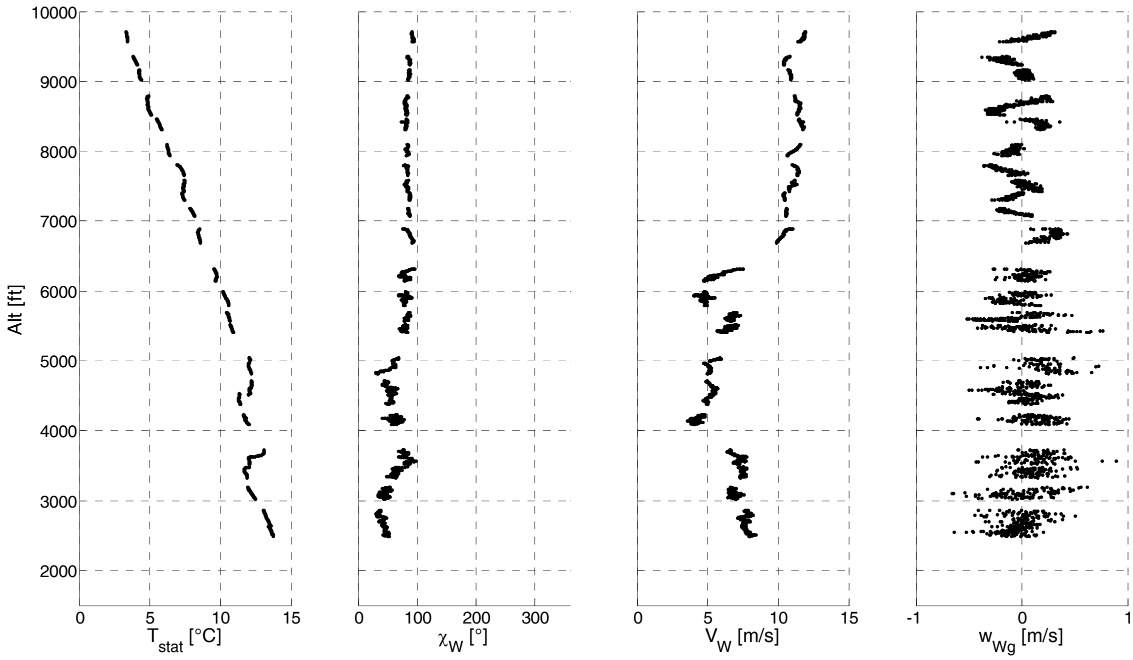

Figure 17: Meteorological data flight 1, Aug 11th2011

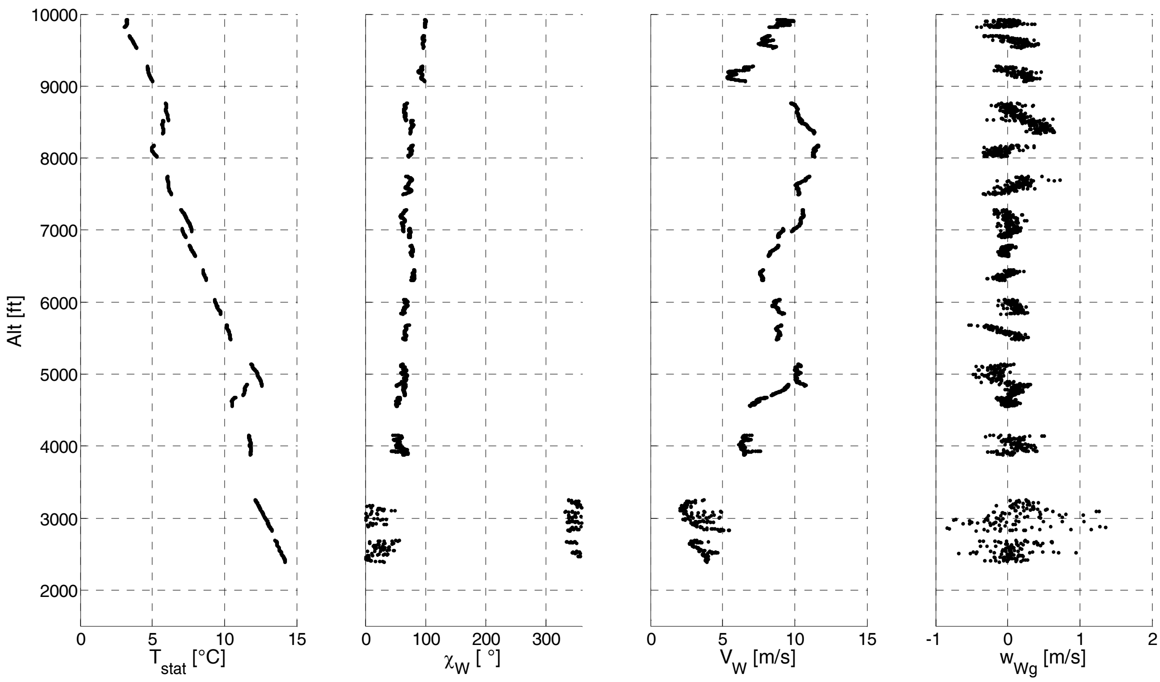

Figure 18: Meteorological data flight 2, Aug 11th2011

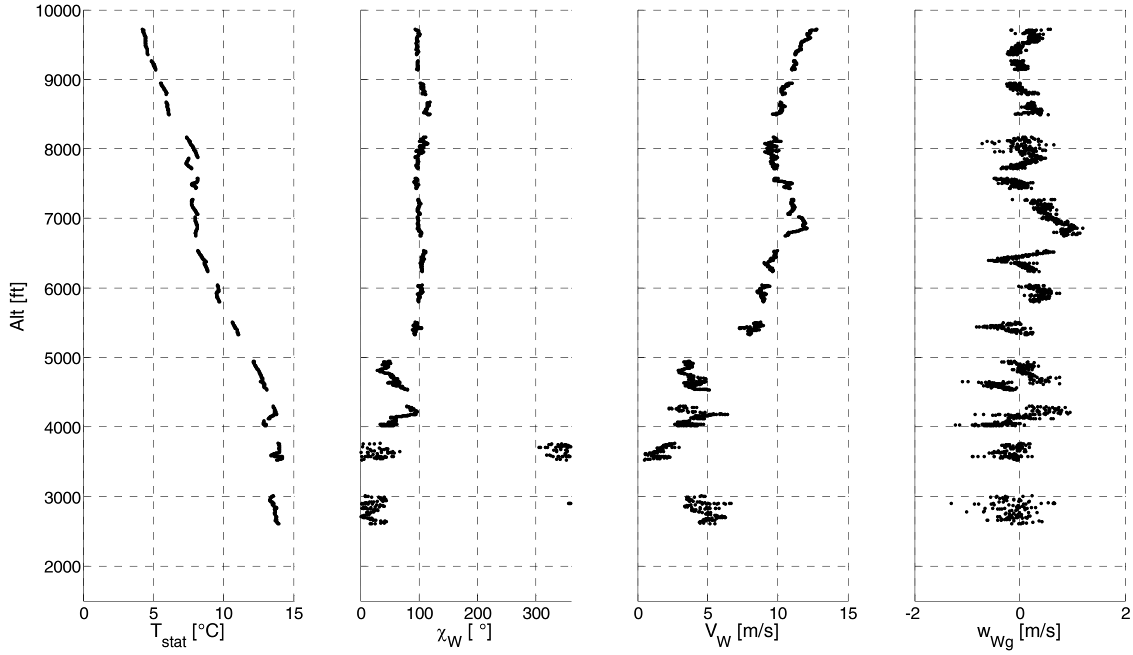

Figure 19: Meteorological data flight 3, Aug 11th2011

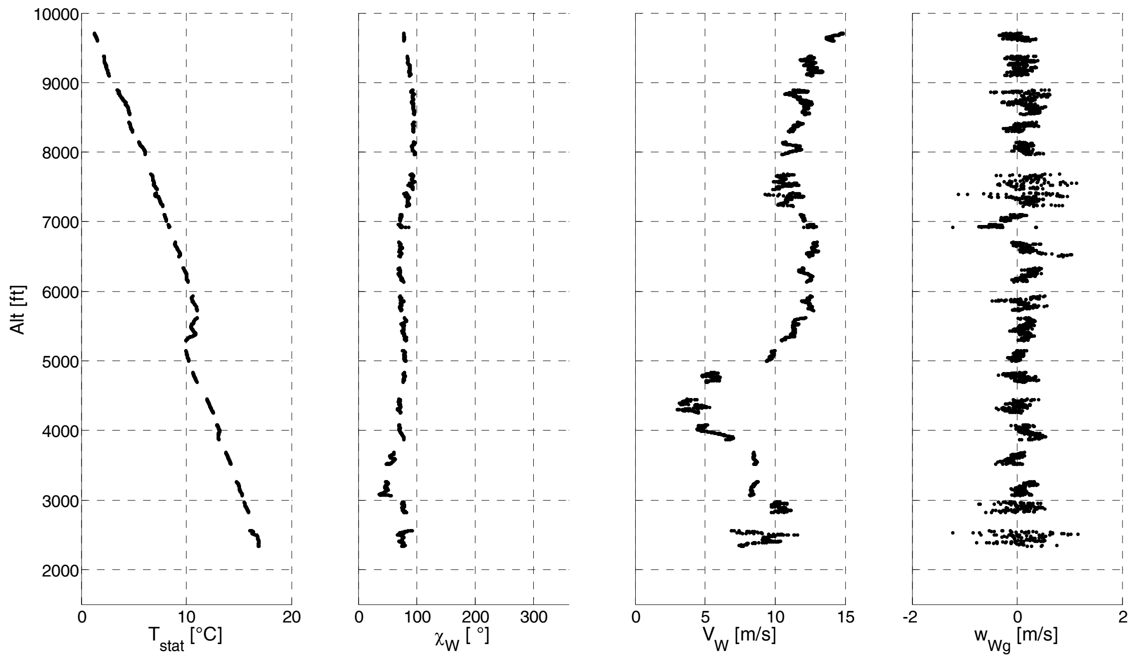

Figure 20: Meteorological data flight 4, Aug 12th2011

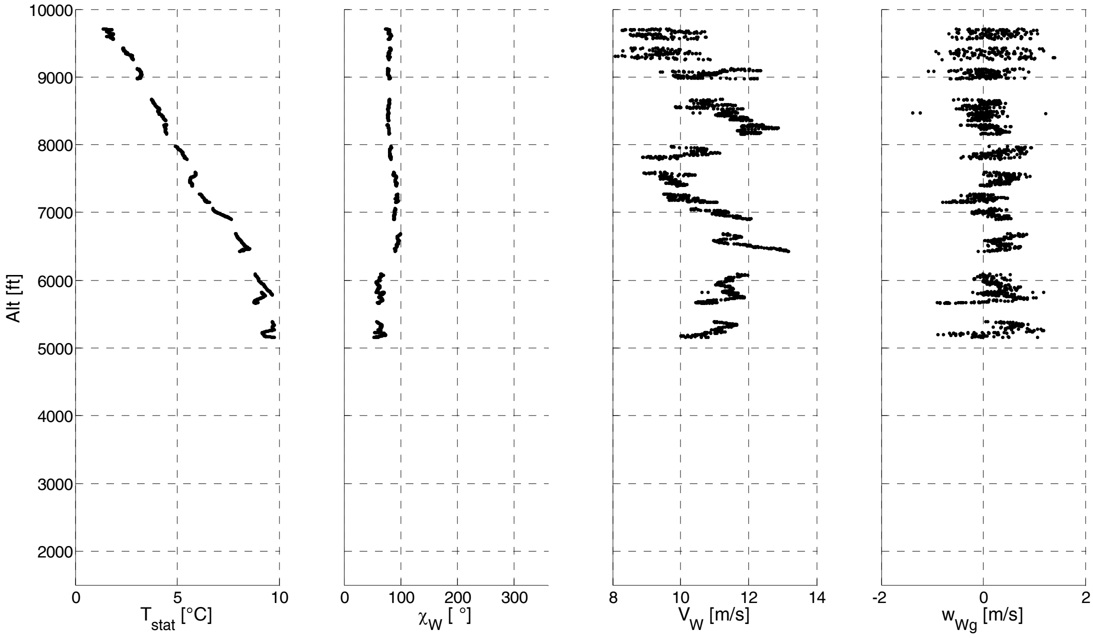

Figure 21: Meteorological data flight 5, Aug 12th 2011

8.2 Partial glide analysis

The performance determination in [2] and [3] were done according the partial glide method. Below the results are depicted of the comparison flight evaluation and the partial glide analysis of the one minute sections for each of the four configurations.

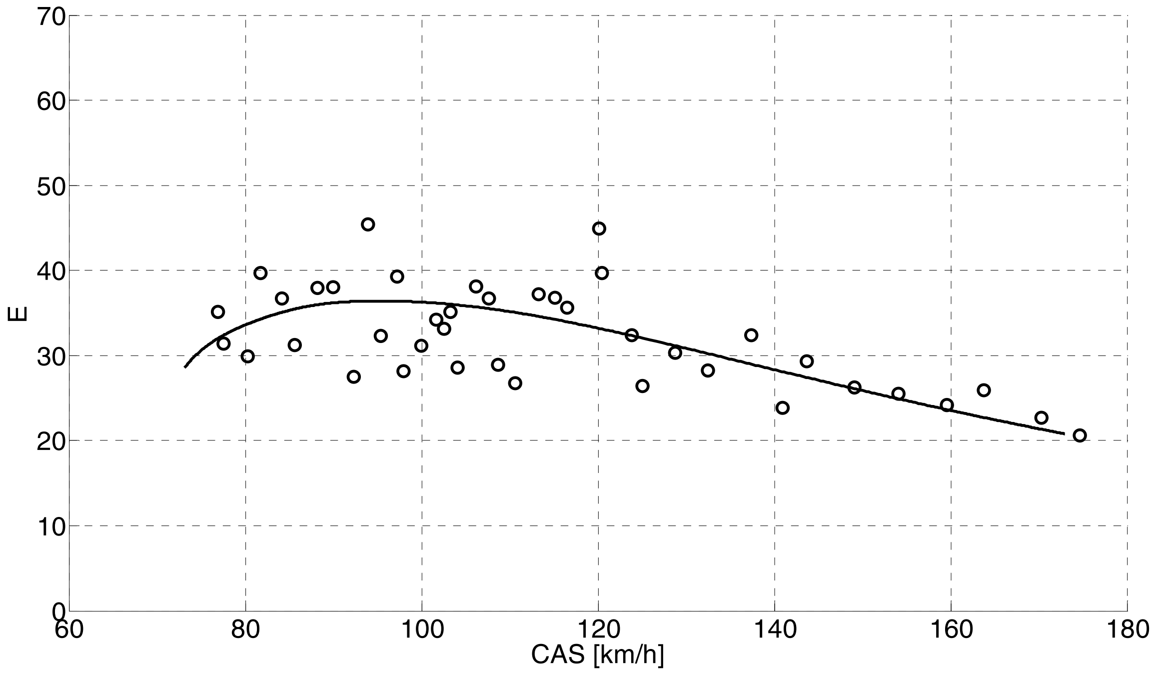

Figure 22: Configuration „clean“, Comparison flight results (line) vs. partial glide analysis (symbols)

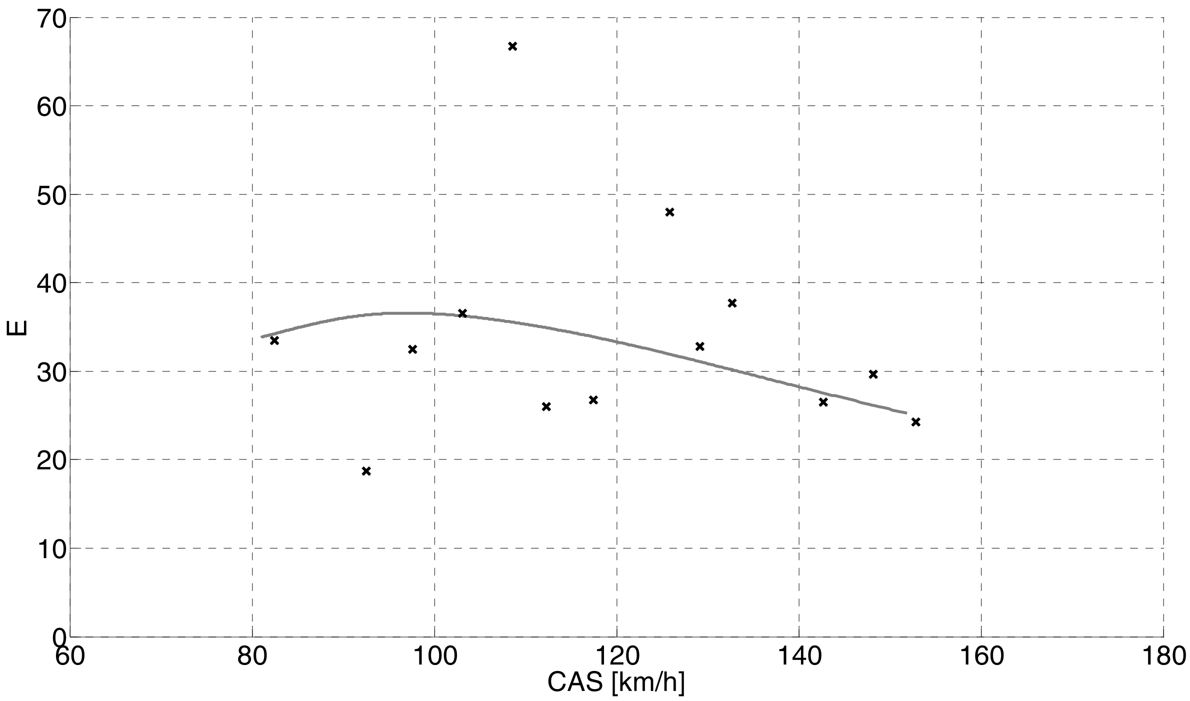

Figure 23: Configuration „vent open“, Comparison flight results (line) vs. partial glide analysis (symbols)

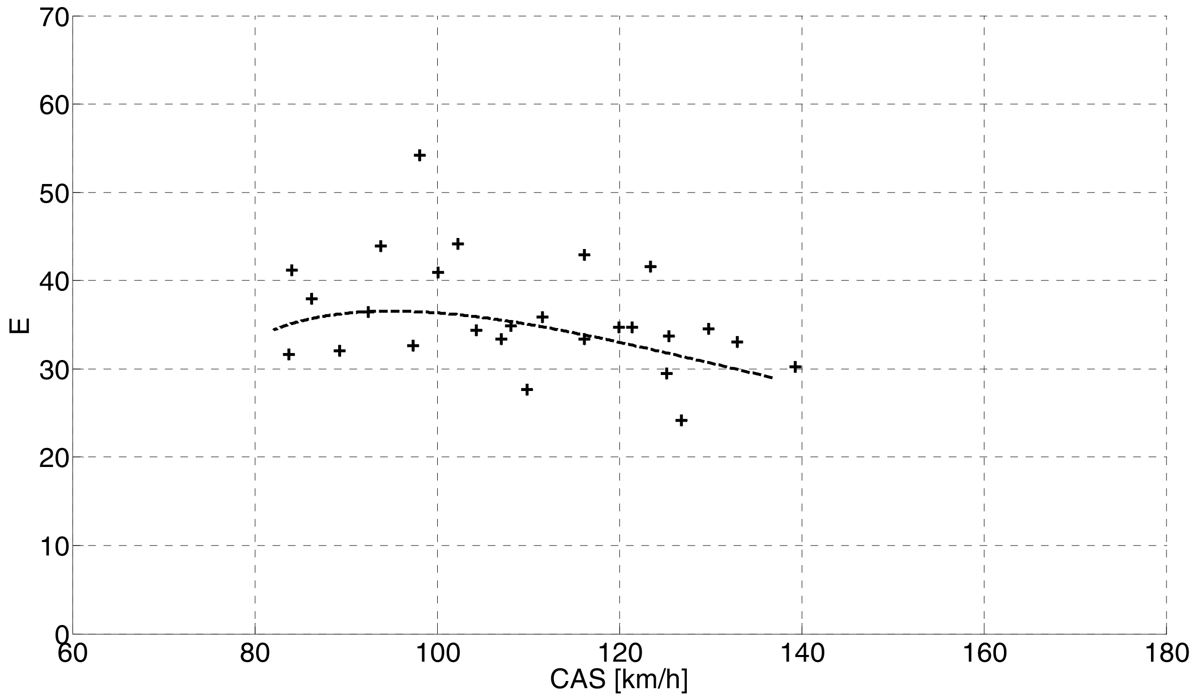

Figure 24: Configuration „small tape", Comparison flight results (line) vs. partial glide analysis (symbols)

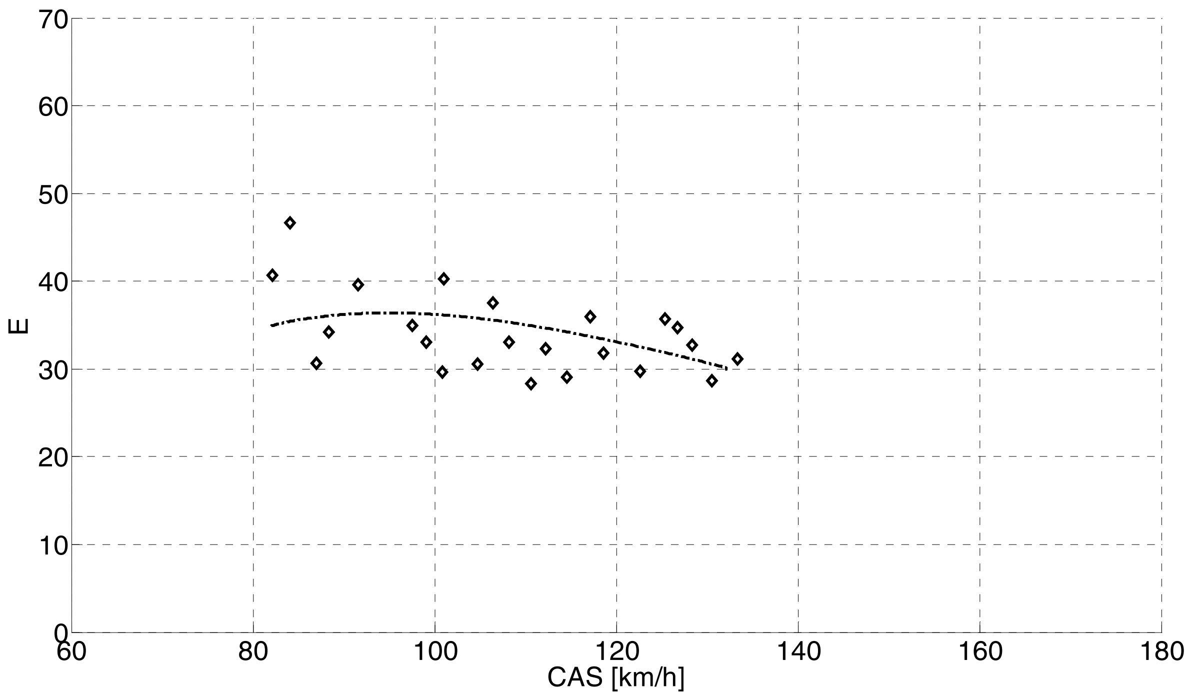

Figure 25: Configuration „wide tape", Comparison flight results (line) vs. partial glide analysis (symbols)

8.3 Weighing log

idaflieg IFF DLR

Schwerpunktwägung (Flugzeuge mit einem Hauptrad und einem Sporn(rad))

Flugzeug: Std. Cirrus Kennzeichen: D-6607 Werknummer: 633

Datum: 9.8.2011 Verantwortlicher: Macht

Waagen

Verwendeten Waagen: Waage 1: 1 (Hauptrad) Waage 2: 2 (Sporn)

Kontrollwaage: 3

Waagenkontrolle: Belastung mit Referenzmasse → Alle 3 Waagen müssen selben Wert anzeigen.

Waagenkontrolle durchgeführt? ja ☐

Piloten	ohne Fallschirm	mit Fallschirm
vorn: kaSasik	Gewicht: – kg	Gewicht: 91,06 kg
hinten: –	Gewicht: – kg	Gewicht: – kg

Bei mehreren Piloten neues Formular verwenden.

Ausrüstung

Messanlage:	Masse: 139 kg	Hebel: 300 mm h. BP
Trimmgewichte:	Masse: – kg	Hebel: – mm h. BP
Fallschirm:	Masse: – kg	Typ: RESL

Flugzeugabmessungen

a = 121 mm (BE – Hauptrad) b = 3450 mm (BE – Spornwaage)

c = 1823 mm (BE – Rumpfnase) l = 6415 mm (Rumpflänge)

Spannweite: 15,009 m Flügelfläche: 10,0 m² Fluglage gem. Handbuch: 100 : 5,1

Wägung

ohne | Rückenlehne Kopfstütze

-- Rüstmasse -- (mit Akku, ohne Fallschirm u. Trimmgewichte)		-- Flugmasse – (mit Pilot u. Fallschirm u. Trimmgewichten)	
GPS-Anlage: ja ☒ nein ☐		GPS-Anlage: ja ☒ nein ☐	
$G_{1Rbrutto}$ 231,2 kg	$G_{2Rbrutto}$ 36,8 kg	$G_{1Fbrutto}$ 334,8 kg	$G_{2Fbrutto}$ 22,2 kg
$- G_{1Rtara}$ 1,4 kg	$- G_{2Rtara}$ – kg	$- G_{1Ftara}$ 1,4 kg	$- G_{2Ftara}$ – kg
G_{1R} 229,8 kg	G_{2R} 36,8 kg	G_{1F} 333,4 kg	G_{2F} 22,2 kg
$G_{Rüst} = G_{1R} + G_{2R} =$ 266,6 kg		$G_{Flug} = G_{1F} + G_{2F} =$ 355,6 kg	
$x_{SL} = (G_{2R} * b) / G_{Rüst} + a =$ 597,2 mm h. BP		$x_{SF} = (G_{2F} * b) / G_{Flug} + a =$ 336,3 mm h. BP	

Gnorm 3427kg

Zulässiger Bereich Leermassenschwerpunkt: 465 bis 630 mm h. BP

Zulässiger Bereich Flugmassenschwerpunkt: 250 bis 400 mm h. BP

Protokoll auf Vollständigkeit und Richtigkeit prüfen!! (Wenn möglich mit alten Wägungen vergleichen.)

Wägeprotkoll_Hauptrad+Spornrad_2011 Erstellt: F.Pätzold (IFF) TU-BS)

8.4 Glider condition log

idaflieg IFF DLR

Zustandsprotokoll

Flugzeug: Cirrus 75 Kennzeichen: D-6607 Werknummer: 633

Starts/Stunden: 900 / 2800 (ggf. seit Grundüberh./Neulackierung) Baujahr: 1976

Vereinsflugzeug ☐ Privatflugzeug ☒ Herstellerflugzeug ☐

Datum: 13.8.2011 Verantwortlicher: Kubasik

Zustand der Flugzeugoberfläche (z. B. Dellen, Abzeichnung von Spanten/Rippen/Gurten, Lackrisse...)

Flügeloberflächen: 2 Reparaturstellen TF-Unterseite li (ca. 1m vom Tip) zeichnen sich ab. Davon abgesehen guter Zustand.

Rumpf + Leitwerk: Zustand gut.

Beschreibung der Ruderabdichtbänder (Breite, Wölbung, Zustand...)

Querruder: Mylar 30mm oben + unten. Zustand sehr gut.

Wölbklappe: —

Höhenruder: — (Pendel-HLW)

Seitenruder: Beidseitig Mylar 30mm. Zustand sehr gut

Beschreibung der Turbulatoren (Art, Zustand, Position in % Flügeltiefe, Ober- oder Unterseite, bei Blasturbulatoren Art und Position der Luftquelle...)

Tragflügel: —

Höhenleitwerk: —

Seitenleitwerk: —

Beschreibung der Stau-Statik-Anlage

Art und Lage der Gesamtdruckabnahme: Pitotrohr im Nasenloch

Art und Lage der Statikdruckabnahme: Rumpfstatik unterm Flügel

Hersteller und Durchmesser des Fahrtmessers: Winter 80mm

Art der Düse für die Variometerkompensation: Einlochsonde auf Rumpfrücken

Sonstige Bemerkungen/Zusammenfassung

Zustandsprotokoll2011, Erstellt: F.Pätzold (IFF TU-BS)

8.5 Results in table form

The followings table gives the numerical results if the file with the high resolution results is not available.

C_L	C_D Clen	C_D vent open	C_D small tape	C_D wide tape
0,24	0,01145			
0,26	0,011622			
0,28	0,011824			
0,30	0,012032			
0,32	0,012267	0,012344		
0,34	0,012505	0,01257		
0,36	0,012765	0,012817		
0,38	0,013038	0,013072	0,013102	
0,40	0,013337	0,013342	0,013403	
0,42	0,013633	0,013625	0,013717	0,013687
0,44	0,013946	0,013927	0,014038	0,013998
0,46	0,014280	0,014244	0,014365	0,014326
0,48	0,014623	0,014574	0,014709	0,014668
0,50	0,014982	0,014934	0,015070	0,015030
0,52	0,015355	0,015301	0,015435	0,015404
0,54	0,015738	0,015683	0,015814	0,015794
0,56	0,016136	0,016076	0,016206	0,016194
0,58	0,016555	0,016483	0,016612	0,016608
0,60	0,016987	0,016901	0,017023	0,017037
0,62	0,017419	0,017336	0,017455	0,017474
0,64	0,017878	0,017786	0,017892	0,017923
0,66	0,018347	0,018240	0,018343	0,018395
0,68	0,018832	0,018721	0,018811	0,018865
0,70	0,019323	0,019210	0,019294	0,019359
0,72	0,019837	0,019723	0,019781	0,019860
0,74	0,020350	0,020239	0,020296	0,020368
0,76	0,020882	0,020785	0,020808	0,020897
0,78	0,021425	0,021339	0,021346	0,021431
0,80	0,021976	0,021921	0,021895	0,021986
0,82	0,022545	0,022519	0,022460	0,022544
0,84	0,023121	0,023146	0,023037	0,023117
0,86	0,023711	0,023786	0,023639	0,023712
0,88	0,024320	0,024452	0,024248	0,024311
0,90	0,024954	0,025138	0,024891	0,024924
0,92	0,025609	0,025836	0,025542	0,025549
0,94	0,026286	0,026560	0,026211	0,026190
0,96	0,026995	0,027289	0,026913	0,026846
0,98	0,027726	0,028039	0,027638	0,027513
1,00	0,028473	0,028789	0,028397	0,028201
1,02	0,029247	0,029556	0,029185	0,028900
1,04	0,030046	0,030325	0,030006	0,029632
1,06	0,030862	0,031106		
1,08	0,031705	0,031886		
1,10	0,032576			
1,12	0,033476			
1,14	0,034406			
1,16	0,035378			
1,18	0,036392			
1,20	0,037458			
1,22	0,038583			
1,24	0,039783			
1,26	0,041065			
1,28	0,042455			
1,30	0,043972			
1,32	0,045683			

Table 3: Flight performance results of the Cirrus D-6607 in table form