Experimental investigation of temporal and local flow separation on glider wings in thermal flight

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Abstract

Within the past few years, Akaflieg Dresden has conducted free flight experiments concerning stall characteristics of glider aircraft. In calm air, the airframe´s behaviour can be studied separately from the influence of atmospheric events. However these events are of particular interest for a sailplan trying to climb in a thermal.

Gusts meet an asymmetric slow flight regime with mean load factors typically between 1.1 and 2. Thus flow sepatation is barely avoidable. Even if there is no separation, distortions of the lift distribution by gust and aileron deflections as a reaction will contribute to induced drag.

In the present paper, the state of a student´s project is shown, which deals with the interaction of a glider with the gusts it experiences in thermal an cross country flight. Besides inertial data, local flow angles are to be measured in order to reconstruct the lift distributions and the shapes of gusts. Therefore, the airplane will be equipped with a set of four three-hole-probes and a multi-hole-probe upstream of the wing.

A lifting line model is used to calculate the distribution of lift and vertical velocity from measured data or, in opposite direction, the flow angles and accelerations to be expected from an asumed gust.

As the recent project is still in coparatively early progress, only few results can be presented so far.

Nomenclature

b	Wing span	[b]=m
c	Wing chord length	[c]=m
c_L	Lift coefficient	$c_L = \frac{2L}{\rho v^2 S}$
c_D	Drag coefficient	$c_L = \frac{2D}{\rho v^2 S}$
D	Drag	[D]=N
g	gravitational acceleration	g=9.81 m/s^2
J	Moment of inertia	[J]=kgm^2
	J_{xx} Moment of inertia about rolling axis	
	J_{yy} Moment of inertia about pitching axis	
	J_{zz} Moment of inertia about yawing axis	
L	Lift	[L]=N
m	Mass	[m]=kg
n	Load factor	[n]=1
v	velocity, air speed	[v]=m/s
x	downstream coordinate	[x]=m
y	spanwise coordinate	[y]=m
y	coordinate perpendicular to x and y	[z]=m
α	Angle of attack	[α]=°; [α]=1
Γ	Circulation	[Γ]=m^2/s
Λ	Wing aspect ratio	$\Lambda = \frac{b^2}{S}$
φ	Rolling angle	[φ]=°; [φ]=1
ρ	desity	[ρ]=kg/m^3

1 Introduction

Since the days of the Versaille treaty, when powered aircraft had been prohibited, glider flying has become the most popular kind of air sports in Germany. The organization in gliding clubs under the umbrella of the German Aeroclub (DAEC) allowes a very cost efficient operation of unpowered aircraft. Until today, german manufacturers dominate the world market for sailplanes.

The Versaille treaty had enforced aerodynamic research and structural development in order to enhance the performance of unpowered aircraft if they wanted to fly for more than a few seconds. Together with the introdution of variometers and the discovery of thermal upwinds by Robert Cronfeld the technical developement soon enabled gliders to stay airborn for hours going several hundret kilometers of cross country flight. In the 1960s, composite materials allowed surface qualities that made laminar airfoil wings really work.

Today, gliders still provide a very interesting field for research due to the absence of disturbing machinery. However, not only their own aerodynamic characteristics should be in the focus of consideraton, but also the environment within they operate. Additionally, the pilot strongly contributes to the performance of his sailplane by the way he is able to fit into his environment. Concerning thermal flight, he has to balance the advantage of slow flight allowing close circles with lower additional g-forces to the disadvantage of temporal flow separation. Flying a bit faster is sometimes better for performance and always safer.

Even concerning only the aerodynimic performance of the airframe itself, the environmental conditions should be concerned more intensively. In the past, british manufacturers such as Fred Slingsby tended to lower wing loading in order to cope with the weak thermals in Britain. Up to now, gliders are optimized for maximum L/D in a stationary straight flight. It is very likely and also known from experience that this contributes to high performance under every day conditions. However, the optimum for operational use might be slightly differend.

Operating in a medium range of Reynolds-numbers, flight data from gliders should provide appropriate test cases for numerical simulation. Additionally, flow is threedimensional of corse, but there are not as strong spanwise gradients and crossflow components as on a swept low aspect ratio wing.

Within the past few years, a number of projects concerning stall characteristics and influence of gusts in thermal flight have been conducted close to the circles of Akaflieg Dresden/Idaflieg.

2 Scientific approach

2.1 General

Despite of lower reynolds-numbers and the absence of engine nacelles flow separation and stall characteristics on glider wings is an interesting topic for experimental investigation.

- Re is still high enough that computational simulation is anything but easy.
- The flow around a glider aircraft in free flight (even in a thermal) has a rather low turbulence level concerning frequencies effective on boundary layers. Such a flow is difficult if not impossible to achieve in windtunnels. High quality surfaces on laminar airfoils and the absence of any machinery make free stream turbulence a key factor.
- On the other hand, thermal flight is highly instationary concerning low frequencies ranging from some Hz downto fractions of 1 Hz. Gusts meet an asymmetric slow flight regime with mean load factors typically between 1.1 and 2. Thus flow sepatation is barely avoidable. Inverstigations on the shape and statistics of gusts have not been done very extensively so far. There are only few sources to refer to [1]. In order to study the behaviour of the atmosphere, one has to go into the air.

All these factors make free flight measurement an essential part of investigation of the problem. Moreover, it is almost the cheepest and definitely the most pleasent way of flow investigation on gliders.

When an airplane is hit by a gust, the potentially asymmetric change in angles of attack will distort the lift distribution. On this the aircraft will react by changing the direction of its motion both translational and rotational. From these inertial parameters and aerodynamic data such as flow angles on certain positions the lift distribution can probably be reconstructed and with that the shape of the gust. Furthermore, the lift distribution provides information about local flow separation as well as induced drag. From this, the effect on the aircraft´s performance can be estimated.

At last, even aeroelasticity contributes to the problem, as aerodynamic loads cause structural deformation which reacts on local angles of attack and therefore lift distribution. Deformation can possibly be derived from the integration of the acceleration measured on several spanwise positions.

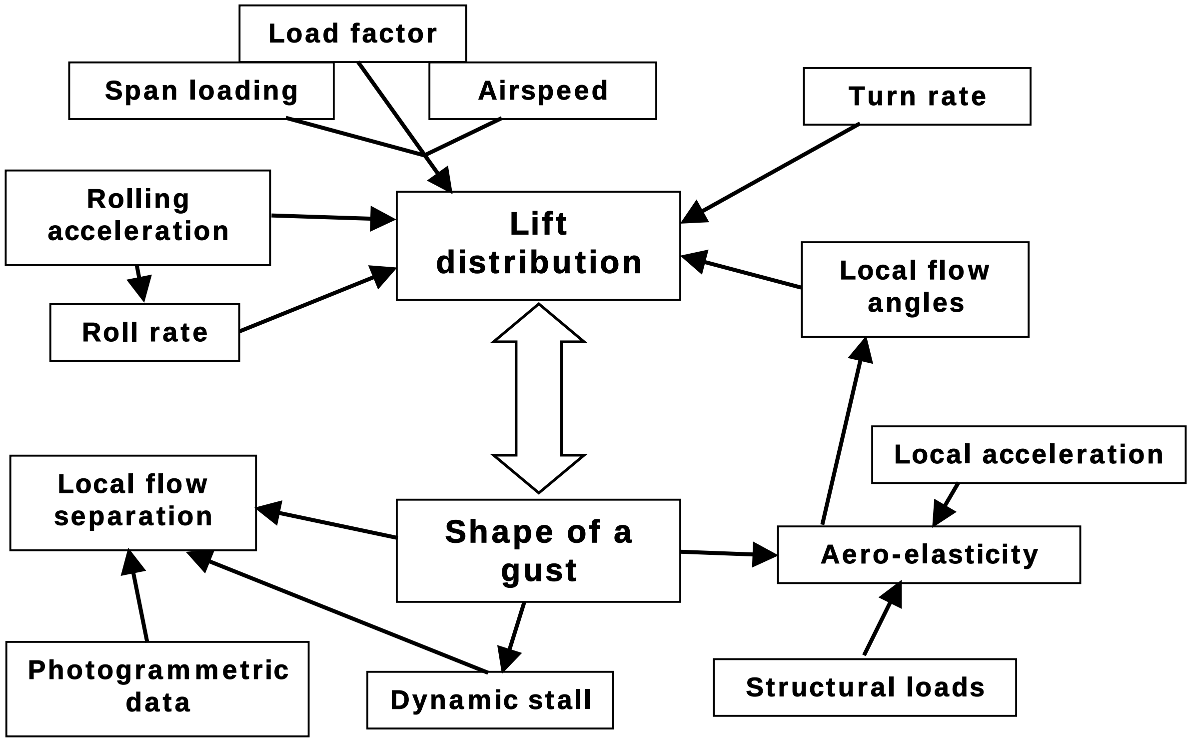

Figure 1: Interdependencies between measurable and interesting parameters

2.2 Theoretical Model

A lifting line model is used to calculate the lift distribution depending on measured data. In opsite direction, from an asumed shape of a gust the inertial behavior of the airframe and local inflow angles can be estimated. As the utilized tool does not incorporate distributed inflow angles, shape of the gust as well as rolling motion and aileron deflections are modelled by a geometrical distortion of the wing. For predicting flow separation, airfoil data have to be added to the model. As there are no windtunnel data available for Eppler´s E-603 airfoil, XFoil calculation are used as a basis. XFoil tends to to a certain overprediction in maximum lift. If necessary, the results can possibly be corrected by transfering corrections from similar airfoils as Wortmann´s FX-73, where measured data have been released.

There are nine equations for measurable parameters depending on the lift distribution allowing up to nine free parameters for its reconstruction. The overall lift has to counterweight the weight for the momentary load factor. Circulation has to be zero at both wing tips. Local flow angles must match the given values at five probe positions (see chapt. 2.3). The rolling moment produced by the lift distribution must fit to an angular acceleration about x-axis.

$$\rho \int_{-b/2}^{b/2} v\Gamma dy = n \cdot mg$$

$$\Gamma\left(-\tfrac{b}{2}\right) = 0; \Gamma\left(\tfrac{b}{2}\right) = 0$$

$$\alpha_i = f\left(\Gamma(y)\right)\Big|_{i=0}^{4}$$

$$\rho \int_{-b/2}^{b/2} v\Gamma y dy = J_{XX} \cdot \ddot{\varphi}$$

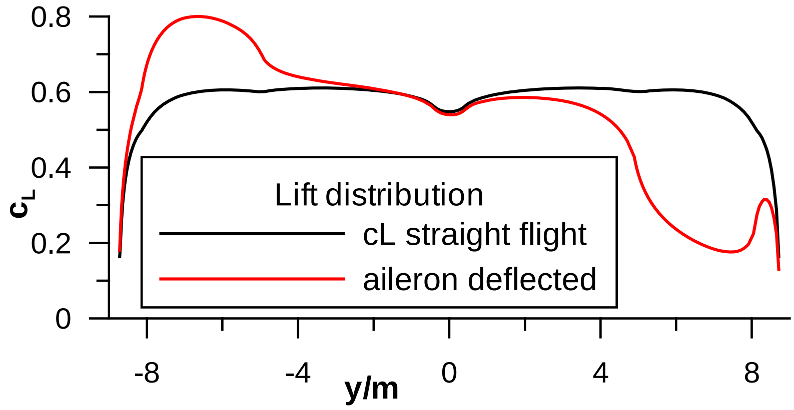

Figure 2: Change in lift distribution caused by aileron deflection with lifting line. Due to differential deflection (+5°,-10°), total lift is slightly decreased. Induced drag increases by 22%.

The Gust Model to be used for preliminary computations has been derived from the EASA CS-25 (commercial aircraft). The the given (1-cos)-shape has been rotated to obtain a circular shape similar to a thermal.

2.3 Experimental Setup

2.3.1 Previous configuration

The initial project conducted during the idaflieg-summer-meetings 2003, 05 and 06 focused on closing the gap between known airframe layouts and their known stall characteristics by the investigation of flow separation on the wing. Wool tuft had to be watched from an unosbructed point of view, therefore the camera was mounted on the tail as a kind of natural tripod. A b/w 1.2-MPixel-cam had been connected directly to the laptop computer via fire wire. But main point was a simultaneous recording of video stream and global fight data (airspeed, angles of attack and yaw) in order to be able to match the flow structures to the flight attitude. Flight data have been displayed and grabbed together the video stream. Methods of image processing have been tested in order to detect the wool tuft and their direction.

Figure 3a,b: L-23 Super Blanik with 4-hole-probe on a noseboom and camera on tail observing flow structures on the wing

Next step was to be measurement of spanwise distribution of inflow angles due to the suggestion that temporal stall could likely occur in a thermal flight regime. As a gust will never hit the airplane symmetrically, it seems obvious, that temporal flow separation might be only local as well. Therefore a central probe would probably deliver no better information than a single g-sensor and the onboard pitot-static system. Moreover, even if there´s no separation, the change in lift distribution by a gust might cause increased induced drag.

As four three-hole-probes were of disposal, wing gloves and a small nose boom had quickly been manufactured preparing for the 2006 summer-meeting. Due to time shortage and poor weather conditions, the part of the project ended with a single calibration flight.

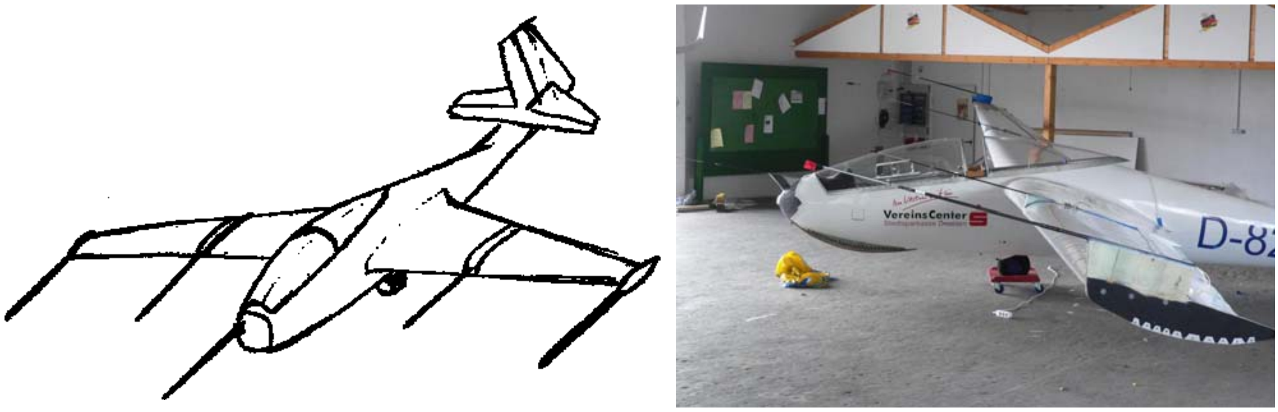

Figure 3a,b: Scetch and photograph of the SZD-9 Bocian equipped with flow angle probes for thermal flight investigation

2.3.2 Recent setup

Putting all together, investigation of stall characteriscics and calibration of local inflow probes in quasi stationary flight regime should be combined with measurement of flow angles and load factors in thermal and cross country flight. Now, a Twin Astir I is to be used and propably more capable for cross country flight with instrumentation. The private laptop will be replaced by an autonomous data recorder (FMA) that won´t have to be tended to during flight so intensively.

The practice of video grabbing is not to be recommended and not suitable using the FMA. Moreover, the FW-cam will be replaced by a 2.1-MPixel-camcorder. Synchronisation will be done externally by the system clocks of camera and computer. In addition to the higher resolution, wide screen better fits to the aspect ratio of a glider wing. Using colour information, tufts are easier to be detected on images with varying illumination.

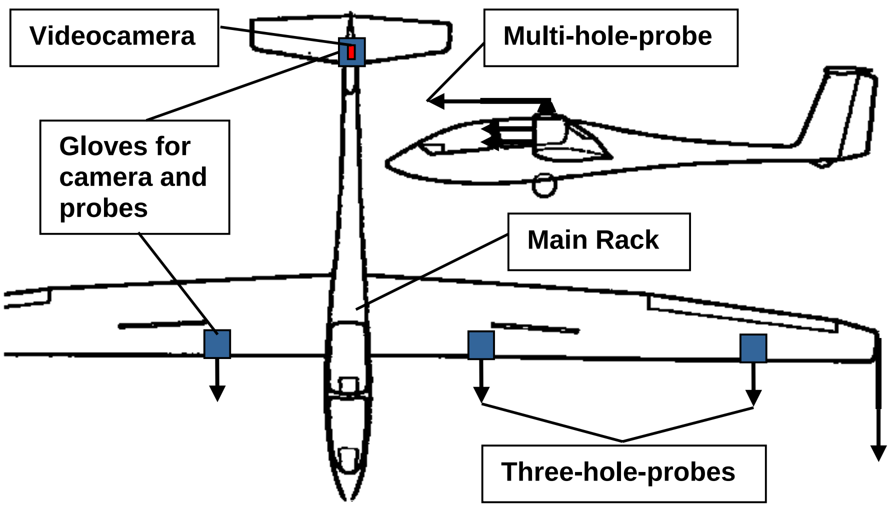

Figure 4: Intended setup on the Twin Astir for thermal flight measurement

The positions of the three-hole-probes have been changed in a way that each of the four probes is now centered in its spanwise section. Deflection of all four control surfaces is to be measured by potentiometers. Recent status is certification of the setup.

Using extremely low budget g-sensors might result in a bad signal/noise ratio. Distributing seven of them in spanwise direction (one on each wing glove, one in the main rack and one on the tail) this noise level shall be lowered by averaging. If these sonsors prove more reliable, deviations in acceleration from the rigid body model could be used to determine aeroelastic effects. A first test rotating one of the sensors form 1g to –1g and back shows promissing results. The gradients have a certain jitter which, however, might be caused by the simple test setup as well as truncation errors.

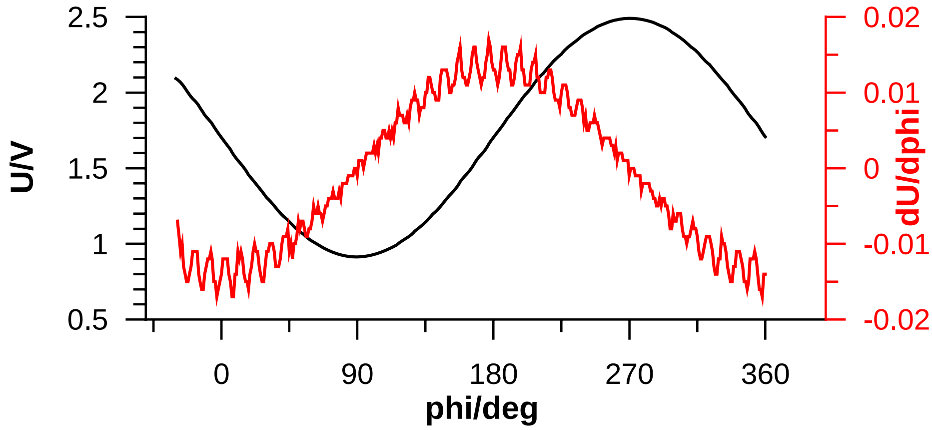

Figure 5: Result of first g-sensor test

3 Results

As the project is still in comparatively early progress, there are only few results to be presented so far.

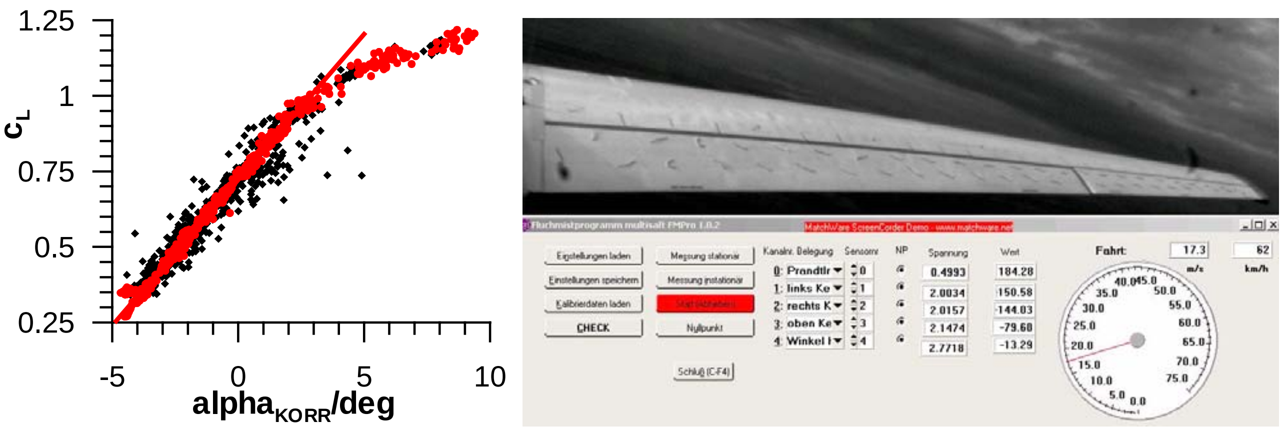

Figure 6a,b: L-23 Super Blanik, lift curve and typical flow structures at stall condition

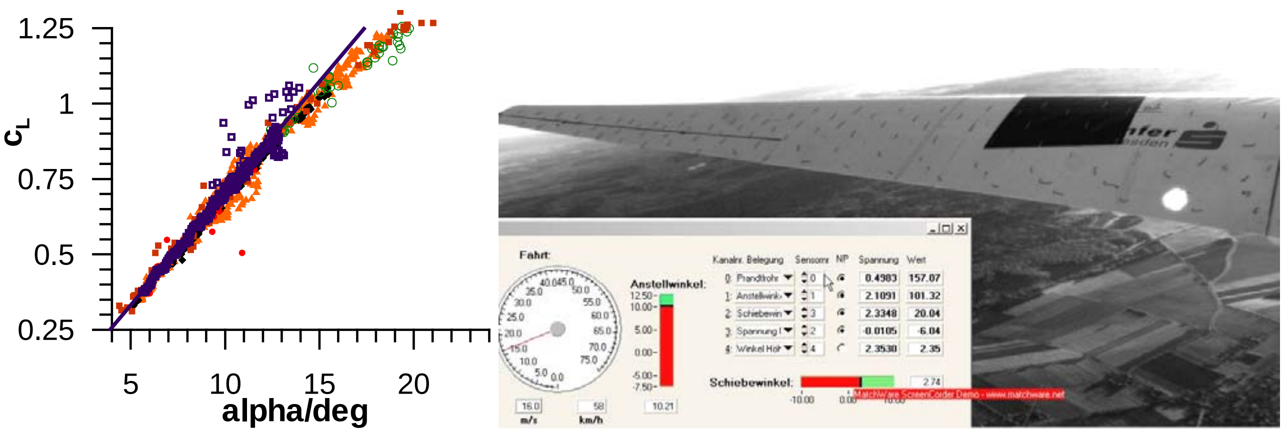

Figure 7a,b: SZD-9 Bocian, lift curve and typical flow structures at stall condition

The Blanik shows a characteristics typical for high planes with only little twist. Additionally, a considerable negative sweep causes a strong crossflow componend at the onset of stall that reaches even onto the ailerons. The lift curve is quite similar to the shape expected for an airfoil in a 2D flow.

A midplane with a strong twist such as the Bocian forms a kind of diffuser near the wingroot. There, flow will separate much earlier than close to the wing tip. That´s why the lift curve very gradually leaves the linear path as the separation slowly propagetes from the root to the tip.

Slight differences in stall characteristics can be explained by the flow structures, especially considering spin.

A diploma thesis has been done to detect the wool threads within the video stream in order to obtain separation lines for each flight attitude. This approach still suffers a bit from the lack of suitable criteria whether the flow is attached or separated. Another problem is the reliable detection of the threads on b/w images with varying ilumination, where the white background is sometimes even darker than the objects to be found. Coloured images are expected to make this a quite easier.

Within the 2006 project on thermal flight only a single calibration flight in calm air could be conducted. Its result is shown below.

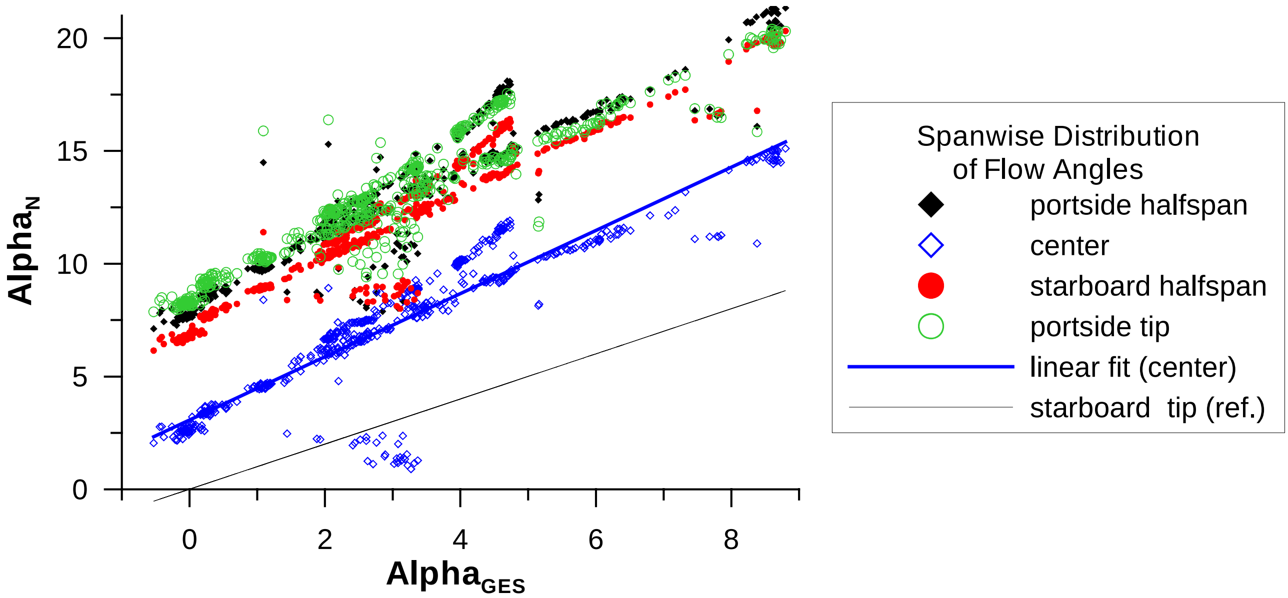

Figure 8: Local flow angles at probe positions 1..4 drawn vs. Flow angle at global probe position

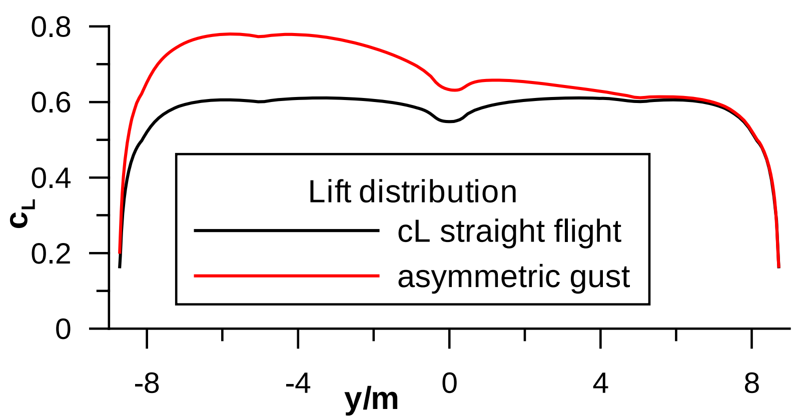

Figure 9: Change in lift distribution caused by an asymmetricly hitting vertikal gust. Total lift increases due to average upwind. Induced drag increases only by 1.6%.

As the recent project is still in comparatively early progress, there are only few results to be presented so far. A number of calculations have been conducted concerning the expected behaviour of lift distribution, flow angles and aircraft motion when flying into a gust.

4 Conclusion

Investigation of flow structures on glider wings has shown that sometomes even small differences in stall characteristics coincide with the onset and propagation of flow separation.

The theoretical model seems to be working quite well. Its consitance with reality still has to be proven. Flight measurements still suffer from a delay in certification cased by EASA regulations.

The theoretical and experimental investigation of vertical gusts and their effect onto the aerodynamics of glider aircraft shows to be a very complex field. There are a large number of parameters that influence each other and that have to be distinguished. The experimental effort is not to be underestimated. Within a diploma/master thesis only a small fraction of the problem can be covered. There will be a plenty of space left for further investigation.

Acknowledgments

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Furthermore, Kamerawerk Dresden (KWD) has supported the stall project by providing a camera in a very uncomplicated manner.

Thanks to National Instruments (NI), a data recorder in form of a singleboardRIO is available now.

Last but not least, there is a grateful personal thank you to Stefan Gaubisch who has taken the risk and a lot of additional work of choosing such a free flight topic for his diploma thesis and he is really doing very well.

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[2] Riedel, H.; Sitzmann, M.: ”Inflight Investigations of Atmospheric Turbulence”. Aerospace Science and Technology, 5/1998, 301-319.