

Improvement of an Artificial Stall Warning System for Sailplanes

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Abstract

In 1987 OSTIV announced a competition for the development of a simple instrument to provide a stall warning for sailplanes. Although seven entries were submitted, there was no system that met all the requirements. Yet, the Polish system was considered to be the best. In 1998 a slight modification was proposed and tested in order to eliminate the dependence on wing loading of this system. However, it turned out that the system did not work properly in an asymmetrical stall. This paper proposes a further modification in order to eliminate that imperfection.

Introduction

In 1987 OSTIV announced a competition for the development of a simple instrument to provide a stall warning for sailplanes. In spite of seven entries, there was no system that met all the requirements. The Polish entry was considered to be the best system, but its operation was dependent on the wing loading; a change of wing loading (water ballast, single/two seater) necessitated recalibration of the system. This dependence on wing loading was eliminated in 1998 by a slight modification of the system¹. That system proved to work properly in straight flight and during coordinated turns, but not in skidding turns, a situation that frequently occurs in the landing phase close to the ground.

This paper proposes a further simple modification to the system and presents results of flight tests that validate the proper functioning of the warning system during wings-level stall, asymmetrical stall, stall during coordinated and skidding turns, different amounts of water ballast, dive brakes extended, with or without the landing gear extended, and thermalling flight.

Basic operation

The Polish system is based on the measurement of the local dynamic pressure at a position a few centimeters behind and below the fuselage nose. A differential low-pressure transducer measures the difference between the total pressure of the pitot probe and the static pressure of that small hole in the fuselage nose. This value is electronically compared with a previously adjusted threshold and if it drops below the threshold, the audio warning starts. Since stalling depends on the angle of attack and wing loading, the dynamic pressure at the position of the hole in the fuselage depends on these parameters as well. A change in wing loading necessitates recalibration of the system.

The modification proposed in 1998 is to divide the dynamic pressure at the hole position by the dynamic pressure used for the airspeed indicator. This dimensionless quantity depends, like a pressure coefficient, on the angle of attack but not on the

wing loading. The principle was tested in flight with the ASW-19BX test bed sailplane of Delft University of Technology, Faculty of Aerospace Engineering. The stall warning system worked properly at wings-level stall, coordinated turns, change of wing loading and extended speed brakes. However, in skidding turns the warning started too late.

The present modification is to replace the pressure of the hole below the fuselage nose by the mean of the pressures measured at a position at the sides of the fuselage nose, taken in the middle of a plastic tube that connects these holes. The holes are at a position where their mean pressure changes with angle of attack but not with yaw angle. This position has to be determined experimentally or by CFD calculation, similar to the determination of the position of the static ports for the altimeter, airspeed indicator and variometer.

Test equipment

The ASW-19BX was equipped with a laptop in the baggage compartment behind the pilot's head and a digital video camera attached to the rim of the cockpit. The laptop computer was used for data acquisition, data reduction and stall warning, and the camera to record the instrument panel and comments of the pilot. Two low cost differential pressure transducers (XCAL4-004GN) were mounted in a small box in the instrument panel; their signals were transferred via a data acquisition card to the laptop.

In addition, a small wind vane mounted on an inductive potentiometer in the tip of an aluminum beam was installed in front of the wing, serving as yaw angle indicator (Fig. 1). The vane was calibrated and its signal was recorded by the laptop too. In addition, the yaw string on the canopy (showing almost twice the yaw angle according to VSAERO calculations) was provided with a degree scale on the inside of the cockpit. For the indication of the bank angle, a Bohli compass was used.

A LabVIEW program was written for the data acquisition, data reduction and stall warning during flight. The ratio of the output of the pressure transducers was online compared with a

preset threshold level. When the ratio surpassed the threshold level an audio warning was activated via an earphone to the pilot. A warning engagement threshold level was set in order to avoid the stall warning to be active on the ground.

The laptop was started in flight by a start/stop button on the instrument panel; the camera was switched on the ground and recorded the whole test flight.

For data reduction the flight speed (calculated from the dynamic pressure q_{inf}), the average local speed (calculated from the average dynamic pressure at the two holes q_{local}), their ratio, and the yaw angle were simultaneously visualized in 30-second time frames. The video film helped to identify and interpret the flight situations.

Flights

The stall warning system was tested during two flights, starting at 3000m and 2200m altitude. Take-off weight was 380kg and 445kg respectively. The system was tested at different situations; each situation was tested at least three times:

- wings-level stall
- wings-level stall with yaw
- stall in coordinated turns
- stall in skidding turns
- wings-level stall with brakes extended or landing gear down
- flying in thermals

Results

Determination of the position of the holes

A wing-fuselage model of the ASW-19BX, made in the digital product definition program CATIA, was used as input for the computational fluid dynamics program VSAERO. VSAERO is a panel method with a coupled boundary layer code. For the Polish hole location and for the new locations of the two holes, surface pressures were calculated at lift coefficients of 0.9 to 1.3 and yaw angles up to 30 degrees.

Figure 2 shows the computed pressure coefficient at the position of the hole below the fuselage nose. In straight flight, when the flight speed decreases (Cl increases) the pressure coefficient increases and the stall warning is activated. When yaw occurs, the pressure coefficient decreases again and the stall warning stops. This confirms the observation in flight tests that the warning system warns too late in case of yaw.

Figure 3 shows the computed average pressure coefficient of the two holes, located in a vertical plane 32cm from the nose and 30% from the top of the local cross section height. Note the different Cp scale of Fig. 3 in comparison to Fig. 2. In straight flight the pressure coefficient decreases when the flight speed decreases. When yaw occurs, the average pressure coefficient slightly decreases (causing theoretically a slightly earlier warning).

Test flights

Wings-level stall

The estimated minimum speed (at sea level), calculated for $W/S = 340 \text{ N/m}^2$ at $Cl_{max} = 1.3$, was 74.4 km/h and the warning threshold was set at 81.3 km/h, i.e. a margin of 9 %, see the upper right figure in Fig. 4. According to OSTIVAS and CS-22, the warning should begin at a margin between 5% and 10% and continue until the stall occurs. At 81.3 km/h flight speed the average speed calculated from the average dynamic pressure of the two pressure holes is 77.4 km/h as shown in the upper left figure. The lower left figure shows the speed ratio and the vertical lines indicate the time that the warning started and stopped, at the preset speed ratio of 0.95 (dynamic pressure ratio of 0.90). These times are indicated by vertical lines in the other figures as well, and horizontal lines ease the reading on the vertical scales. The lower right figure is the indication of the wind vane.

During the tests the flight speed was reduced by $\leq 2 \text{ km/h}$ per second. Data reduction after the flight revealed a minimum speed, calculated from the dynamic pressure q_{inf} , of 69 km/h as shown in the upper right figure. Hence, with a margin of 17.5% the threshold level was set somewhat too high.

The warning stopped at 70.7 km/h, shortly after the start of recovery.

Wings-level stall with yaw

As indicated in Fig. 5, the yaw angle was about 15 degrees (30 degrees indicated by the tuft on the cockpit), the warning started at 86.6 km/h, the minimum speed was at 63 km/h and after recovery the warning stopped at 78.2 km/h. The margin is 37%, but it should be realized that these speeds are not the actual speeds due to incorrect pressures. Obviously the system warns for yaw as well.

Stall in coordinated turn with bank angle 30 degrees

As shown in Fig. 6, with the same threshold velocity ratio of 0.95 the warning started at 83 km/h, the minimum speed was, as calculated, 74 km/h (margin 12%) and the warning stopped at 76.5 km/h, again shortly after the start of recovery. The vane indicates the yaw corrections applied.

Asymmetrical stall, skidding turn

Flying a normal turn of 30 degrees bank angle, the rudder was deflected inward, up to almost full rudder. At the same time the speed was decreased (Fig. 7) and when the glider was near stalling, a reversed aileron deflection was given. This made the inner wing to stall and drop, leading to the beginning of a spin, which was recovered.

The vane recorded an oscillating yaw angle due to corrections but no clear large yaw angle. The warning started at 88.6 km/h, the minimum speed was at 77 km/h (margin 15%), the warning stopped at 79.4 km/h after the start of recovery.

High wing loading

With 65 litres of water ballast the wing loading was increased to 400N/m^2 . This causes a calculated increase in minimum speed of 8.5%, for wings-level stall from 69 km/h to 75 km/h, and for 30 degrees bank angle from 74 km/h to 80 km/h. Figures 8 and 9 show these cases. At wings-level stall, with the same threshold velocity ratio of 0.95 as before, the warning starts at 85 km/h, minimum speed is at 75 km/h (margin 13%), and the warning stops at 76.8 km/h after the start of stall recovery. In a 30-degree turn, the warning starts at 93.9 km/h, minimum speed is 80 km/h (margin 17%) and the warning stops at 81.6 km/h. Hence, the system works with different wing loadings.

Speed brakes and landing gear extended

As expected, the extension of the landing gear has no effect on minimum speed and functioning of the warning system. Extension of the speed brakes cause a loss in lift in the corresponding part of the wing but the angle of attack at stall of the remaining wing is not changed. Consequently, flight tests show an increase in warning speed, minimum speed and warning stop speed of 4 km/h (comparable to a change in wing loading).

Thermalling flight

After the water had been dumped in the second flight, three climbs in quite narrow and moderately gusty thermals were made. As shown in the lower left figure of Fig. 10 the ratio of speeds peaked some times above the warning threshold of 0.95. The horizontal lines in the flight speed graph show the speed range that was flown. The first 10 seconds were flown at about 85 km/h, a little too slowly, and after that at about 90 km/h, and the warning barely went off anymore. As mentioned before, the warning threshold was set somewhat too high; at a lower setting (speed ratio 0.96 at 10% speed margin) the warning does not go off in thermal flights unless the flight speed is too low.

Conclusions

In all the situations tested, the warning system worked well. The warning threshold was set at a somewhat too high velocity; if set at the required speed between 5% and 10% above the stall speed the warning would not have gone off during thermalling.

The stall warning system can be integrated in the airspeed indicator, with a possibility to adjust the threshold level (once) and a LED indicating that the system is active.

Acknowledgement

The authors are indebted to Stefan Bernardy who developed the instrumentation and software for data acquisition and reduction.

Reference

¹ Cnossen, J. M., "Artificial stall warning for sailplanes," *Technical Soaring*, Vol. 22, No 3, 1998.



Figure 1 Wind vane installed in front of the ASW-19BX wing.

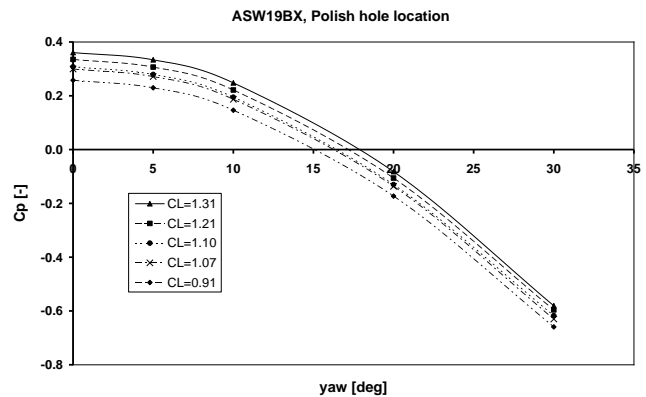


Figure 2 Calculated pressure coefficient at yaw angles for ASW-19BX at Polish hole location.

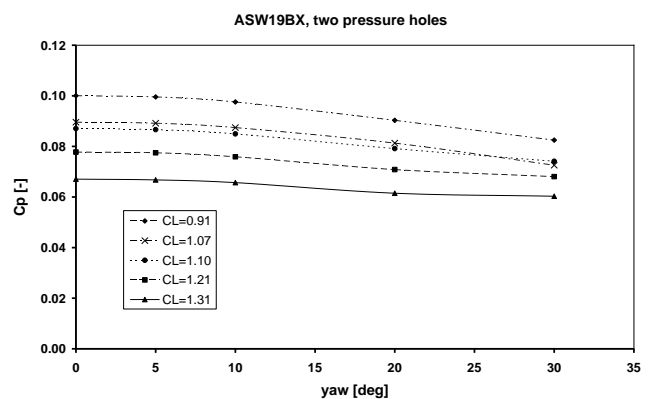


Figure 3 Calculated average pressure coefficient of two new holes at yaw angle for ASW-19BX.

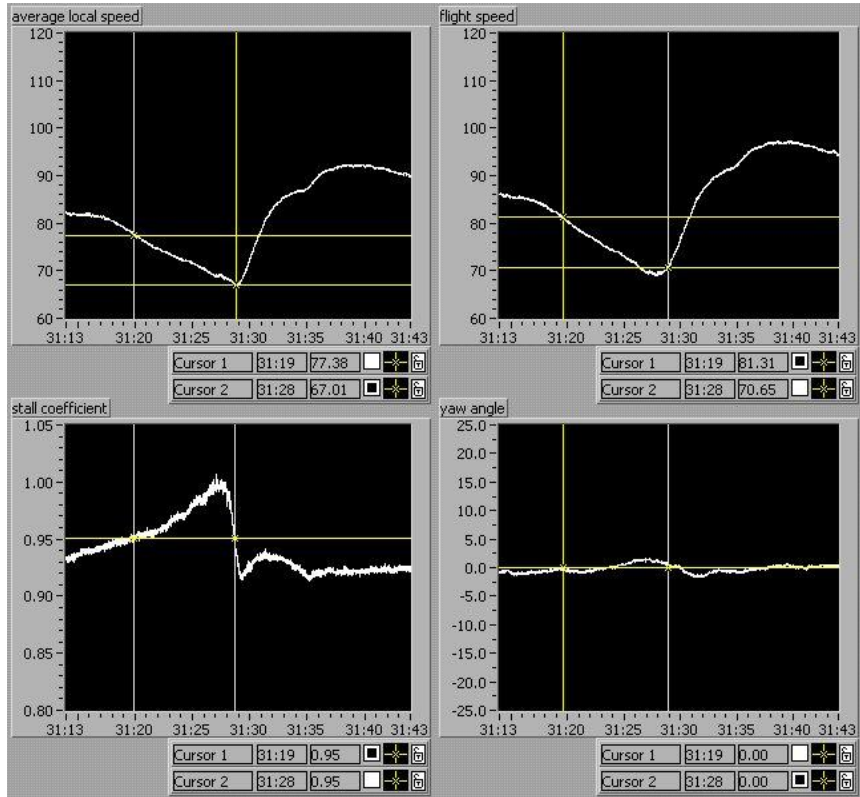


Figure 4 Wings-level stall, no yaw.

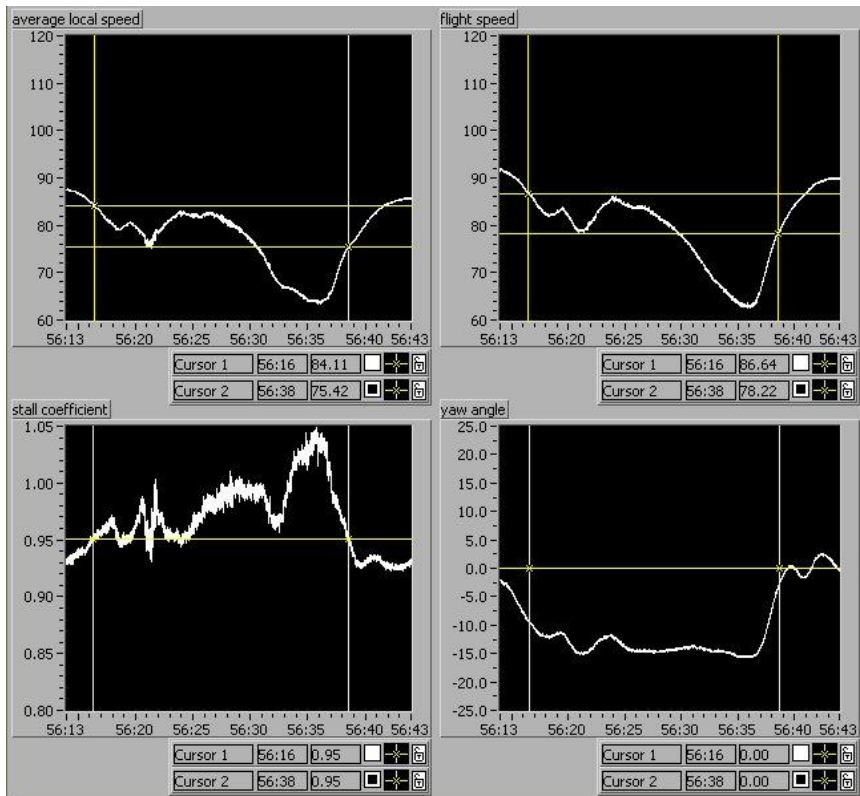


Figure 5 Wings-level stall, 15 degrees yaw.

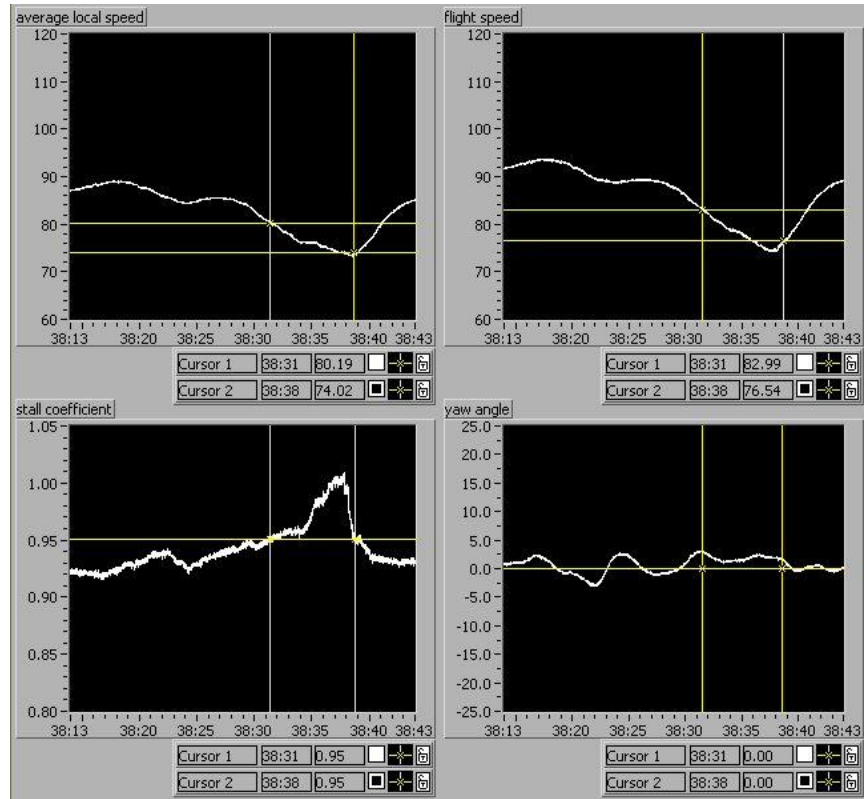


Figure 6 Stall in turn with bank angle 30 degrees.

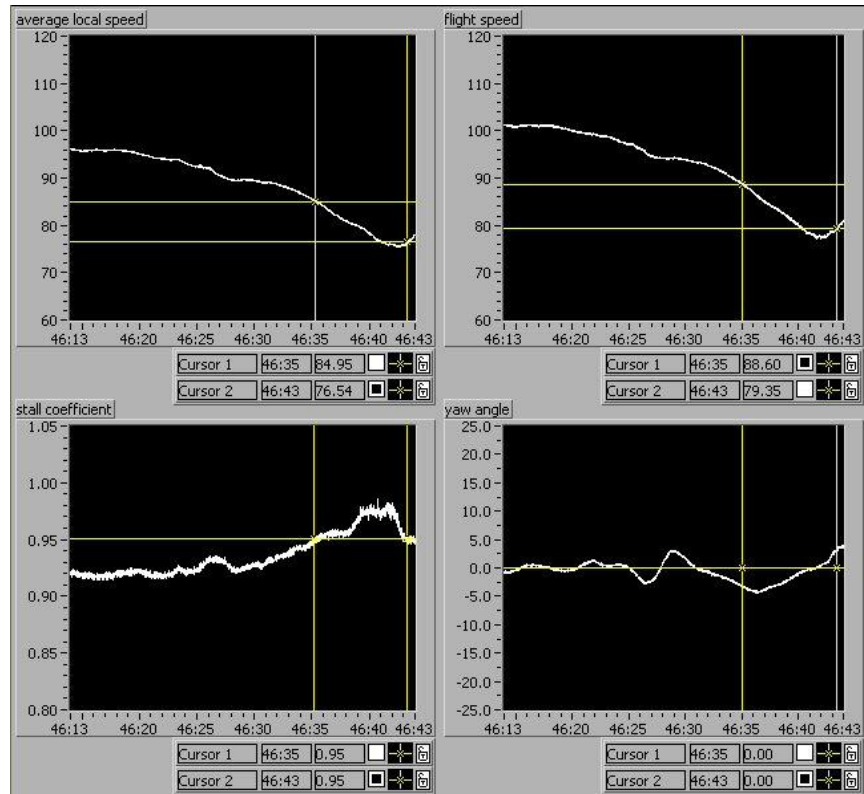


Figure 7 Asymmetrical stall, skidding turn.

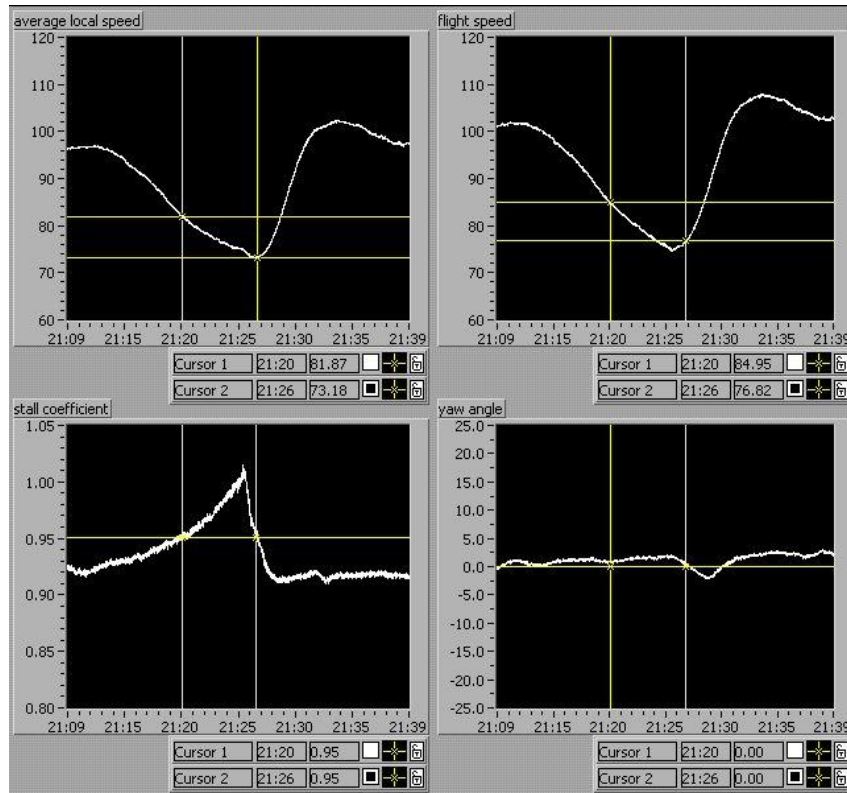


Figure 8 Wings-level stall, high wing loading.

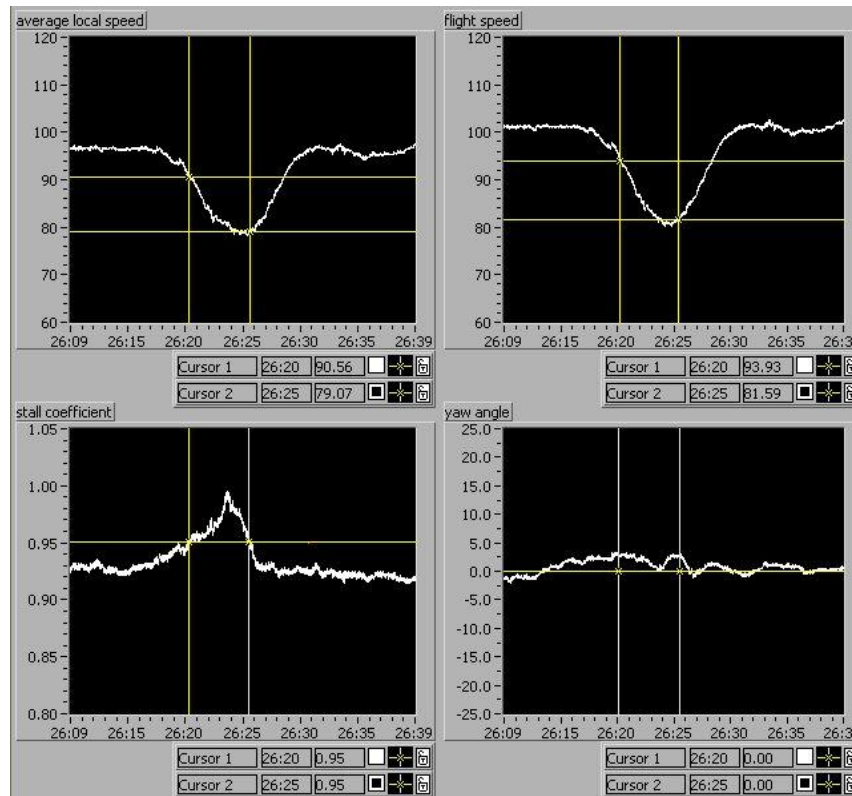


Figure 9 Stall in turn with bank angle 30 deg., high wing loading.

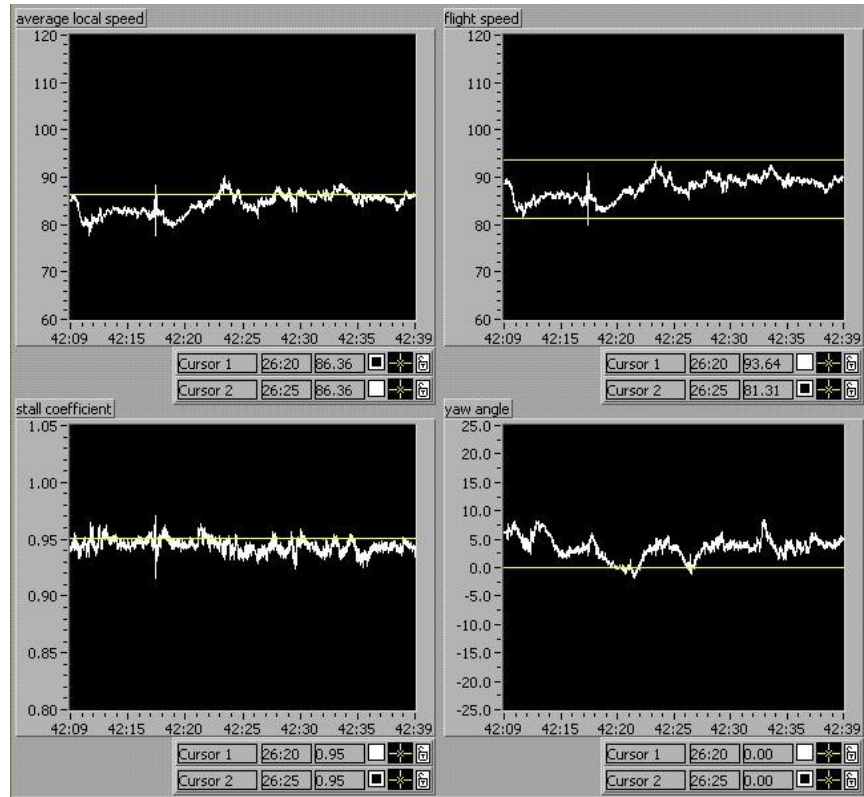


Figure 10 Thermalling flight.