Yaw-Free Multi-Probe for Soaring

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Abstract
The construction details of the new type of a yaw-free multi-probe are presented and the results from tests under real conditions are discussed. The measurements demonstrate not only the dependency of the suction coefficient on the angles of attack but also the impact on the quality of indicated speed measurement. The free rotatability of the relevant components for the measuring of pressures reduces the sensitivity for undesirable effects like turbulence, gusts and yaw, and helps the pilot with reliable variometer readings.

Nomenclature

c_{Probe}	suction coefficient
α	angle between the direction of probe main tube and air stream vector in the vertical aircraft plane
β	angle between the direction of probe main tube and air stream vector in the horizontal aircraft plane
γ	TE pin angle in respect to the probe main tube
v_{IAS}	indicated air speed
p_{TE}	total suction pressure
p_{Static}	static pressure
p_{Total}	total pressure
q	dynamic pressure

Introduction

Today's high-performance variometer instrumentation installed in gliders allows sampling and digitizing of the air pressure signals with a frequency and a precision which is much higher compared to the ability of instruments of previous generation. Such improved and novel readings of vertical and horizontal velocities help the pilot during the search for thermals and serve also as input data in many sophisticated strategic calculations. On the other hand, such a variometer measuring system does not consist only of a digitizing and computing electronics. One further, but no less important, component of this system is the probe bodies which guarantee the optimal detection of the different air pressures in the air stream. Whereas the electronics and the data acquisition underwent, in the past, a major improvement, the concept of the rest of the system, especially of the probe, remained more or less unchanged for the last 20 years. The common probes are mounted still in a fixed position with respect to the glider axis, usually parallel to the flight axis. It turns out that this position may not be optimal for all flight attitudes[1]. Further, the air stream can significantly change its direction compared to the flight direction as well the flow can change from laminar to turbulent. Even the last effects can be partially induced by the glider itself when it enters the turbulent area of thermals and the flight direction and the angle of attack are changed. All these effects influence the measurement of static and total pressure and also of the speed induced suction are required for the total energy compensation.

Design of the yaw-free probe

In order to improve the performance of the whole variometer system and to understand the systematic effects of the air stream on the probe surface, a new type of, so called, yaw-free probe was developed.

The innovation of the new probe is a refinement of the standard total energy probe (TE) concept[2]. It affects both the standard one-way TE probe as well as the multi-pressure probe. The latter one is often used due to its advantage to measure the relevant pressures at one place and at the same time in the air stream. Figure 1 shows the principle design of a 3-way probe which records the total pressure p_{Total}, the static pressure p_{Static} and the speed dependent suction pressure p_{TE} used for the total energy compensation. The orifices for the pick up of the static pressure and of the TE suction have the usual diameters (0.8mm) and are situated on a common tube. The probe has two holes (opening angle of 30°) as orifices for the TE suction. The static pressure inputs are located left and right on the side of the short (ca. 50mm) horizontal tube and the total pressure input on the front side of this tube. The total pressure input is a tube with a 5mm diameter. This tube is attached to the TE-pin in a direction parallel to the probe main rod and aligned to the flight direction. The TE-pin is mounted on a long bearing sleeve with an angle $\gamma = 105°$ with respect to the main tube in the vertical plane (see Fig. 1). The pressure inlet system consisting of the TE-tube and the total and static pressure tube is freely rotatable around the center line of the TE-pin which is approximately parallel to the vertical or yaw axis of the glider. A small fin attached on the back side of the TE-tube acts as a vane and turns the pressure inlet tubes to the correct positions with respect to the air stream which is of course not always parallel to the direction of flight. This correct position is perpendicular to the air stream for the measurement of total pressure and TE suction and parallel to the air stream for the measurement of static pressure.

During the first test it turned out that, although the vane weights just 1g, this weight has to be balanced by a small counter mass to keep the axis free from moments and to reduce the sensitivity to oscillation. The counter mass for this case is a 1.2 g heavy iron tube which forms the orifice for the total pressure.

Experiment

The goal of the experiment is an objective and quantitative comparison between the results of the standard and the yaw-free probes. The best way to achieve such unbiased numbers would be a continuously recording and analyzing of climb rate, air speed, and GPS position with two independent probe-variometer systems during the same flight and at the same position on the glider. Such an experiment is foreseen for the near future.

In the first experiment, an indirect quantitative measurement of probe characteristic numbers was performed as a function of air speed and of angle of attack. The quantities analyzed were the suction coefficient $c_{\mathrm{Pr}obe}$ and the indicated air speed v_{IAS}. For the second experiment, 3-way probes A and B were used. One of them, the probe A, was mounted in a fixed position parallel to the flight direction with α and $\beta = 0°$. Probe B was prepared in such a way that the angles of air stream attack β and α were adjustable. The yaw angle β in the horizontal plane was varied in 5° steps from 0° to 40°, the angle α in the vertical plane was adjusted to 0°, 5° and 15°. The variation of angle α corresponds to variation of the TE-pin angle with respect to the air stream where γ = 105° corresponds to a pitch angle α = 0° and γ = 90° to α = 15° (see Fig. 1). In order to study the impact of the angles α and β on the indicated air speed, measurements from 80 to 110 km/h and α and β combinations were obtained. Altogether for each α, β, v_{IAS} triple the six pressures (three from probe A and three from probe B) were digitized and stored. The pressures from the probe A served as reference unbiased measurements.

Most of the data was taken with an experimental set up mounted in front of a car 150cm above the surface. To the check for systematic influence through the car-borne experiment, a few flights with fixed attack angles α and β were carried out and are marked in the results in Fig. 2. In the airborne experiment the probe heads were mounted 80cm in front of the glider. The airborne measurements were taken at v_{IAS} = 100km/h during a straight-ahead flight with no significant thermals.

Results and discussion

From the pressure measurements, the suction coefficient $c_{\mathrm{Pr}obe}$ can be immediately calculated using the formulas

$$p_{TE} = p_{Static} - c_{\mathrm{Pr}obe} \cdot q \quad (1)$$

and

$$p_{Total} = p_{Static} + q \quad (2)$$

Due to the fact that we are interested in the α, β dependence of the suction coefficient $c_{\mathrm{Pr}obe}(\alpha,\beta)$, we have to put $p_{TE} = p_{TE}(\alpha,\beta)$ into the above formula, and for the total and static pressures we have to use the reference values $p_{Total}(\alpha = 0°, \beta = 0°)$ and $p_{Static}(\alpha = 0°, \beta = 0°)$. From this, we obtain

$$c_{\mathrm{Pr}obe}(\alpha,\beta) = \frac{p_{Static}(\alpha = 0°, \beta = 0°) - p_{TE}(\alpha,\beta)}{p_{Total}(\alpha = 0°, \beta = 0°) - p_{Static}(\alpha = 0°, \beta = 0°)}$$

The results of the suction coefficient $c_{\mathrm{Pr}obe}$ as a function of the yaw angle β for the three α values are shown in the Fig. 2. Furthermore, also the airspeed influences the suction coefficient (the Reynolds number varies from about 6000 to 9000). This is clearly visible in Fig. 2 as a set of significant parallel curves for each α value. The same results are summarized also in Fig. 3 as a function of the reference air speed v_{IAS} for $\alpha = 0°, \beta = 0°$. Also, it is seen that the measurements cluster into groups with the same α value and the spread for same air speeds results from the different yaw angles. Finally, the air speed dependence on the yaw angle β is plotted in Fig. 4 for 90 and 100km/h reference air speed v_{IAS}.

The measurements show a relatively big variation of the suction coefficient with changes in the angle of attack. It is obvious that such a big variation of air stream direction is not common in a stationary flight. But, larger amplitudes in the angles of attack can occur in fast maneuvers as with entering thermals. The second and probably more important sources for big changes of suction coefficient are gusts and flowfield interactions with the airframe. For this reason the suction coefficient cannot be treated as a constant factor if the pilot interprets the fast variometer amplitudes during searching for or centering thermals. A qualitative estimation of the change of the coefficient $c_{\mathrm{Pr}obe}$ on variometer readings can be directly calculated from the Eq. (1). The pressure p_{TE} appears in the difference to the static pressure in a total energy compensated variometer. For example, the reduction of $c_{\mathrm{Pr}obe}$ value by 10% from 1 to 0,9 in one second at 100km/h causes a variometer signal of +2m/s. Here the yaw-free probe can help the pilot to filter out at least the variation of the suction coefficient due to the yaw effects.

Conclusion

A new type of a multi probe has been developed and the performance was tested in comparison with a standard fixed probes. The aim to compensate the fluctuation of the suction coefficient by keeping the optimal airflow conditions around the probe body was achieved. The construction allows the head of the probe to swivel free in the air stream and to turn the orifices for the different pressure inputs always in the optimal orientation to the air flow. With this simple improvement, the influence of yaw and turbulence on the pressure measurements in the horizontal plane is minimized. The probes were tested many times in flights by different pilots and the improvement in the stability of variometer readings was reported. A first set of quantitative measurements was done and the results explain the probe behavior in reasonable manner.

References

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[2]Nicks, Oran, “A Simple Total Energy Sensor”, NASA Technical Memorandum, NASA-TM-X-73928, 1976

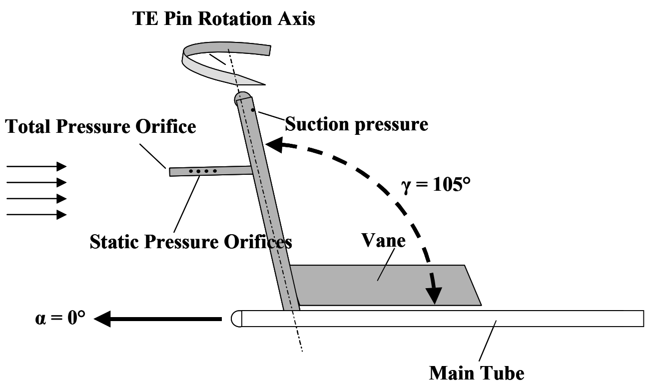

Figure 1 A schematic view of the yaw-free multi-probe.

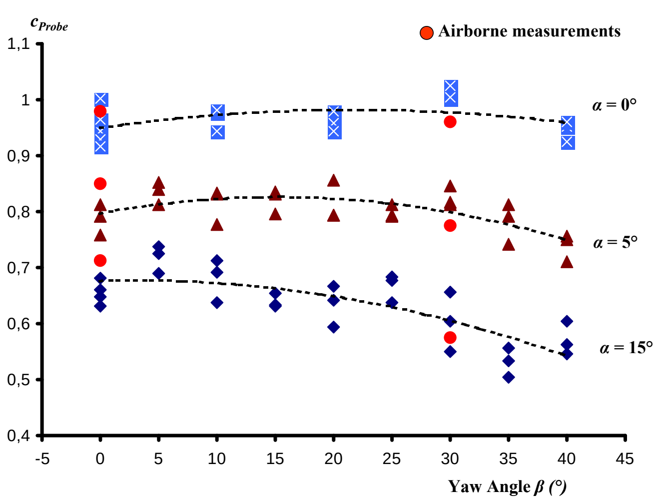

Figure 2 The suction coefficient as a function of the yaw angle for three different attack angles α and air speeds. The splitting of the data points in approximately three curves for each α– value comes from the measurements at three similar air speeds. The full circles mark the airborne measurements.

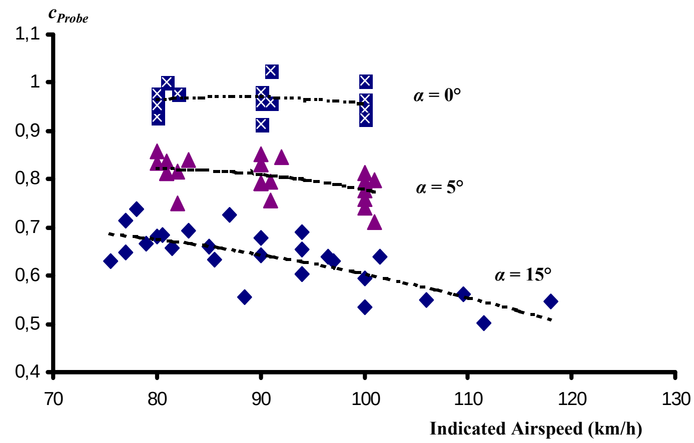

Figure 3 The suction coefficient as a function of indicated airspeed v_{IAS} for three different α and yaw angles. Also in this case the data points for each same α value show the spread due to the variation of the yaw angle.

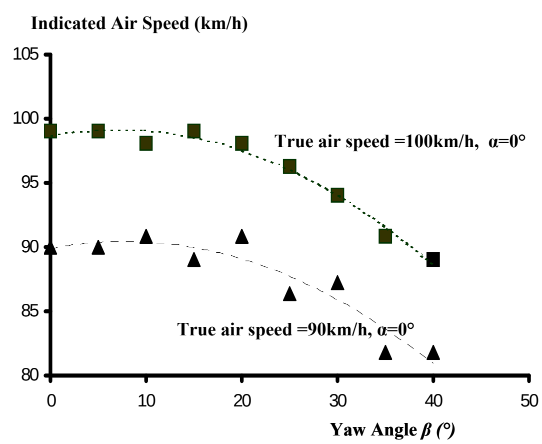

Figure 4 The indicated air speed measured with yawed probe as a function of the yaw angel for 100km/h and 90km/h true air speeds.