DLR's latest research sailplane: Discus-2c DLR

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Abstract: Latest in a long line of research sailplanes, the Discus-2c DLR is the successor of the DG-300/17. It is employed as benchmark in evaluating glider performance using the GNSS based comparison method. The higher performance of the 18 m-span base aircraft Discus-2c compared to the DG enhances measurement accuracy when testing the newest generation of high performance sailplanes. The DG-300/17 was used almost exclusively as a performance benchmark. The Discus-2c DLR, however, can also be operated as fully-fledged research aircraft for a variety of missions. This presentation will showcase its basic sensors and DAQ equipment as well as several missions that have already been carried out. Lastly, some concepts for possible future research campaigns will be presented.

Keywords**:** *research aircraft, sailplane, airborne research, in-flight measurements.*

Introduction

DLR operates Europe's largest fleet of research aircraft. Twelve different aircraft make up the fleet, of which four are jet airplanes, two helicopters, and four turboprop airplanes, as well as one single-engine piston airplane and a research sailplane which will be the main topic of this presentation.

DLR and its predecessors have always used research gliders and sailplanes due to their simplicity and very low operating costs. Several different models have been operated over the last decades such as a Ka6E, Cirrus, ASW 15, Kranich, Janus and the specially modified DG300/17. A recurring mission for which the Kranich and Janus were known was the "flying wind tunnel". A test rig made up of a short wing segment and sidewalls was mounted on the nose (Kranich) or above the wing-fuselage junction (Janus) to measure the characteristics of the wing segment, such as drag or pressure distribution. The use of sailplanes was a major benefit for this setup, as the boundary layer could not be influenced by any engine vibrations.

Figure 6: DG-300/17 with ASW28

Figure 5: Janus with flying wind tunnel

Another very important use of sailplanes in aerodynamic research is the measurement of flight performance. There are serveral methods to determine the glide ratio of an airplane of which the comparison method is the most accurate and least time consuming. By using a sailplane which has been calibrated precisely, so that the glide polar curve is known accurately, and flying in formation with another sailplane which is the test article of the measurement, the unknown polar curve can be determined by measuring the relative vertical velocity at different airspeeds. Thus, ideally any atmospheric disturbance are cancelled out and the polar curve can be detemined very accurately in 2-5 flights. The Ka6E, the Cirrus and the DG300/17 were used for these measurements using photogrammetric methods to determine the relative vertical velocity between the two airplanes – GPS was introduced with the DG300/17 and continued with the Discus-2c DLR which now makes use of a moving base differential GNSS technique.

Because of the evolution of high-performance sailplanes with high glide ratios of 1:50 and more, and ever higher wing-loadings, the DG300/17 was at the limit of practicality. So late in the first decade of the new millenium, a new research sailplane was needed, the search for which ended in the Discus-2c DLR. It was introduced into the fleet in 2012 and was fully operational in 2015.

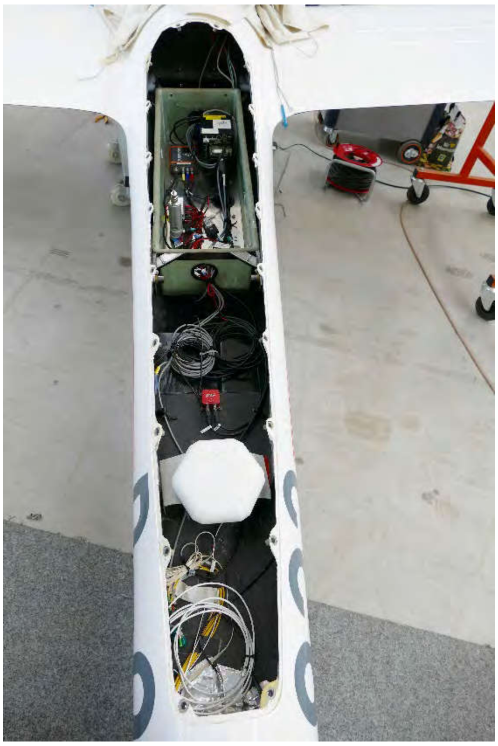

Figure 7: Equipment bay

Aircraft and Systems

The Discus-2c DLR is based on the well-known 18m-class high performance sailplane Discus-2c manufactured by Schempp-Hirth. It has an empty mass of 337 kg, an MTOM of 565 kg, and a wing of 18 m span and 11.39 m² area (Schempp-Hirth, 2005). The basic aircraft was modified in several ways to accommodate our special needs. The fuselage is equipped with an engine bay which is usually built into the Ventus series gliders but used as a compartment for measurement equipment in our case. This bay features a removable lid instead to the bay doors of the standard version to minimize drag. The most prominent modification of the fuselage is the large nose-boom in front and above the nose. It is used to collect total and static air pressures as well as angle of attack and sideslip using a five-hole probe at the tip. To complete the set of air data, a total temperature probe combined with a humidity sensor is fitted to the fuselage under the starboard wing. Furthermore, the fuselage has hardpoints in the cockpit area to attach external probes to the sailplane.

Figure 8: Discus-2c DLR

48 strain gauges and 22 measuring points using fibre Bragg grating are built into wings and fuselage to determine aerodynamic loads in different flight states. The Discus-2c DLR features magnetometers and accelerometers in various locations which can be used in experiments concering aeroelastics and flight mechanics. All control surfaces have deflection sensors. The sensor data are recorded using a data acquisition system which is located in the fuselage bay. The DAQ system is powered by a LiFePo4-battery with a capacity for several hours.

To reduce pilot work load and to implement precisly reproducable control inputs, an experimental digital autopilot was integrated into the sailplane. It uses electromagnetic linear actuators on elevator and ailerons. To keep the system simple and to circumvent a complex certification, the actuator can be easily depowered by switching off the power supply. Then they are still connected to the controls but produce virtually no friction in the system.

The measurement of glide polars using the comparison method depends strongly on the determination of the differential vertical sink speeds and relative positions between the Discus-2c DLR and the other sailplane. The measured sink speed difference is added to the known sink speed taken from the polar curve of the Discus. The exact relative position between the two sailplanes is needed to determine the influence of the Discus' flow field on the performance of the other sailplane. Both values are determined using a moving-base differential GNSS system which is highly accurate and gives sink rate differences in the order of a few cm/s (Rohde-Brandenburger, 2017).

Figure 9: Performance measurement, JS3 and Discus

Missions

The first experimental campaign for the new research sailplane was the project *iLoads*. The overall goal of this project was to determine loads on an aircraft in flight by measuring the deformation of wings, fuselage and empennage. To achieve this, the Discus is equipped with strain gauges in various parts of the structure. There are 6 in the fuselage, 36 in the wing and 3 in the empennage.

To determine loads in flight by measuring the deformation, the strain gauges had to be calibrated first. This was carried out by loading the wings and other structure of the Discus with predetermined weights and measuring the signals of the different strain gauges. This had to be done in several orientations, most importantly upright and inverted to calibrate for wing bending and torsional loads, and determine sensor hysteresis.

Figure 10: Strain gauge calibration

With the calibrated sensors, a flight test campaign was performed. Over about 25 flight hours, a system identification was carried out by using a variety of control inputs in different conditions while recording the reaction of the aircraft regarding deformation, trajectory and orientation. The result of these experiments is a highly refined model of flight mechanics of the Discus-2c DLR which can be used to calculate different manoeuvers and which will be useful over the life of the sailplane (Viana, 2015).

The latest campaign on the Discus-2c DLR apart from our performance measurements, which are performed each summer in cooperation with the Idaflieg, was the project KonTeKst in which the pressure distribution around the Discus wing was the main interest. As opposed to determining flight loads by measuring deformation, the forces on the wing can also be calculated by integrating the static pressure distribution at several wing sections. This was done by using tiny MEMS pressure sensors which where integrated into a thin wing glove. This glove is a 3D-printed scaled-up part of the wing which was 3D-scanned beforehand to determine the exact shape of the wing in this position. Due to manufacturing inaccuracies the wing airfoil cannot perfectly match the theoretical airfoil shape and this also had to be scaled up. 60 pressure sensors where distributed with 30 each on the upper and lower surfaces of the wing. The results showed a very good agreement with Xfoil calculations of the real airfoil and even the laminar turbulent transition was clearly visible in plots. Due to unsteady measurements with a sampling rate of 200 Hz, the stall behavior of the wing with its corresponding flow fluctuations could be observed. After further miniaturization of the system, it will be used in experiments on our latest research aircraft ISTAR, a modified Falcon 2000 (Raab, 2019).

Figure 12: Measurement glove

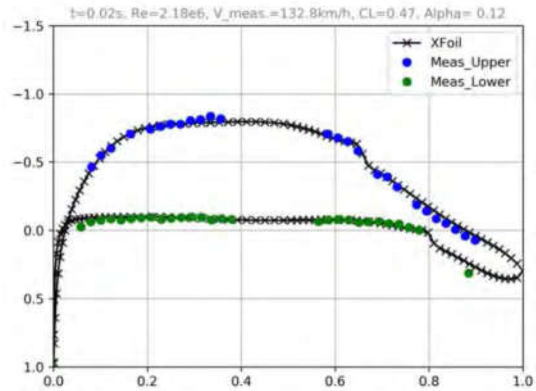

Figure 11: Pressure distribution

Conclusion and Outlook

The Discus-2c DLR has already shown, that it can be used as a highly flexible and capable research aircraft. This is mainly due to the simplicity in its operation and systems. A very good cooperation with the LBA, the responsible certification authority, also helps, of course. As the Discus has no essential electric or electronic systems needed for a safe flight and is of a very rugged construction typical of most sailplanes, it can be used for a wide variety of experiments with a minimum of effort.

In the future, the Discus will continue to be the main player in the flight performance measurements of sailplanes, but will also fly several new experiments. Next in line is the measurement of atmospheric turbulence to determine its impact on flight performance. This will be done by swapping the total energy probe on the tail for a five-hole probe with pressure sensors directly behind it in the vertical stabilizer to maximize the possible sampling rate by minimizing drag due to long pressure lines. After that, a new pressure rake system will be used to demonstrate the suitability of MEMS pressure sensors for this application. This will also enable the Discus to be the new flying wind tunnel on which airfoils can be tested in flight by using wing gloves. To complete the experimental autopilot system, a rudder actuator will also be fitted later. This will make controlled flight in all three axes possible.

The Discus might be DLR’s smallest and lightest research aircraft but is by no means the least capable.

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