Measurement Platform Development for the Investigation of Paraglider Turning Characteristics

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Abstract: Investigation of UAS (unmanned aerial systems) is a developing field in modern aircraft development. Numerous investigations focus on UAS with a paraglider canopy. This group of UAS could be successfully used in applications where stable, low speed flying and mobility are required. This paper describes a UAS test platform, which could be used to perform different measurements with alternative canopies. The test platform is planned to be used for different purposes: (1) investigate and calibrate the sensors developed for the special small (leisure or sport) flying machines; (2) measure the aerodynamic characteristics of the canopies; (3) develop and test the UAS subsystems; (4) perform parameter and state identification of the motion equations related to the paraglider to develop an advance control system. In this paper, the investigation on paraglider turning characteristic is also described, as an example of using the UAS test platform of this research. The platform is coupled with a custom measurement system, to make it more suitable for the investigation of the balanced turn related to the paragliders.

Key words: Paraglider, UAV (unmanned aerial vehicle), UAS (unmanned aerial systems), measurement, turn.

1. Introduction

Nowadays, UAS (unmanned aerial systems) are developing widely for many different application purposes as surveillance, fire, area monitoring, weather investigation, hurricane monitoring, land observation, pipeline inspection, traffic monitoring, damage assessment [1-3]. Most of them are fixed and rotary wing aircraft that may have relatively high speed, large dimensions and weigh in comparison with the "commercial load", sensors, data collections, evaluation and communication equipment. Generally, those being lighter than the air are constructed with a significantly larger airframe than their payload. While building UAV (unmanned aerial vehicle) with a paraglider canopy is not an old concept, just one company in the USA is focusing his main activity in this field [4]. Other company is developing a special, man-portable hybrid UGV/UAV (unmanned ground vehicle/unmanned aerial vehicle) [5]. Such system has a significant advantage compared to UGV or UAV, as the target areas could be investigated and monitored by the ground vehicle, while the vehicle can return to its home base by air. This paper introduces the civilian application of powered paraglider UAV (PPG UAV) and shows a field in which the platform can be used successfully. An investigation of turning characteristics of paraglider is also shown, which can be a key question when the control algorithm for PPG UAV is developed. Several papers, such as Refs. [6-7], have investigated the longitudinal motion of paragliders but the lateral motion is weakly researched, probably because in this direction the paraglider has rather a large stability.

A special UAS, paraglider has several advantages compared to other UAS when the stable, low speed flying and mobility characteristics are required [4]. Probably, the most important benefit of the powered
paragliders for unmanned aircraft use is their unique ability to glide to the ground in a relatively safe manner, even if all control systems are disabled. This is particularly desirable in urban environments where a failure of any large UAV would most likely result in a collateral damage to structures on the ground. Therefore, the paragliders are widely used for leisure flying, as numerous users claim that this is the way of flying with the highest degree of freedom. Another important advantage of the PPG UAV is their excellent portability, since it is folded on the ground, and unfolded when it flies. As the paraglider is subject to wind disturbances, the portability justifies the uses of the paragliders as UAV, for example as a recovery system of a spacecraft [8], for example in the NASA X-38 project [9] in which a flexible wing (a paraglider canopy) was intended to be used to gently land the spacecraft. Some studies are aimed to three-dimensional flows over parafoil canopies for UAV applications [10], in order to understand more deeply the internal flow features inside the canopy.

This paper has been organized as follows: Section 2 is about the relevant features of paragliders in general; In Section 3, the unmanned platform used for the measurements is shortly introduced; Section 4 describes the measuring device developed specially for this measurement; and finally in Sections 5 and 6 the results reached are shown and the conclusion is drawn.

2. Paraglider Characteristics

The technical history of paragliders started in 1986, when this kind of sport is separated from hand gliders. Of course, the full history is dated earlier, but the first professional paragliders were manufactured by the first producers in this year. Once compared for example the gliding ratio of the paragliders in the (Deutscher Hängegleiterverband: German Hang Gliding Association) DHV 1-2 category, one could notice that the improvement of gliding ratio is reaching a limit nowadays, after a strong rising in the 90s (Fig. 1).

Seeing the technological development history of the paragliders, it seems that new techniques are required to improve the flight performance. Until now, the manufacturers developed their paragliders based on empirical studies, and most frequently they did not use scientific research or investigation. Now, these methods reached their limits, and thus it is getting harder and harder to achieve minimal improvements in the flight characteristic. New methods could be based on in-flight measurements, wind tunnel investigations, motion simulations and computational simulations (like CFD, FEM). Using motion simulations, the parameters can be only determined by custom measurement systems and platforms.

Paragliders have unique flight characteristic that come from (1) the big distance between the centre of gravity and the aerodynamic centre of the canopy; (2) the unique shaped wing, which has anhedral angle (keel effect). Paraglider is an extreme example of the effect of vertical CG (centre of gravity) on dihedral effect. The dihedral effect created by the very low vertical CG, is more than compensating the negative dihedral effect created by the strong anhedral of the strongly downward curving wing.

Only lateral control could be made by changing the length of the appropriate (left or right) suspension lines. By this way, the canopy form is shaping (deforming) and the drag as usually rising significantly and lift increasing only slightly. Therefore, this “breaking” and the moments developed cause the tilt of canopy. Canopy changes created by the brake deflection subsequently cause predictable changes in the
aerodynamic loads which is leveraged for the control of the vehicle [11]. For most of the parafoils, deployment of the right brake causes a significant drag and lift increase on the right side of the parafoil canopy, combined with a slight right tilt of the canopy. The overall effect causes the parafoil to skid turn to the right when a right parafoil brake is activated. The developed and deployed paraglider dynamic models [7, 11-14] are based on the simplified concept: The paraglider is the rigid body, and the reference system is the body system put into the center of the paraglider. In this case, the flight dynamic can be described by a 6 or 9 DOF (degree-of-freedom) model. The rigid approximation of the canopy is quite close to the real world, despite of the flexible structure, as long as the canopy does not stall. This approach is true, because all lines and the canopy are continuously pre-stressed; therefore, they form a rigid structure in the air. The aerodynamic force and moment components generated on the canopy and payload must be transferred to the body system. The 6 DOF equations in non-traditional models, in which the canopy is not fixed to the payload rigidly, must include the changing canopy orientation. This way the equations form an 8 or 9 DOF models [7].

3. Unmanned Platform

The requirements of the PPG test platform, being developed at the Department of Aeronautics, Naval Architecture and Railway Vehicles at BME (Budapest University of Technology and Economics), were primarily defined upon the goals of future application.

These goals are the following:

• Investigate and calibrate the sensors, developed for special small (leisure or sport) flying machines, for small aircraft, including MEMS based sensors, micro and mini actuators, cost sensitive new avionics solutions;

• Measure the aerodynamic characteristics of the canopies, develop the aerodynamics models and their estimation;

• Develop and test the UAS subsystems;

• Perform parameter and state identification of the paraglider motion models, study the system of motion equations, perform mathematical modelling and solve the models required for the development of automatic control system related to the paragliders.

The UAV platform developed has a take-off weight up to 110 kg. It is fully developed and built at the department.

The propulsion unit consists of a paramotor type Solo210, a fuel tank, a wooden propeller, an exhaust system, a transmission system, a starter motor and a propeller protection frame (Fig. 2).

The mechanical system consists of the followings:

• Propulsion unit;
• Frame (3 wheeled trike);
• Brake line actuators;
• Avionics block;
• Canopy (paraglider wing).

The frame of the platform is made of steel, as we have to provide the necessary weight of the trike. The weight of the whole platform has to be in the range of 75-105 kg, as the used paraglider has this range of total weight in flight. The used material allowed to manufacture the frame in the workshop of the Department.

The system has been described in detail in Ref. [15], thus in this paper it is not shown again. The test platform can be used in the investigations presented here, and has been tested many times at an airfield.

4. Measurement System

One of the goals of this paper is to investigate the turning characteristic of the paragliders. This could be
done with the measurement of the forces generated on
the wing, with the measurement system. Other
necessary parameter in this investigation is the bank
angle, which is quite hard to measure directly. Instead,
the radius of the turn and the turning velocity has been
measured by a GPS module, and the bank angle is
calculated using the following Eq. (1):

$$\psi = \arctan \left( \frac{V_{SP}^2}{g \cdot R_{SP}} \right)$$

where $\psi$—bank angle; $V_{SP}$—velocity of CG; $g$—gravity; $R_{SP}$—turn radius.

The block diagram of the measurement system can
be seen in Fig. 3. The measurement system was
already described in another paper [16].

The force measurements realized by strain gauge
 glued to carabineers. The sensor prepared can be seen
in Fig. 4.

The carabineers were used on a paraglider to connect
the pilot (harness) with the risers of the canopy. There
is one carabineer on both sides that transport the force
from the lines (risers) to the harness. The sides are
separated, there is no cross connection between the lines
of the left and the right wing, therefore, at the
carabineers the forces can be measured separately.

Carabineers have to be prepared to install the gauges.
Its surface is anodized which has to be removed before
 gluing. The installation finished with a protective cover
insertion. In order to properly process the raw signal of
the strain gauge, it is usually built into Wheatstone
bridge. The bridge is widely used to measure extremely
low changes in resistance. The signal given from the
bridge has to be amplified, for which numerous
solutions are available. In the measurement system
described here, a precision instrumentation signal
amplifier from Texas Instrument is used (type
INA125). This integrated circuit contains everything
that is needed in such investigation. It contains very a
low offset voltage amplifier and voltage reference
circuit to supply the bridge with precise voltage. The
output of the amplifier is a voltage, proportional to the
force on the carabineers.

Unfortunately, the force sensor cannot be used to
measure the absolute value of the force, as is its load case
is unknown. The resultant forces can be developed in
many directions and the position on the carabineers can
be also changed. The impact line of the force applied
on the bottom and the top side of the carabineer must be
the same line, since the carabineer cannot support
moments, only tensile force.

To investigate this phenomenon, the possible limits
of the load cases were tested. Fig. 5 shows the result of
these tests. It can be observed that the carabineer sensor
gives a linear response to the applied load, in all cases,
and at zero load, the sensor signal is the same. It means
that once the same load case for both carabineers are
assumed, the difference between them can be
precisely computed.

To compute the difference between the left and
right side forces, Eq. (2) was used.

It can be seen that the absolute difference is always
related to the sum of the sides, which means that the
load case must be the same only in one data row, not in
the whole measurement.

$$ddL = \frac{L_1 - L_2}{L_1 + L_2}$$
where $L_1$—outer wing force sensor value; $L_2$—inner wing force sensor value.

To compute the bank angle using Eq. (1), the turn radius and turning speed need to be determined. This was performed by the analysis of the flight path recorded by the integrated GPS (global position system) module of the measurement system. The technique is shown in Fig. 6.

**5. Flight Tests, Results**

The measurements were performed by a paraglider Nova Rookie S (Fig. 7).

Several turns were made while the data were recorded, with different bank angles. The computed bank angles and $ddL$ values are shown in Table 1.

The maximum bank angle during the test flights was about 37 deg for safety reasons. The results show that the measurement is reliable, gives suitable values for the investigation of turn of paraglider.

In Fig. 8, a comparison of simulation results and the measured values is shown. The simulation is described in Ref. [17] and is based on force equations, which describe the forces in static, balanced turn of paraglider. It can be seen that after the adjustment of the parameters of the simulation, the results are very close to the values measured.

**6. Conclusions**

As it has been shown, based on the technological development history of the paragliders, it seems that new techniques are required to improve its flight performance. The unique characteristics of paragliders can be described precisely only by using nonlinear, higher degree-of-freedom equations, which parameters can be determined by special, dedicated measuring systems.

In this paper, an investigation of paraglider turning characteristic was introduced, based on special
measurement techniques and custom systems. The results of measurements are used to compare the simulation results, and adjust simulation parameters to the selected type of paraglider. The investigation of the paragliders’ turning mechanism is rather important in designing PPG UAV-s. The lateral, is the only controllable direction on a paraglider, all controlled movement can be only generated by the brakes and there is no other control possibility in general.

The unmanned test platform designed to test paragliders in different ways can be also used in these investigations. However, it needs improvements in order to make it more suitable for this kind of tests.

The measurement system described here is based on a Hungarian patent “EFIS—Embedded Flight Instrument System for the small and sport flying machines”.

References