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# Design of UAV for photogrammetric mission in Antarctic area

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## ABSTRACT

The history of UAVs is relatively long and many such vehicles are in service for different tasks. They can be used even in environment, which is inhospitable for the humans, e.g. in case of extreme temperature. Moreover, they can perform a task that is difficult or impossible for a manned aircraft because of its size and usually relatively high airspeed. The photogrammetric tasks belong to this group, especially if we need to take the high resolution pictures during low level flight. The advantages of the small UAV for such mission are more evident if we want to investigate the natural environment, where the wild animals are. The paper presents the small UAV designed for a special task, which is the counting of the penguins in Antarctica. Inhabited area, extreme weather conditions, the fearfulness of penguins and the goal of the mission put up certain requirements for the UAV. It had to be a reliable, stable platform, which is able to take photogrammetric equipment and to perform precise flight to cover all investigated areas. The presented UAV has been on such a mission in Antarctica from November 2014 to January 2015. All mentioned tasks were completed with success.

## 1 INTRODUCTION

A decade ago in Warsaw University of Technology the project of simple training glider (PW-USZATEK) was developed, with the wings placed on the high pylon, just to be able to operate in rough terrain where there are often no prepared landing strips or runways (like the hang-gliders taking-off from the mountain slopes). In order to investigate dynamic properties of such configuration and compare them with the results of calculations a scaled model of this glider was built. This model was later redesigned as the UAV platform for testing different propulsion systems. Flight test of the scaled model of PW-USZATEK proved good static and dynamic stability in a large range of the airspeed, especially also in a near-stall speed (which was caused by specific properties of the Tsagi R3 airfoil used in the wings of this model).
The skills gained during realization of this project became very helpful for a current project devoted to designing the UAV for photogrammetric missions, which have to operate from the area with many obstacles on the landing fields.

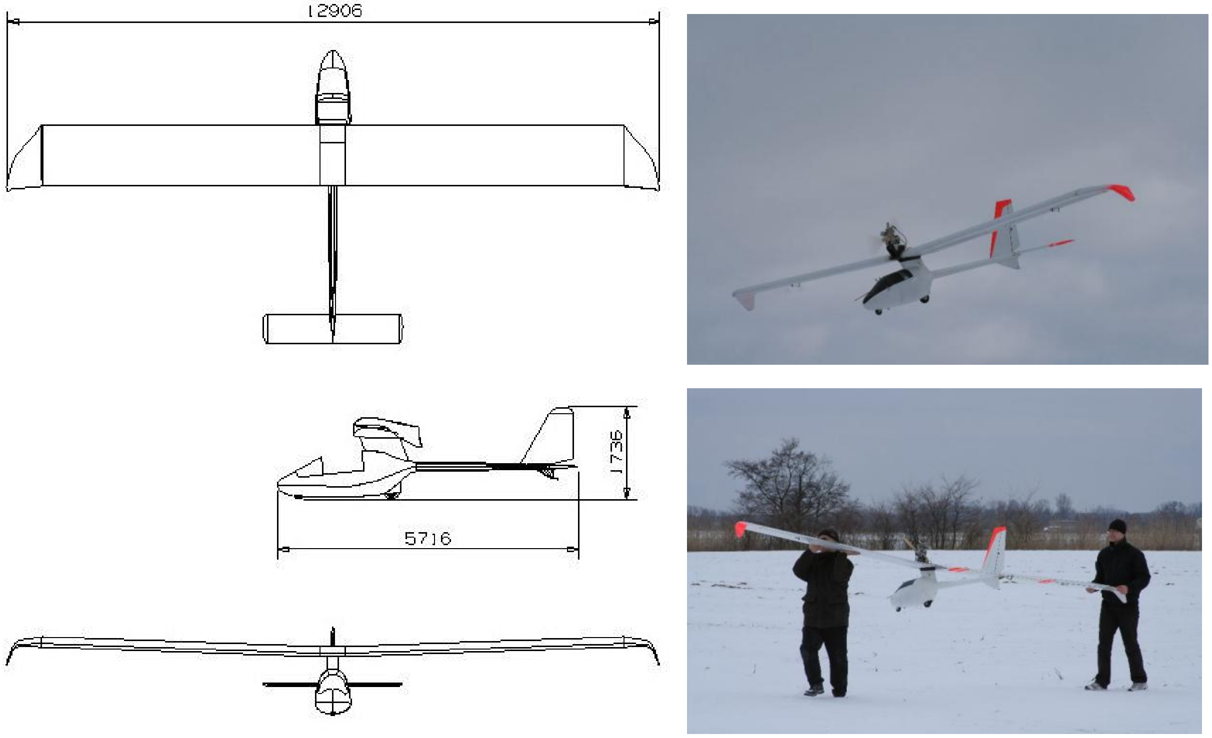


**Figure 1**: Project of the PW-USZATEK and a scaled model build as the UAV platform

## 2 REQUIREMENTS

The basic aim of a photogrammetry mission is the ortophotomap, which consists of the set of ortophotos. There are several requirements for successful result of photogrammetry work:

- The resolution of the photos must be sufficient (the objects on the ground of 5 cm sizing should be recognizable on the pictures taken from 300 meters at least!)
- The optical axis of the camera should be vertical; (a tolerance for a roll and pitch deviation is less then 3 deg)
- The photo-shots should be in the same scale, so it means that the flight level should be constant
- The photo-shots frame should be overlapped in both – longitudinal and lateral directions (60% as a minimum!)
- The flight trajectory should exactly follow a planned grid. In order to fulfil this requirement, the dynamic systems of the plane and autopilot must be well integrated, and especially a special procedure of turning on the ends of the photogrammetry grid-lines should be applied [1] (see Figure 2).

A very important fact, is that in light-weight UAV's special systems of stabilisation of the camera are not applied, thus the static and dynamic stability of the plane must be considered as an inherent feature of the UAV designed for photogrammetry purposes.

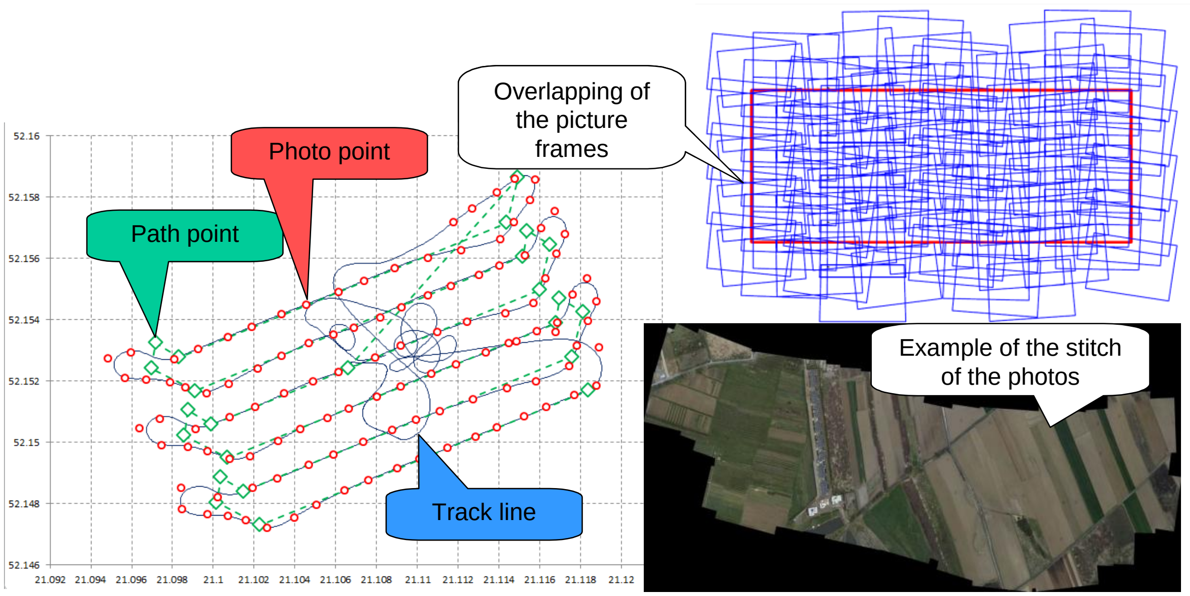


**Figure 2:** The covering of the investigated area**.**

## 3 AERODYNAMIC DESIGN

The initial configuration was designed as a glider with relatively small wing loading. For windy conditions in Arctic area such configuration could be very sensitive to gusts. Therefore the span of main wing was reduced to obtain lower wing loading and also span of horizontal tail was reduced respectively to save similar stability margin. The airfoils for main wing were selected based on computation of basic performance and taking into account small Reynolds number (Re=500 000). Five airfoils were considered (NACA 1414, TSAGI-R3, DF-101, Eppler 205, Selig S-2027). Computations of performance characteristics, made for each of mentioned airfoils show, that for smaller airspeeds, the best L/D ratio and climb rate (Figure 3) was obtained for Eppler 205 airfoil. So, this airfoil was finally selected.

Main geometry data of the modified configuration:

| | |
|---|---|
| wing area | $S = 1.23\ m^2$ |
| wing span | $b = 3.0\ m$ |
| mean aerodynamic chord (MAC) | $C_a = 0.41\ m$ |
| | |
| horizontal tail area | $S_H = 0.1938\ m^2$ |
| horizontal tail span | $b = 0.76\ m$ |
| mean aerodynamic chord of H-tail ($MAC_H$) | $C_{aH} = 0.255\ m$ |
| | |
| take-off weight | $m_{TO} = 16.0\ kG$ |

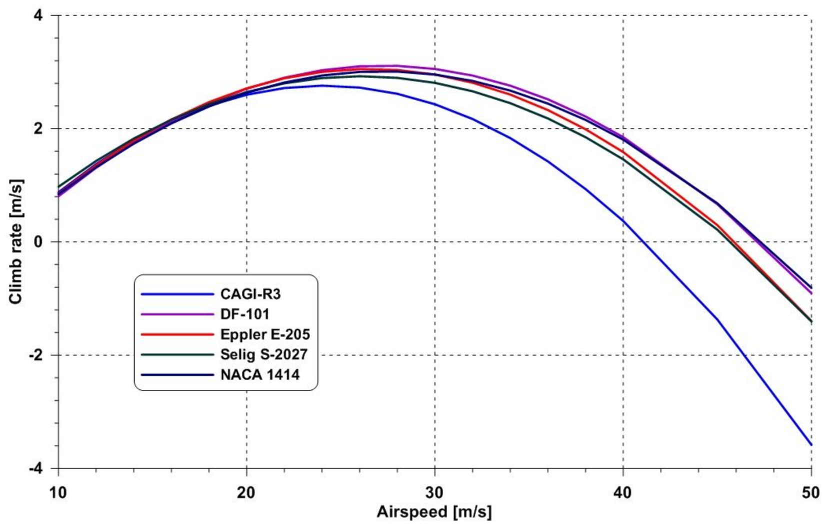


**Figure 3:** Climb rate for five analysed airfoils.

### 3.1 Static margin

First stability factor, which had to be determined is static margin. The horizontal tail area was reduced to have the same horizontal tail volume as in PW-Uszatek, however the weights breakdown was also changed, so the static stability had to be checked. Static margin can be defined as follows:

$$h_N = \bar{x}_N - \bar{x}_{SC} \tag{1}$$

where:

$h_N$ – static margin with fixed stick (% of MAC)

$\bar{x}_N$ – dimensionless position of neutral point of stability for fixed stick (% of MAC)

$\bar{x}_{SC}$ – dimensionless position of centre of gravity (% of MAC)

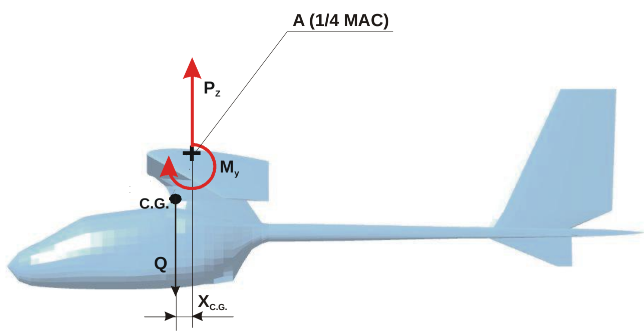


**Figure 4:** Forces acting on the aircraft (simplified system)

The neutral point of stability is defined as the point which satisfies condition, that pitching moment coefficient is constant versus angle of attack or lift coefficient is constant. Thus the value of derivative of pitching moment coefficient with respect to lift coefficient gives the position of the neutral point. To compute this, panel method was used (PANUKL package [2]). Results of calculation are presented on Figure 5. It shows, that for higher airspeed static margin decreases but value above 15% looks save.

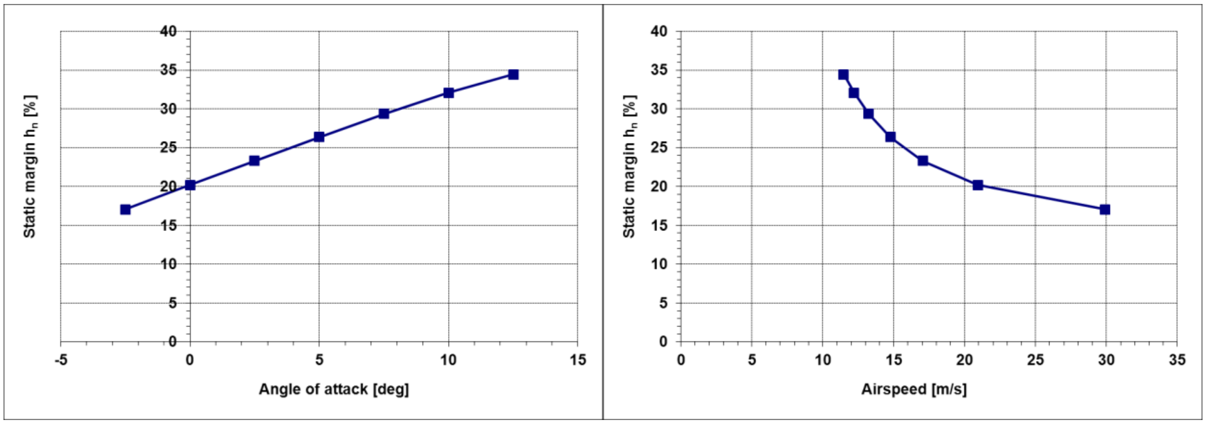


**Figure 5:** Static margin (fixed stick) versus angle of attack (left) and airspeed (right)

### 3.2 Stability derivatives

The complex aerodynamic calculation for the modified configuration was made using the same panel code [2]. Figure 6 presents the mesh prepared for numerical computation and exemplary pressure distribution. All characteristics, including stability derivatives were computed. Some damping derivatives with respect to acceleration (with respect to $\dot{\alpha}$ ) were computed using ESDU reports [3]. and other methods [4][5]. Potential code is not able to give total drag, only induced drag can be computed. The minimum drag coefficient was estimated using handbook methods [6] and added to induced one.

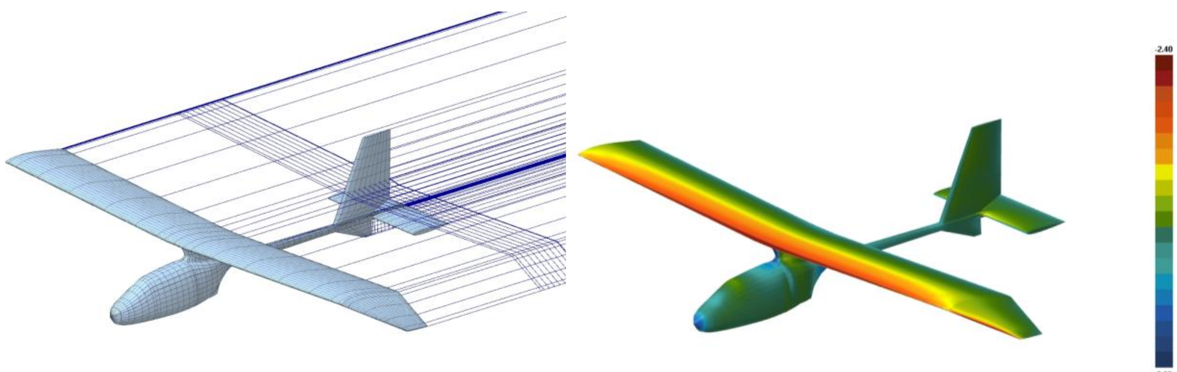

**Figure 6:** Aerodynamic analysis: mesh (4083 panels) – left, pressure distribution for α=5° - right.

## 4 FLYING QUALITIES

The requirement of strong stable flight causes, that very good flying qualities are necessary. Therefore stability analysis was made in early stage of design using SDSA [7] package. The computation were done for the range of airspeed 12-40 m/s and all modes of motion were analyzed comparing results with stability criteria described in airworthiness regulations [8] and other documents [9].

### 4.1 Phugoid

The first symmetrical mode is phugoid. The requirements, according to CS-23.181 [8] are as follows: „Any long-period oscillation of the flight path (phugoid) must not be so unstable as to cause an unacceptable increase in pilot workload or otherwise endanger the aeroplane." The results of computation show (Figure 7), that phugoid is not stable in whole airspeed range. It can be unstable for small airspeed. The period is also relatively short (5-6 s) but time to double the amplitude is long (not shorter, than 30s). Such result seems to be acceptable, especially, because any autopilot stabilises the flight.

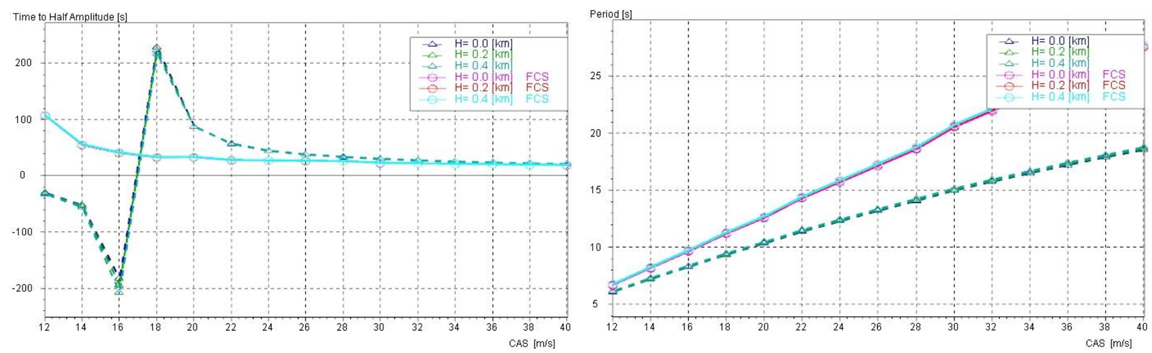


**Figure 7:** The phugoid characteristics: time to half amplitude (left) and period (right)

## 4.2 Short Period

The second symmetrical mode is Short Period oscillation. The requirements according to CS-23.181 are as follows: „Any short period oscillation not including combined lateral-directional oscillations occurring between the stalling speed and the maximum allowable speed appropriate to the configuration of the aeroplane must be heavily damped …" The computation results show, that Short period oscillations are strongly damped in whole airspeed range ().

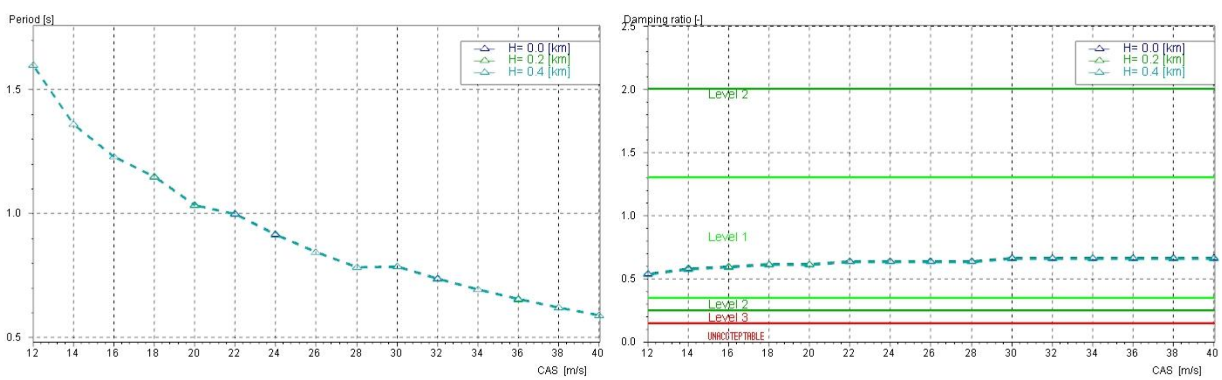


**Figure 8:** The Short Period characteristics: period (left), damping ratio against background of MIL-F-8785C criteria [9] (right)

## 4.3 Dutch roll

The lateral periodical mode is Dutch roll. The requirements according to CS-23.181 are as follows: „Any combined lateral–directional oscillations ("Dutch roll") occurring between the stalling speed and the maximum allowable speed appropriate to the configuration of the aeroplane must be damped to 1/10 amplitude in 7 cycles …". The results of computation show, that this requirement is satisfied (Figure 9).

The evaluation by MIL-F-8785C specification is also good. It largely satisfies requirements of the first and second level, for the flight phase A, that requires precise flight-path control.

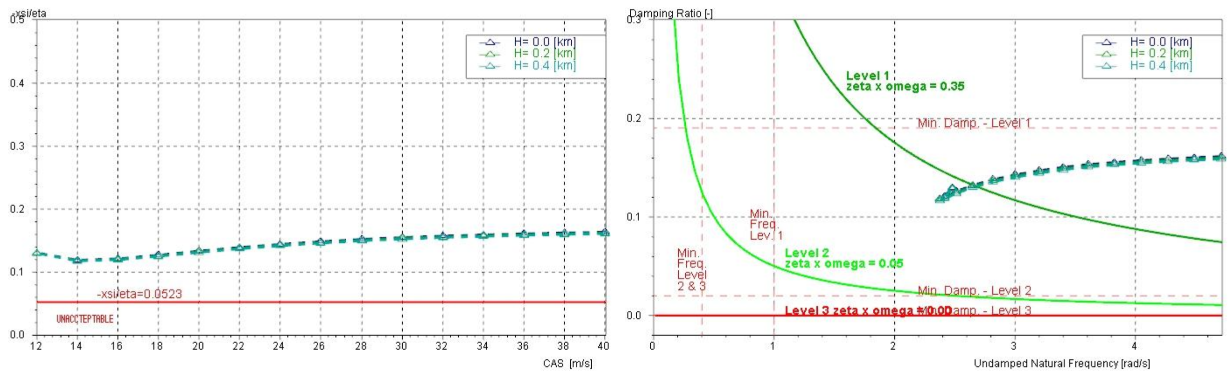


**Figure 9:** Dutch roll characteristics against background criteria by CS-23.181 (left) and MIL-F-8785C (right)

## 4.4 Spiral mode

There is no requirement to have stable spiral mode. Airworthiness regulations in CS23-BOOK2 say: „… a slowacting mode called the spiral which may be stable, but is often neutrally stable or even mildly divergent in roll and yaw;". The similar requirements are included in MIL-F-8785C. Computation shows, that spiral mode is stable and satisfies first level of MIL-F-8785C criteria (Figure 10).

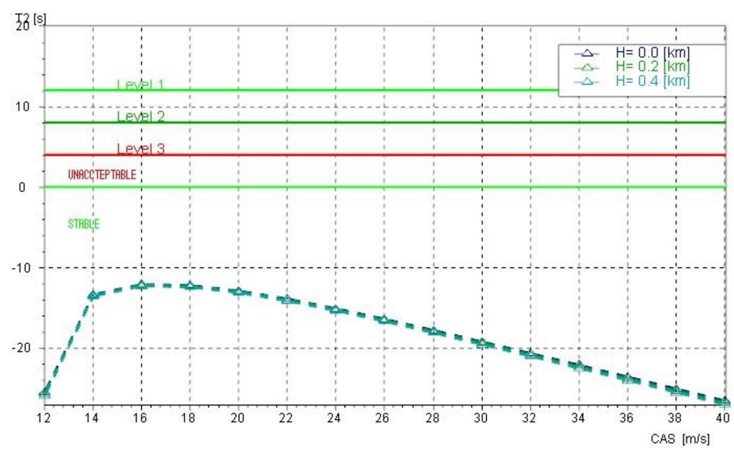


**Figure 10:** Spiral mode characteristics against background MIL-F-8785C criteria

## 4.5 Summary of flying qualities

The results of static stability analysis were satisfying. Static margin was in range 15-35% of MAC. The dynamic analysis proved that all modes of motion are stable in almost whole airspeed range and only phugoid can be unstable in small airspeed regime. First test flight (Figure 11) confirmed good stability and correct flying qualities, excluding lateral stability during turns. There was observed a small tendency for increasing a bang angle and tithing the turns. After analysis of possible reasons the winglets were removed and this tendency disappeared. Therefore in the plane used in Antarctica those winglets do not exist (see Figure 12).

**Figure 11: First take-off and test flight of PW-ZOOM**

## 5 ANTARCTIC MISSION

Two PW-ZOOMs were used in the first Antarctic expedition, which took place from middle of Oct 2014 up to the middle of Jan 2015. The expedition were organized within the frame of MONICA, which is an acronym of Polish-Norwegian research project titled „Monitoring the impact of climate change on Antarctic ecosystems". The project is supplied by Norwegian Financial Mechanism under administration of The National Centre for Research and Development.
The aims of the project are:

- Aerial monitoring of ASPA 128 i ASPA 151 (ASPA = Antarctic Specially Protected Area) in the King George Island placed on South Shetland Archipelago, and counting of penguins population, which are considered as a biological indicators of the sea resources;
- Photogrammetry and data collecting for ortophotomaps of ASPA 128 & ASPA 151

Polish UAV expedition Team consisted of the following persons (Figure 12 see from left): prof. M. Rodzewicz (team-leader), C. Janas (UAV-pilot), dr. A. Zmarz (mission planner and ground station operator). This team was operationally supported from Poland by J. Hajduk and D. Glowacki (UAV systems hardware and software specialists). During this expedition PW-ZOOM performed several photogrammetric missions of total length 921 km and total time 8h 52min, collecting almost 2 TB of photogrammetric data.
The example of photogrammetric mission, reconstructed from the autopilot-log is shown in Figure 13. From one such mission the plane brings from 400 up to 1000 high resolution photos (18MP each), which are the input data for ortophotomaps making process.

**Figure 12: Polish UAV Antarctic Team and their PW-ZOOM (photo Kiell-Sture Johansen)**

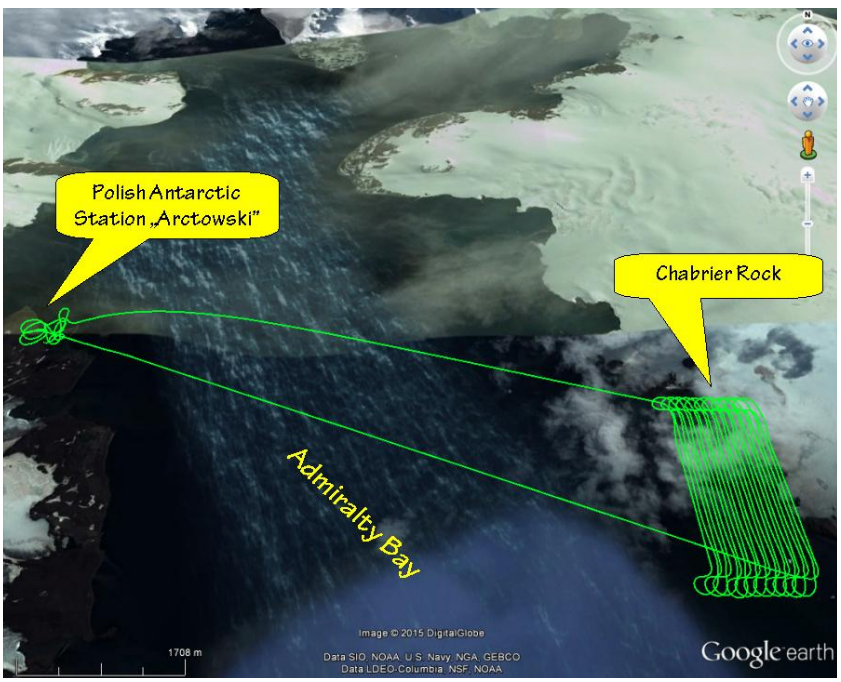


**Figure 13: Photogrammetric mission over Chabrier Rock isle in the eastern part of Admiralty Bay in the King George Island (distance 98,8 km, time 55 min, max dismissal 10,3 km)**

The following picture shows a specification of 6 telemetry missions over ASPA-128, and Chabrier Rock of total length 605 km. In this region about 17 thousands of penguin nests were noticed.
The accuracy of aerial monitoring of Antarctic ecosystems were confirmed in a traditional way [10] (ground team expeditions and straight observations) and was much more effective, because one PW-ZOOM flight substituted 3-4 days expedition of the team of biologists.

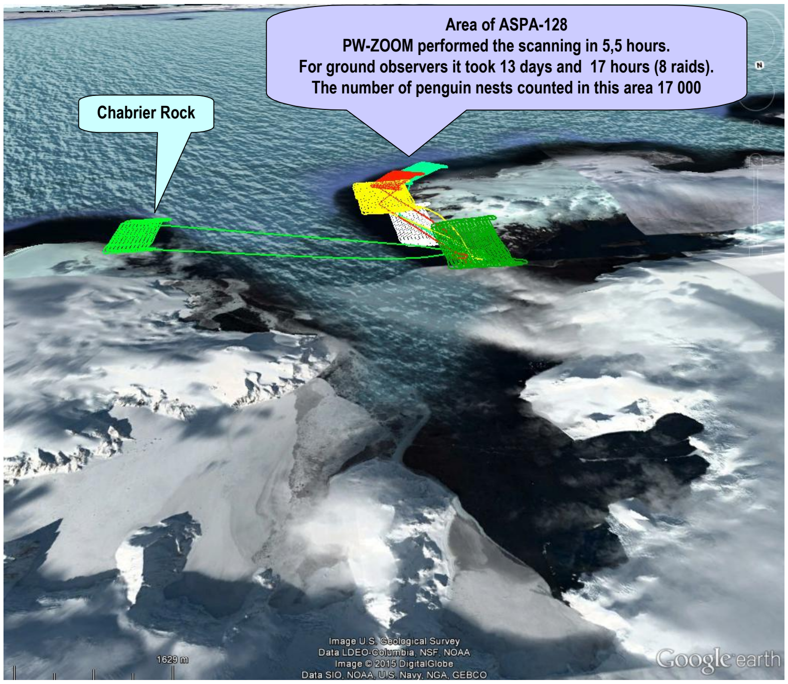


**Figure 14: Photogrammetric missions of PW-ZOOM over coasts of Admiralty Bay**


**Figure 15: Stitch of the set of photos taken during one flight of PW-ZOOM.**
**Red frame shows one of the penguins colony.**

## 6 AKNOWLEDGMENT

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