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Lightning tests of Unmanned Aircrafts with impulse Generator

Abstract. *This article presents the results of experimental research on the susceptibility of multi-rotor aircrafts to atmospheric discharges. The study was carried out in the Laboratory of Lightning Immunity Tests of Avionicsat the Rzeszów University of Technology, using the only such equipment in Poland. The influence of disturbances arising during lightning strikes on the drone's work was investigated, simulating a flight in the immediate vicinity of the storm front. Specialist pulse generator designed for avionics research made it possible to perform repeat measurements for different variants of the propagation path of the disturbance and its value.*

Streszczenie. *W niniejszym artykule przedstawiono wyniki badań eksperymentalnych dotyczących podatności wielowirnikowych statków powietrznych na wyładowania atmosferyczne. Badania prowadzono w laboratorium przepięciowych badań awioniki w Politechnice Rzeszowskiej, wykorzystując jedyny tego typu sprzęt w Polsce. Badano wpływ zakłóceń powstających podczas wyładowania atmosferycznego na pracę drona, symulując jego lot w bezpośrednim sąsiedztwie frontu burzowego. Specjalistyczny generator impulsów przeznaczony do badania awioniki umożliwił wykonanie powtarzalnych pomiarów pod kątem różnych wariantów toru propagacji zakłócenia oraz jego wielkości.* ***Badanie bezzałogowych statków powietrznych generatorem impulsów piorunowych.***

Keywords: drone, lightning strikes, pulse generator, avionics
Słowa kluczowe: dron, wyładowania atmosferyczne, generator impulsowy, awionika

Introduction

Unmanned aircraft, called drones, are increasingly used in various aspects of our life. The rapid development of these machines meant that they are not just an entertainment, but are tools for work on industry. They are used for military, statistical, surveying and inspection purposes in hard to reach places [1, 2]. During the annual "Droniada" competition prototypes of drones are presented, eg. whose task is to search for the missing in the mountains [3]. Such machines will be a support for emergency departments. It is connected with work in various weather conditions, especially in unfavorable conditions. Therefore, it is important not only resistance to strong wind and rain, but above all to atmospheric discharges. The question then arises whether there machines are resistant to lightning strikes (direct and indirect) and what can be done in the scope of such protection in the future?

The study of the lightning protection of drones is a difficult issue. There are no standards for such machines. They can be considered as aircraft and analyzed with aircraft testing systems. We can base on MIL-STD-461 standard [4]. There is not much research on the effects of indirect lightning strike on the work of drones. An experimental simulation of direct lightning impact at the University of Manchester showed that the machine was completely destroyed [5]. However, it should be shown what size and character of the disturbances induce in the circuits during the discharge at a very short distance. Surge analysis can show how resistant the drones are and how strong the discharge can damage to it. It can be the answer to the question about shielding protecting against lightning, just like in airplanes. There is the possibility of simulation [6] but it doesn't replace experimental research. The main reason is extremely difficult conditions during atmospheric discharge, which is still difficult to simulate in the absence of the proper drone model. Other method is to detect thunderstorm and rerouting the way [7].

To carry out such experimental tests at the Rzeszów University of Technology, pulse generator for avionics was used. It is specialized device, certified and meeting the requirements in accordance with the standards applicable in the aviation industry. The research involved two drones of various construction and size. Disturbances were injected in various ways and the measurements of induced transients in the electronics of the drones were made at various points of theirs circuits, as described in more detail later in this article.

Experimental setup

The lightning susceptibility tests were carried out using EMC Partner modular impulse generator dedicated for aviation industry. It meets all the most demanding standards in aviation. Two drones were tested: 4-rotor with 2.4 GHz and 6-rotor with 5 GHz communication. The construction of both machines is similar. The motors are connected via controller (general: central or with motors) to the motherboard that controls the drone and communicates with the peripherials (camera, GPS module, LED panels). The radio communication module is located on the control board and has an external antenna [8]. The power source is a lithium-polymer battery with a voltage of 3.7 V or 7.4 V depending on the thrust generated by the engines. However, its capacity determines the length of the flight time. The whole structure is made of polymer (ABS - Acrylonitrile Butadiene Styrene) ensuring rigidity and low weight. The schematic structure of the typical drone with measurement points is shown in Figure 1.

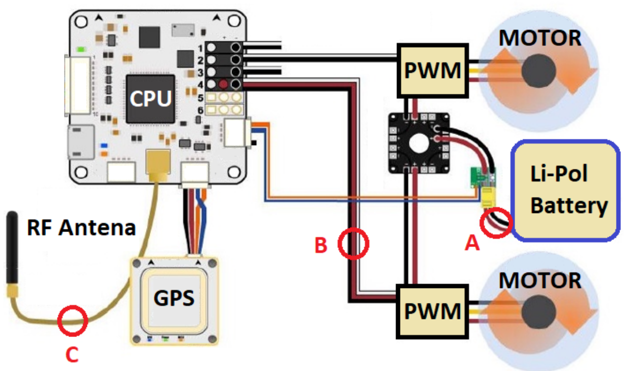

Fig.1. Typical construction of the drone [8, 9]

Of course this structure is typical for entertainment drones. Specyfic purpouses needs indyvidual equipment e.g. sensors, High Resolution cameras, compas, Infra Red detectors, chemical compounds sensors etc.

The device was placed on isolating pad above a wooden table and grounded metal plate on table top as is shown in Figure 2. A 4-channel Rigol 250 MSPS/channel oscilloscope with appropriate voltage and current probes was used to observe disturbances. The drones were supplied with 7.4 voltage. This means that interference induced in the power line not exceeding 8V are harmless to the machine [10,11]. Both, pulses with a higher value and smaller ones for low voltage circuits are a threat.

For this purpose, measurements were made at the terminals of the battery, motor connectors and RF antenna. Analysis of overvoltages on integrated circuits would involve significant interference in the small PCB. The effects of the research were observed on a working machine, standing on a table with both, running and not engines.

The tests were divided into three series depending on the method of coupling the lightning disturbance. In the first case (cable B on Fig. 2) impulse current flowed through a straight conductor placed close to tested device (DUT). In the second variant (cable A on Fig. 2), the conductor was replaced with an aluminium foil surrounding the chassis of the DUT. Measuring stand with connections and both of scenarios is shown in Figure 2.

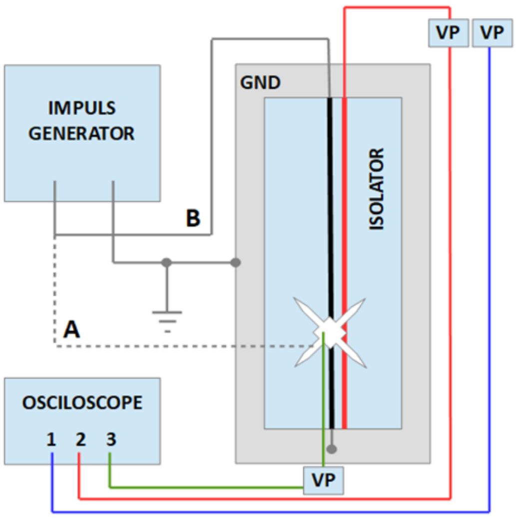

Fig.2. Measuring stand, where: 1 – signal at parallel line (noise measure), 2 – signal at parallel impulse amplitude, 3 – voltage on Drone parts (different scenario): A – second scenario with aluminium coating, B – first scenario with line disturbances

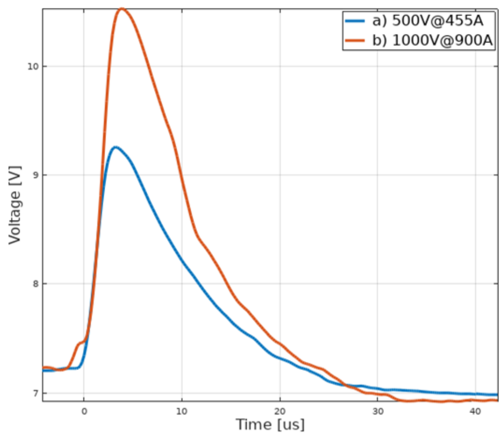

Fig.3. Disturbances on dron's power supply on first scenario for two voltage levels of impulse

The third scenario assumed a direct connection of the generator output with two points of drone's circuit. In this case, there terminals of extremely distant motors were selected. In each series, tests were performed with various levels of generated surges. The MIG0618SS generator was set to produce single stroke voltage impulse with the shape of 6,4/69 μs for open circuit condition. Its level was gradually increasing from 250 to 3400 V. The final peak of the current pulse depended on total impedance of connected system and for one of the series it changed from 300 to 2500 A respectively.

The results of the first series of tests where the drone was located above the interfering wire with the maximum impact range is shown in Figure 3. The measuring point was the power supply. In Figure 4, the results of the second series are presented for the charge spread over the machine body.

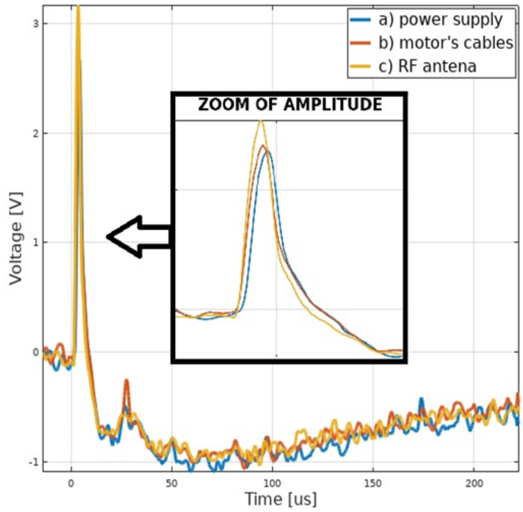

Fig.4. Level of signals inducted on different parts of the drone (as A, B, C points, see Fig. 1) with 1 kV impulse on second scenario

Another aspect was the analysis of disturbances in different places for the same pulses. Conducting such tests was possible only with the use of the described generators, because, as already mentioned, they ensure the repeatability of the generated pulses. Figure 4 shows measurements for disturbance with a 1 kV impulse and a 900 A surge current observed on the accumulator terminals (a), motor (b) and RF antenna (c). The disturbance arising in each case is clearly, but not sufficient to cause adverse effects. Figure 4 shows disturbances brought to one voltage level in order to better visualize differences in the signal amplitude.

A very important element of the research was the determination of the reference level, i.e. the method of measuring the interfering voltage.

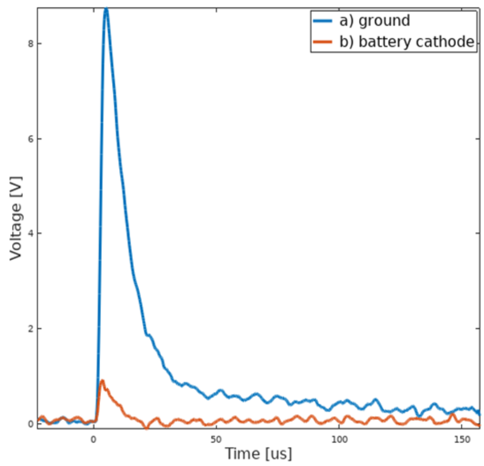

Fig.5. The amount of measured interference depends on the selected reference point

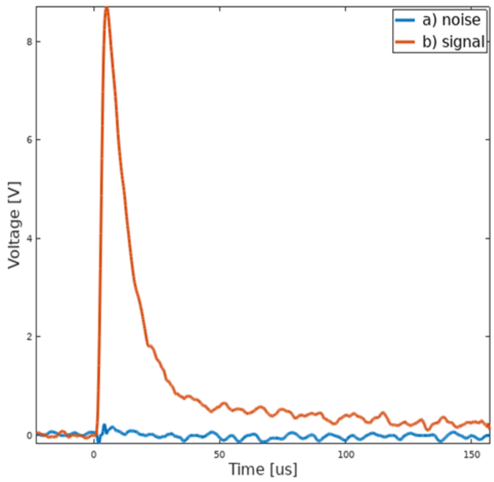

Fig.6. The scale of signal size difference and interference in the measuring path

A number of measurements were made at various locations for different impact voltages for two variants: the GND of the oscilloscope connected to the ground and the negative pole of the drone battery. The difference in measured signals is significant, which is expected and correct. Measurements made to the level of the ground give higher values (the oscilloscope and the generator are connected to the same ground field). Such measurements, however, are applicable to devices located on earth and connected to the grounding system. For a flying machine that is not grounded, the actual interference refers to its local zero point, i.e. the GND of the battery, which is the GND of the whole circuit. Therefore, all measurements should be considered only as local interference within the electronics of the drone. The discussed differences for a 1 kV impulse with a measurement at the kathode of the battery are presented in Figure 5.

Scenario with ground level was to measure disturbances e.g. on motor power connectors. Impact voltage range from 300 to 1000 V. An increase in the signal induced in the circuits supplying the motor directly proportional to the pulse. However, the recorded disturbances at the level of 8 V do not constitute a real threat to the operation of electronics [10,11], as no effects of this measurement series have been noticed. Of course, real noise on motherboard of the drone was smaler, because as written, there is necessary to measure disturbances only on dron's curcuits with dron's GND.

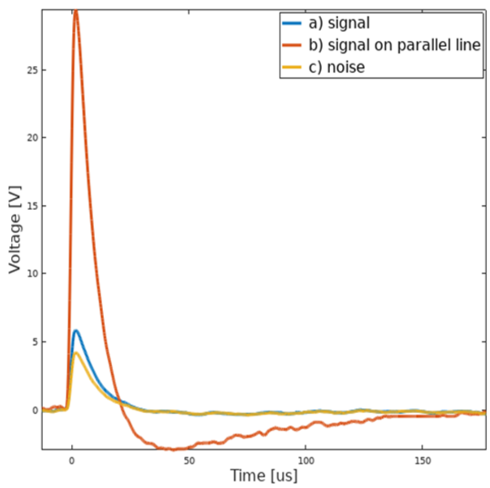

Fig.7. The difference of signal levels during measurement scenario B (fig. 2)

When carrying out described measurements it is important to protect against interference induced in the measuring lines. There is a risk of high level of noise that may interfere with the correct measurement signal because both the object being tested and the measuring path are subjected to direct pluse of the electromagnetic field generated during the stroke. The first step to minimizing the noise was the use of high quality shielded measuring cables. They were placed under a metal and grounded top. The length of the measuring paths has been reduced to a minimum. In order to verify how much noise interferes with the measurement signal, an identical reference probe was placed next to the correct one (see Fig. 2). It was not connected to measuring points but its task was to record disturbances arising around. On this basis, it is possible to determine how much noise is recorded in the right measurement signal, because both paths are identical and parallel. The results are presented in the graph in Figure 7. This was on first scenario (see Fig. 2). Signal on fig. 7 is measured on dron (input no. 3 on Fig. 2), signal in parallel line (b) is input 2 on Fig. 2. Noise in measuring path is shown on graph “c” (1 input on Fig. 2).

In Figure 6 is shown differential between level of the signal and noise on measuring path for scenario A. In final calculations used information about noise to reduce it in the measuring signal. For beter presentation was used median filter (10 points) to minimalize distorsions of the graphs.

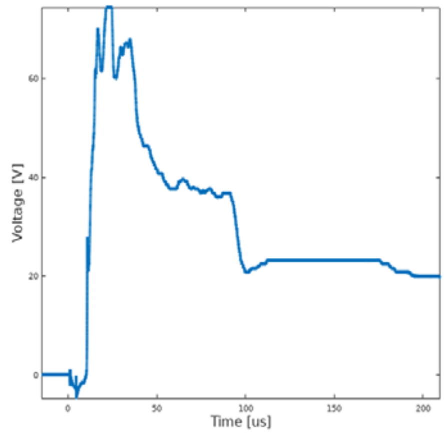

Fig.8. Destrucion signal observed on camera power supply

The presented graphs show impulse interference that are induced in various places of the drone's circuit when disturbed by a shock pulse. They have a pulsed character with a duration of a few microseconds and an amplitude proportional to the stroke value. The graph presented in Figure 8 presents signals recorded during the impulse, which destroyed the drone.

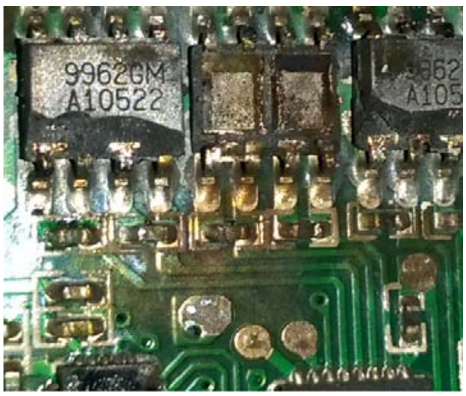

Fig.9. Destructions on the motherboard

The measurement signal was recorded on the camera supply. The disturbing pulse was 3.4 kV at a current of 2.5 kA. We can to observe a very difficult to describe signal shape with a large amplitude. It is a shape of progressive propagation of damage and short circuit that arose in the electonic systems. It imposes here not only the impulse response of the system itself, because it is simultaneously destroyed by short circuits. It is therefore not possible to repeat such a measurement, because the electronics of the drone have been completely destroyed after this experiment as shown in the photo in Figure 9. After all tests the drone was disassembled to verify size of destruction. Main part of electronic components (controlling the motors), li-pol battery, motors, camera were destroyed.

Conclusion

The test results show how large disturbances induce in the drone circuits during atmospheric discharges. Experiments carried out only up to 3.4 kV showed that the voltage induced in its circuits can reach a value of over 80 V. Such large impulses are capable of damaging the control unit and peripherials. The motors and the battery are not resistant too. The greatest distortions on scenario A and B are induced at the antenna's terminals. A part of the observed disturbances of the measured results come from reflections and noise in measuring path. It is also possible to use the differential method, subtracting the noise from the signal by measuring two paths at the same time. Overvoltage protection for unmanned aerial vehicles will be become crucial over next years. The number of such machines and their capabilities are constantly increasing. It will be necessary to develop appropriate norms and standards similar to those currently using in aviation.

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