Miniaturized flight data recorder for unmanned aerial vehicles and ultralight aircrafts

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***Abstract*—**Flight data recorder is a device that records various flight parameters and is able to survive the crash for increasing aviation safety. Aircrafts which can have an impact on the safety of flights in the airspace are becoming smaller and more accessible. Good examples are unmanned aerial vehicles or ultralight aircrafts. It would be appropriate to equip these objects with flight data recorders in order to ensure that every crash will be accompanied to improvement of the aviation safety. While the legitimacy of FDR (flight data recorder) installation into manned objects is pretty obvious, for a UAV (unmanned aerial vehicle) it is not so clear. There are some cases that the UAV has dropped and damaged some facilities or even dropped on human, additionally loss of often very expensive object should occur as rarely as possible. In both cases, the lifting capacity is very limited so there is requirement to significantly reduce the weight of the recording device. Minimum dimensions and weight are strongly dependent on the assumed conditions of the accident and on the size of the aircraft. The paper describes design of the electronics module, partial concepts of the whole flight data recorder and the first crash survival tests.

Keywords*— *flight data recorder; semiconductor memory; UAV; aviation safety; acciden; ultralight aircraft

I. INTRODUCTION

Almost all modern aircrafts contain two or more types of devices to record flight parameters. The first one is called as Flight data recorder and is used for storing flight data even after an accident occurs. Another type almost equally widespread is the Quick access recorder used in the exploitation process and ensuring the safety of flights[1]. The rapid growth in digital technology including memories and microcontrollers allow to use this modern solutions to minimize size and weight of recording devices. A special area for development is the ability to mount the recorder surviving crash on unmanned aerial vehicles or on ultralight aircrafts where lifting capacity is very limited[2]. To be able to accomplish this task there is a necessity to significantly lower the weight of such a recorder nevertheless keep an ability of surviving. It seems impossible to ensure survival on all terms contained in the regulations regarding to civil aircrafts. On the other hand such lightweight objects in case of crash behave differently. It is able to conjecture that accelerations will be significantly lower and time of burning will be shorter especially on electrically propelled aircrafts. However, in order to get closer to these requirements a completely new approach to design of flight data recorder must be undertaken. The first major step is reducing to minimum the size of the electronic module that has to survive a crash. Subsequently consequently will be possible to reduce the volume and weight of the housing for electronics. The further step worthy of consideration would be the usage of modern materials such as composites and innovative insulating materials in assembly of protection case. Another important issue is selecting electronics components capable of proper work at high ambient temperature conditions allowing using more efficient phase- change material into thermal block.

II. SPECIFICATION FOR CRASH SURVEILLANCE

Over the years, the requirements for (FDR) flight data recorders changed over time with the development of technology. The actual specification is described in the EUROCAE document ED 112 (Minimum operational performance specification for crash protected airborne recorder systems). The paper contains variety of requirements for software and hardware. One of the most important issue is ability of FDR to survive in conditions of crash. The flight data recorder shall be capable of preserving the recorded information when subjected to the three following sequences of tests:

- Impact shock, penetration resistance, static crush, high temperature fire and fluid immersion,
- Impact shock, penetration resistance, static crush, low temperature fire and fluid immersion,
- Impact shock, penetration resistance, static crush, deep sea pressure and sea water immersion[3].

Any integrated circuit cannot survive such as conditions therefore, the system is placed in the appropriate housing structure. Design of standard flight data recorder protection case is presented on figure 1. Simplifying the steal armor plate prevents from penetration and static crush. In addition it must be sealed to withstand deep sea pressure and sea water immersion. In the case of burning isolation layer and phase-change material are able to protect from extremely high temperatures. From the figure below we can infer that along with decreasing size of memory unit it will be possible to trim all layers constituting the protection case. Taking into account the institute's experience in designing such as devices. We can assume that the hardest part is to fully prepare to withstand

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high temperature fire test. It means that the device must be prepared for one hour of burning at 1100 ºC. Volume of the thermal block is the largest in a context of whole FDR[4].

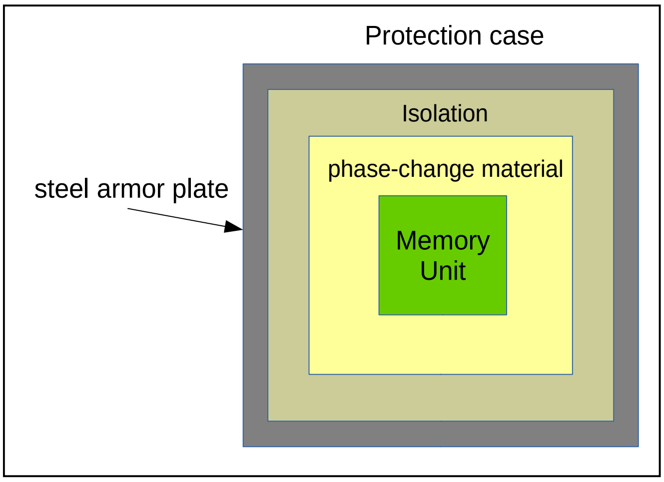

Fig. 1. FDR protection case

III. Project of minimalized flight data recorder memory unit

In the majority of civil aircrafts flight data recorder is integrated with FDAU (flight data acquisition unit), however only FDR is protected from appearance of circumstances descripted in chapter II. In this paper there is presented another approach to arrangement of units. In this case flight data recorder and flight data acquisition unit are separated and connected via communication interface. In this case POF (plastic optical fiber) interface is selected. Such a solution allows for convenient deployment of components maintaining electromagnetic compatibility. Conceptual drawing is featured on the figure 2.

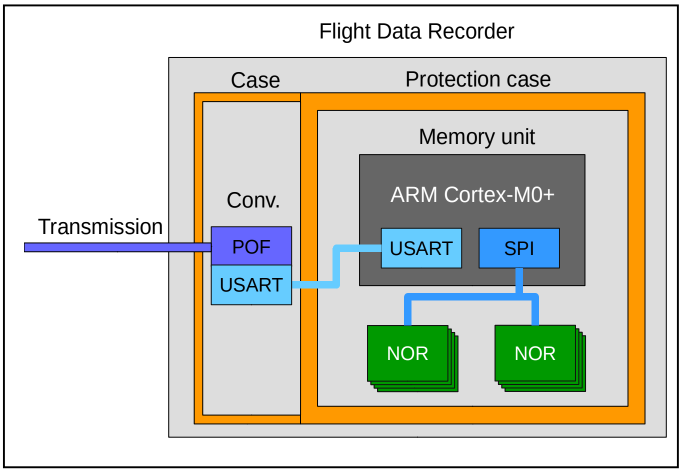

Fig. 2. Flight data recorder conception

It can by noticed that protecting case secure only the absolute minimum of elements and even media converter (marked as Conv.) is foreseen to not survive a crash. The memory unit consist of a microcontroller and two semiconductor memory chips. Each element is rated to proper work up to 125 ºC ambient temperature. An application of such components allows to reduce amount and the change type of isolation and phase- change material layers. The most common memory chips are rated to 85 ºC and for those thermal block maintain a temperature not greater than 60 ºC. There are some additional elements not placed on the picture. For example a power supply unit which also meeting assumed temperature requirements. Project was held in Altium Designer and diameter reached only 18 mm. There were not used any BGA (Ball Grid Array) elements regarding to prototype character of solution. Commercial version can be further reduced as a result of application of BGA technology. Figure 3 shows project of described module which is compound from two connected PCB boards making small cylinder. Module was placed near the coin with dimensions close to the PCB and in order to introduce real scale of elaborated solution. The entire structure is characterized by simplicity and limitation of applied elements. Despite the higher density of storage space into NAND Flash memory chips, NOR Flash were selected due to easiness of use and excellent price to environmental conditions endurance factor[5].

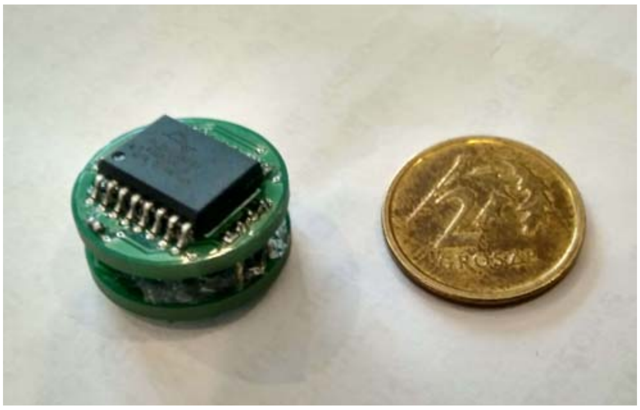

Fig. 3. Memory unit size

IV. Data tranmission to the recorder

The miniaturized memory module has been designed to be compatible with the developed recording systems. Such a situation allows relatively rapid prototyping of the device. At present, Air Force Institute of Technology has implemented two kinds of flight data acquisition units as elements of the S2-3a system. This system is operated by the Polish army and is deployed on various aircrafts. Both are characterized by the same line connecting FDAU and FDR. They are configurable in a wide range of registered parameters. The modular design allows the FDAU to be adapted to a particular aircraft. Natively, there are two ARINC 429 bus receivers installed but the unit can be equipped with additional digital bus modules. The number of registered analogue and digital parameters is only limited by the internal data bus. This serial data bus is rated by 1 MHz clock. If we register about 150 different parameters mostly with 1 hertz frequency, we are not even close to the limitations. The designed memory module should be as universal as possible. Therefore, a asynchronous serial bus similar to RS-232 has been selected. Its maximum speed is about 300 KB/s and depends on the baud rate which is configurable. Media converter presented on the figure 2 can be exchanged depending on the requirements. For the needs of the research, the module was recorded without using this element. It is planned to conduct a memory test based on continuous recording until an error is obtained. Currently, such errors have not been observed. It can be caused by the use of modern flash SLC (single logic cell) memories. The manufacturer provides minimum correct 100,000 program/erase cycles. However, it may be important to verify this data.

V. Recording System Arrangement Considerations

Separated FDAU and FDR arrangement was selected. This is the second most spread installation of recording system on civil and military aircrafts. The possibility of unrestricted and optimal deployment of components have to be considered as undeniable advantage of such a solution. However, the disadvantage is a necessity to equip the object with reliable transmission medium to connect the registration system. Another very important aspect is high system integration in unmanned aerial vehicles which pretty often means that module for recording each important parameter is already embedded. In this case the only feature missing is presence of crash survivable memory module. In that situation flight data acquisition unit is superfluous. Peeled architecture is conducive to such a situation. UAV should be equipped with flight data recorder with accordingly manufactured media converter located outside protection cover. For General Aviation aircrafts and other small flying objects we meet the very different avionics which often entails individual approach to constructing the flight data acquisition unit. In essence there are the same parameters that must be measured but the diversity of the transducers can be very large. Finally, the level of equipment in avionics is also different. It is possible that completely different measurement electronic components must be applied for two seemingly similar aircrafts. Building a universal device can be very expensive and extremely difficult. The easiest solution seems to be a situation where the manufacturer of the aircraft provides FDAU equipped with the standard data bus. This would enable a simplification of the entire system similarly to previously mentioned UAV case. Unfortunately, enforcement of mounting a relatively sophisticated unit on often inexpensive object is difficult. It can be predicted that the formation of appropriate legal regulations will result in decreasing accessibility of small manned flying objects.

VI. Software Assumptions

Air Force Institute of Technology possess experience in the software production for flight data recorders. Among another things a high reliability recording system for flash has been created and could be counted as evidence. Despite the fact that it was developed for NAND Flash memory chips characterized by complicated handling procedures and much higher memory capacities, it is intended to adopt examined software procedures for NOR Flash memory. Due to simpler handling procedures and regular synchronous serial communication interface, selection of the microcontroller with fewer resources seems reasonable. Additionally microchips based on Cortex M0+ architecture are transparent and widely approachable for severe environmental conditions. Another important advantage is very low price which has large significance for small and comparatively inexpensive flying objects. The current solutions are based on three extracted software layers:

- main program;
- recording system;
- memory handling.

Main program controls receiving procedures of data and takes control over entirety. Recording system takes over some wear leveling task but mainly it is responsible for providing suitable arrangement of records and manages writing and reading procedures. Finally memory handling is responsible for communication with memory. In comparison to the NAND Flash chips minor edits has to be done in recording system and main, whereas memory handling changes into much easier[6].

VII. Impact Shock Test Procedure

As it was written in the second paragraph one of the procedures is to check whether it can withstand overload acceleration of 33 342 m/s² (3 400 g). Air Force Institute of Technology possess all necessary laboratory apparatus to perform all mentioned tests. The most difficult one in terms of necessary effort is featured in this chapter. Each of the individual tests begins in writing recorder memory by known pattern and it ends with a comparison this pattern with read memory.

A. Requirements for the procedure

Crash protected memory module must be subjected to an impact shock applied to the most damage vulnerable axis in the most damage vulnerable direction. The energy content of the impact shock shall be equal to or greater than that provided by a half-sine wave shock of 6.5 millisecond duration and a peak acceleration of 33 342 m/s² (3 400 g). The waveform shall be such that a peak acceleration of at least 3 400 g is achieved. The shock may be generated by subjecting the recorder to an increasing or decreasing velocity change[1].

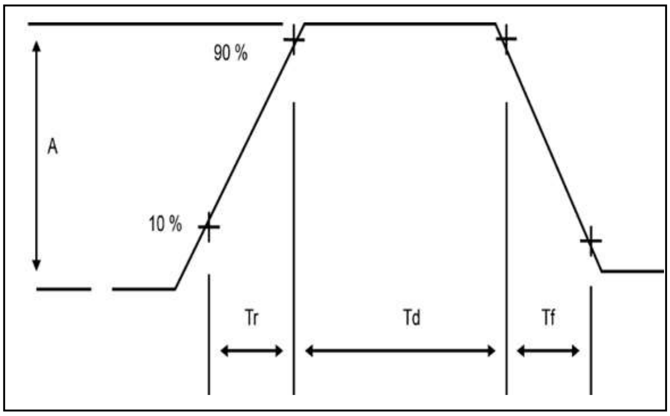

Fig. 4. Trapezoidal impact shock waveform(Tr = 3.5 ms maximum; Td = 3.0 ms minimum; Tf = 0 ms minimum; A = 3 400 g (33 354 m/s²) minimum)[1]

B. Laboratory bench

The following issues of testing procedure can be identified:

- give the object the appropriate speed;
- deceleration of the object in accordance with the required energy-time characteristics;
- registration course of the experiment.

The measuring probe launched from a pneumatic gun hit a sand deposit obstacle in the braking stand. The flight and the process of sticking the measuring probe into the sand were recorded by the high-speed camera. Figure 5 presents a schematic of the measurement station with the specified main elements[7].

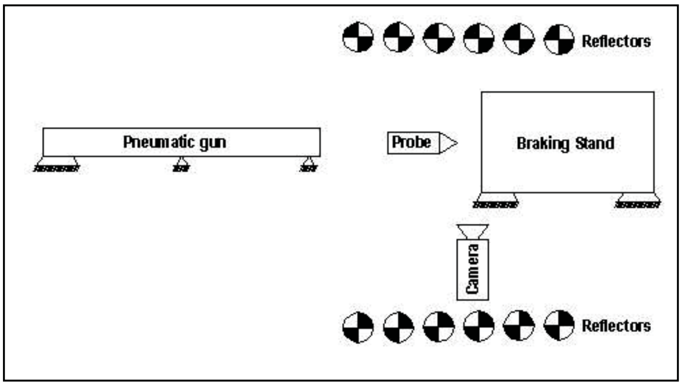

Fig. 5. Laboratory bench schematic

Elements included in the experiment are:

- pneumatic gun - a station propelling the test object;
- measuring probe - an element which movement in space was recorded in order to determine changes in velocity over time and allowing for the target development of a test object, i.e. an electronics package for a protective cassette and a registration system;
- braking stand - a sand deposit ensuring the retention of the test object placed on a rigid base;
- high-speed camera;
- reflectors illuminating the flight of the measuring probe[7].

C. Description of the study course

The DPZ-250 pneumatic gun and a measuring probe were prepared for the experiment. Since inserting the probe into the barrel, the probe was embedded in the sabot. Figure 6 presents a probe just before impact the breaking stand. Separating sabot can be observed.

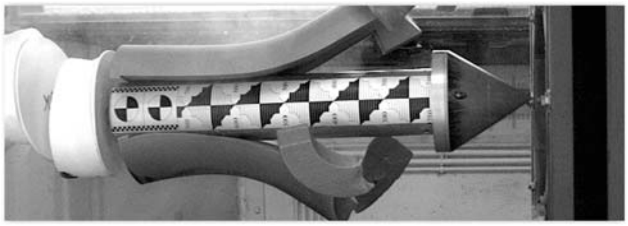

Fig. 6. The probe view in flight

The course of the probe's braking speed changes is presented in figure 7. The course of acceleration changes affecting the measuring the probe with reference to the acceleration required by the regulation is shown in figure 8.

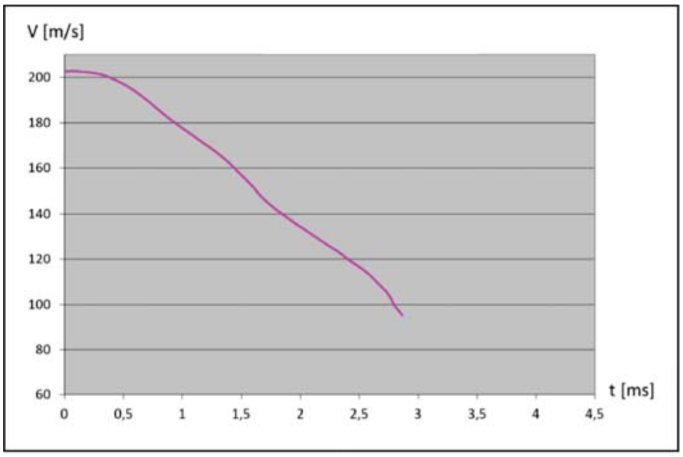

Fig. 7. The course of the probe's braking speed changes

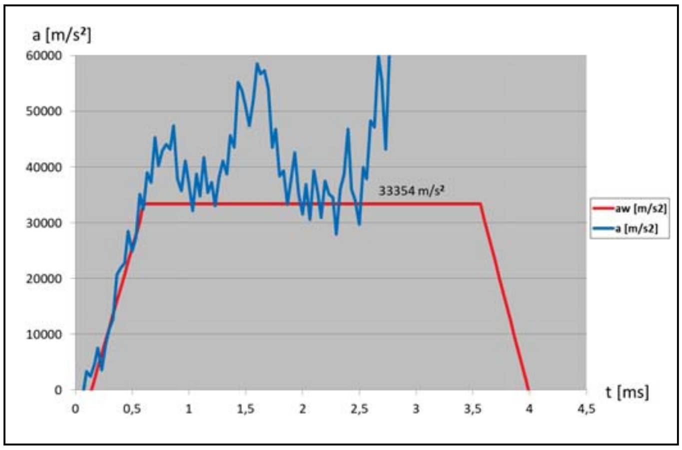

Fig. 8. The probe acceleration changes with regard to the required pulse

The speed registration process was interrupted as a result of covering the markers placed on the probe body by damaged rear sabot elements. Therefore, it was not possible to obtain the required time of recording. The registered course of the acceleration changes shows the discrepancy between the normative profile and the profile obtained in the experiment. It can be assumed that the energy-time requirements of the test have been met. The measurement method still needs to be further corrected. It will allow to reduce the amplitude exceedances of the overload and to limit the covering of the markers on the probe body by damaged sabotage elements. The housing of the electronics were dismantled from the integrator. The silicone cover of the electronics package was not damaged. After removing the silicone no mechanical damage to the PCB was found. The correct work of the electronic system was verified. The positive result was obtained. A control record from the memory of the electronics package was read and corresponded entirely with the record previously saved. Figure 9 shows the electronics package disassembled from the measuring probe.

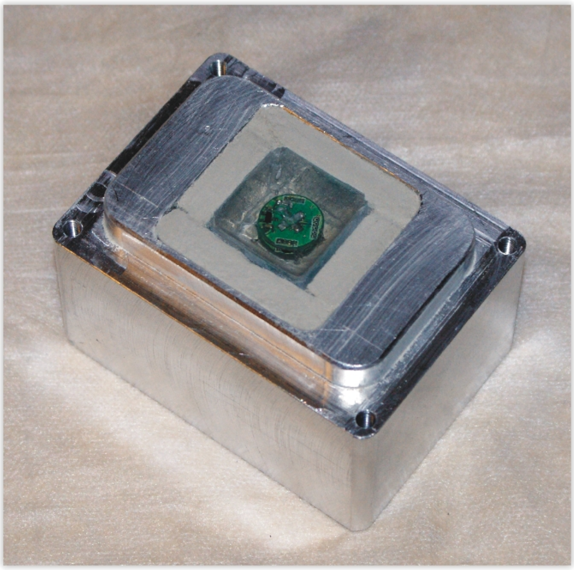

Fig. 9. View of the electronics package in the disassembled housing

VIII. CONCLUSION

Variety of objects that fits into anticipation for developed solution is wide. The aircrafts are very different from each other. Therefore it would be wise to produce single project of electronic module as small as possible and few projects of protection cover. Depending on the size of protection cover less or more strict assumed crash conditions will be fulfilled. A matter of choosing the adequate level of protection will be very difficult. It is understandable that the determination of such requirements would have to be supported by concrete researches including crash tests. Examination of this type entails the huge costs. However, such works seem to be much needed in which there is no little doubt that UAV's will be operating in newer and newer innovative applications often integrating with National Airspace.[8] Currently, attention is focused on determining which properties will be the most difficult to achieve. Bearing in mind civil aviation regulations and our experience, the most difficult test may be high temperature fire. On the basis of the performed experiment, it can be stated that achieving resistance to impact shock will not be a significant difficulty. Produced device is characterized by 64MB memory space what allows to store any parametric data for sufficient amount of time to accident analysis. Make usage of BGA elements will result in even greater reduction of size while simultaneously allows to increase recording area. There are no contraindications that experience acquired while pursuance of this project will be transferred to modified flight data recorder for regular aircrafts. In accordance with previous experience, a suitably prepared electronic module is able to withstand impact shock study.

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