

## MODULE FOR WIRELESS COMMUNICATION IN AEROSPACE VEHICLES

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### **Abstract**

*The increase in air traffic and space flights, the rising cargo volumes and passenger numbers all set complex research and applied scientific tasks and therefore pose more complex requirements for obtaining up-to-date information on the system parameters and on the environment in which they function. After the advent of IoT platforms, their use in all areas of technology has been growing rapidly, as for instance in data collection and processing systems that are fully applicable to aviation needs. One of the major problems in the building of new systems or upgrading existing ones in line with current trends is the high cost of the innovations and the long time before their implementation. In line with the current trends in aviation, this paper proposes an approach for unified modules comprising a large set of possible sensors operating on a wireless standard for transmitting information and connected in a single and cost-effective network and with minimal time for construction, upgrading and renovation.*

### **1. Introduction**

There has been an exponential growth in the use of aeronautical and aerospace vehicles for various purposes. Also, a number of new types have come into existence, such as drones, unmanned aircraft, new classes of space rocket systems, and more.

Most devices related to the operation of aviation systems or their missions utilize multiple sensor-based, communications, executive and other types of means and it is often necessary to establish continuous or ad hoc information exchange between the ones located outside the skin of the aeronautic vehicle and those located inside [1–3]. In many cases, it is appropriate that the communication between the modules located on each side of the skin should be non-contact [4]. This will reduce the complexity of building a structure that requires resistance to

high mechanical accelerations and vibrations, as well as to sudden changes in ambient temperature.

Over the last few years, wireless sensor networks have focused professional interest towards the numerous theoretical and practical challenges associated with their application capabilities. Their wireless architecture enables easy measurement of physical parameters such as temperature, humidity, pressure, etc., as well as their integration into already existing measuring systems. Their flexibility and capabilities for mathematical analysis and processing of the data, as well as their easy programming, make it possible to build complete solutions for technological process monitoring [5].

Three basic technologies for wireless communications are available to date: radio frequency (RF) communication characterized by its high performance, optical transmission, which requires positioning on the line of sight, and the one most commonly used in modern underwater communications – acoustic (respectively hydroacoustic). In all these technologies, it is important to also consider the cost of bringing into production in relation to the target data bandwidth for a given frequency range. The wireless communication technologies suitable for use in aviation technology are the RF and optical ones. Nevertheless, the provision of a communication channel often requires engineering constraints that are extremely difficult to overcome [6, 7].

The article proposes an approach for providing wireless communication in aerospace vehicles based on the use of composite materials and of unified modules connected to a single network and operating on a wireless standard for transmitting information at a relatively low cost and requiring minimal time for building, upgrading and renovation.

The article proposes an approach for providing wireless communication in aerospace vehicles. The approach is based on the use of composite materials and of unified modules connected to a single network and operating on a wireless standard for transmitting information. It is characterized by its relatively low cost and requires minimal time for building, upgrading and renovation.

## **2. Problem statement and solution**

In the general case, the task of wireless communication comes down to the positioning on the skin of the aerospace vehicle of a device with good radio conductivity and/or optical transparency, and mounting on both of its sides of the transceivers of the wireless communication system. There are therefore two aspects to solving this problem:

- The first one involves the selection of a device with good radio conductivity to ensure contact between the on-skin and the under-skin wireless communication modules. The device should be able to withstand high mechanical loads and provide small radio signal attenuation.

- The second one involves means of reliable and stable wireless communication.

### 3. Results:

#### 3.1. Device providing contact between the on-skin and the under-skin wireless communication modules

The contact device between the on-skin and the under-skin wireless communication modules is generally a multi component device consisting of a mechanical housing and a radio-transparent element. It is desirable that this device should also be provided with a window transparent to light, in this way enabling reduction of the energy consumption of the external sensor by activating the operation of the wireless communication system through a pair of light source and light receiver (LED). Magnetic impulse activation, for example with a reed relay, is also possible, though this method poses the risk of disrupting the performance of the electronic devices and of distortion of the radio signals.

The mechanical housing must be compatible in shape, construction and material with the mechanical structure of the aerospace vehicle and its manufacture should not generally constitute a serious engineering problem [8].

The main component of the composite device is the radio-transparent element, which, among other things, should be relatively light, inexpensive, easy to process, and must be able to withstand high mechanical loads.

It is known that the force that must be overcome when moving an object in the air is:

$$(1) \quad F = \frac{1}{2} \cdot c_x \cdot \rho \cdot S \cdot V^2, \text{ where:}$$

- $\rho$  is the density of the air;
- $S$  is the area of the transverse projection of the object (referent area);
- $c_x$  is Drag coefficient;
- $V$  is the velocity of the object relative to the air. The force of the air resistance depends on the square of the velocity and at a given constant high velocity can be reduced by varying within certain limits the cross-sectional area of the object.

Pressure (denoted by  $p$ ) is a physical quantity characterizing the magnitude of the normal force component acting on a unit of area. Pressure is a scalar value. According to the definition in ISO / IEC 80000, pressure is the ratio of the force to the surface area:

$$(2) \quad p = \frac{F}{S}.$$

Therefore, with some approximation, we can state that the pressure on the contact device between the on-skin and the under-skin wireless communication modules will be:

$$(3) \quad P = \frac{1}{2} c_x \rho V^2.$$

The Drag coefficient values are shown in Table 1.

*Table 1. Drag coefficient values*

Shape	Drag Coefficient
Sphere	0.47
Half-sphere	0.42
Cone	0.50
Cube	1.05
Angled Cube	0.80
Long Cylinder	0.82
Short Cylinder	1.15
Streamlined Body	0.04
Streamlined Half-body	0.09

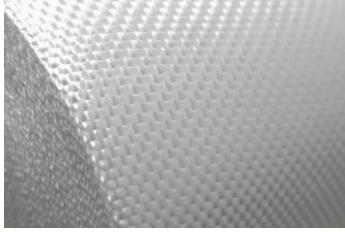
Measured Drag Coefficients

Calculations show that in extreme cases where the contact device is a long cylinder (for example, a flat porthole that can be approximated in this way), the speed of the spacecraft is in the range of 20 – 30 M (M ~ 300 m/s – first cosmic velocity at Mach number 27 is 8 km/s), assuming average air density of 1.5 kg/m<sup>3</sup>, the pressure on it reaches 26 MPa (~ 260 bar). At subsonic speeds the pressure reaches 0.4 bar and at speeds with Mach number below 5 it is up to 10 bar.

Our calculations allow the conclusion that for spacecraft from the moment of their launch until their orbit positioning it is appropriate that the contact device between the on-skin and the under-skin wireless communication modules should be provided with screens protecting them from the high dynamic external pressure values. For other aircraft this will not be necessary.

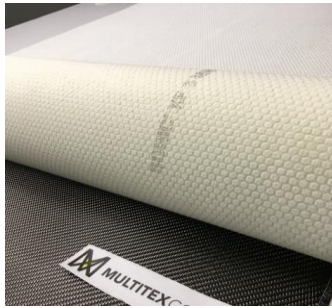
These requirements can be satisfied by a limited number of materials, mainly by composites. To this end, several types of composite materials have been developed at IMSETHC-BAS. They consist of different combinations of the following components:

- Fiberglass 300 gr/m<sup>2</sup>, 500 gr/m<sup>2</sup> (Fig. 1);



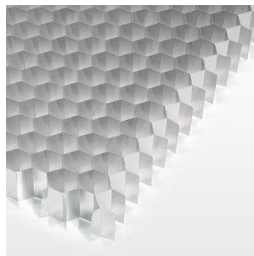
*Fig. 1. Fiberglass*

- Lantor Soric XF 3 mm (Fig. 2) – a special type of pressure-resistant core material (filler) designed specifically for vacuum infusion. Unlike traditional fillers such as Coremat, Soric is made of pressure-resistant cells that do not shrink in vacuum, thus preserving the structure and the thickness of the material;



*Fig. 2. Lantor Soric XF*

- Aluminum honeycomb structure (Fig. 3), intended as a filler in the manufacture of composite panels and parts. Used properly, aluminum honeycomb can reduce weight and increase the rigidity of composite panels in a wide variety of applications;



*Fig. 3. Aluminum honeycomb*

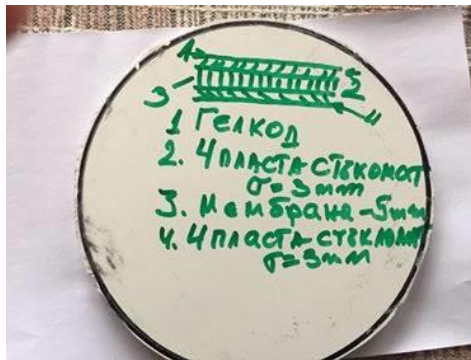
- Polyester resin MULTIPOL® TP200 – high quality polyester resin, thixotropic, pre-accelerated. It is very good for manual lamination or infusion. Hardener: MEKP Catalyst (from 1 to 3%) of BUTANOX®. Color: blue, transparent after application;
- Polyester isophthalic with neopentyl glycol gelcoat E-120. Composition: Styrene. Thixotropic unsaturated polyester resin designed to be sprayed onto the surface of the die as a protective layer against environmental influences. It gives the products resistance to impact, light, water and aging.

For the purpose of the research experiments, three types of composite material constructions have been developed at IMSETHC-BAS for contact devices between the on-skin and the under-skin wireless communication modules:

### 3.1.1. Composite plate designed to withstand pressures of up to 14 bars.

Composition:

- 4 layers of 3 mm thick fiberglass 500 gr/m<sup>2</sup>;
- 1 layer of 5 mm thick core material;



*Fig. 4. Composite plate designed to withstand pressures of up to 14 bars*

- 4 layers of 3 mm thick fiberglass 500 gr/m<sup>2</sup>;
- Polyester resin MULTIPOL® TP200;
- Polyester isophthalic gelcoat with neopentyl glycol E-120.

Total thickness: 12 mm.

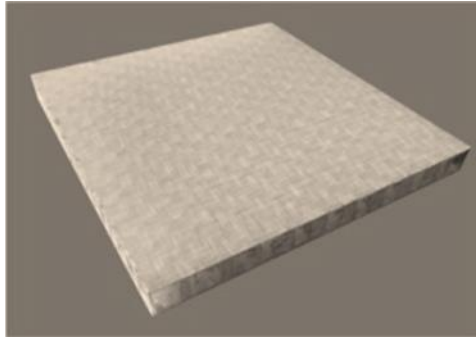
Features – opaque to light, radio transparent, include for frequencies of up to 6 GHz.

### 3.1.2. Composite plate designed to withstand pressures of up to 10 bars.

Composition:

- 4 layers of 2 mm thick fiberglass 300 gr/m<sup>2</sup>;

- 1 layer of 5 mm thick core material;
- 4 layers of 2 mm thick fiberglass 300 gr/m<sup>2</sup>;
- Polyester resin MULTIPOL® TP200;
- Polyester isophthalic gelcoat with neopentyl glycol E-120.



*Fig. 5. Composite plate designed to withstand pressures of up to 10 bars*

Total thickness: 10 mm.

Features – opaque to light, radio transparent, include for frequencies of up to 6 GHz.

3.1.3. Composite plate designed to withstand pressures of up to 10 bars.

Composition:

- 3 layers of 2.5 mm thick fiberglass 500 gr/m<sup>2</sup>;
- 1 layer of 5 mm thick Aluminum honeycomb;
- 3 layers of 2.5 mm thick fiberglass 500 gr/m<sup>2</sup>;
- Polyester resin MULTIPOL® TP200.

Total thickness: 10 mm.

Features – transparent to light, radio transparent, including for frequencies of up to 6 GHz.

Fig. 6 shows the experimental model for testing the functionality of the three types of composite material constructions for contact devices between the on-skin and the under-skin wireless communication modules.



*Fig. 6. Experimental model for testing the functionality of the three types of composite material constructions*

It consists of a metal cylindrical body (3) and a metal cylinder (2), mounted on which are respectively the elements of the on-skin and the under-skin modules for wireless communication.

The antennas of the transmitter and receiver module are connected by means of diaphragms (4, 5), in which circular plates of various radio conductive materials can be placed to analyze the communication efficiency.

### **3.2. Wireless communication device**

Modern systems mainly use sensors producing digital output data, which also makes it easier to upgrade existing systems or to build new ones using wireless standards for data transmission. The requirements to be met by the channel used, taking into account the specificities of the particular application, are as follows [9]:

- provision of sufficient capacity to transmit sensor data without delay caused by the channel;
- validation of information transmitted by the sensor;
- guaranteeing uniqueness of the transmitted data in a multi-sensor mode of operation;
- channel capacity in working conditions;
- ensuring autonomy when using battery power supply.

In wireless data transmission, account must be taken of environmental features, i.e. the space distribution in the spacecraft/aircraft, which is a solid metal structure that would impede the passage of electromagnetic waves. This necessitates the availability of collector systems in single volumes. A single volume defines a space without partitions and whose linear dimensions do not exceed the maximum communication distance determined by the wireless protocol used [10].



Bluetooth is a wireless technology for short-distance data exchange from fixed or mobile objects, which is used for personal area networks (PANS). Bluetooth uses ultra high frequency UHF in the ISM frequency range from 2.4 to 2.485 GHz.

◆ Advantages:

1. Low power consumption.
2. Bluetooth can be integrated across devices, including portable devices and mobile phones.
3. Low cost – steadily decreasing price of the hardware module (single chip solution);
4. The distance between two devices can reach up to 60 m.
5. Well-designed structure.
6. Bluetooth uses 2.4 GHz bandwidth, data transfer speed can reach up to 1Mbps.

7. Supported by a free-membership consortium established in 1998, with more than 2,000 members, including IBM, Intel, Nokia, Ericsson, Toshiba, 3COM, Lucent, Microsoft.

◆ Disadvantages: Its operating range is smaller compared to other wireless technologies.

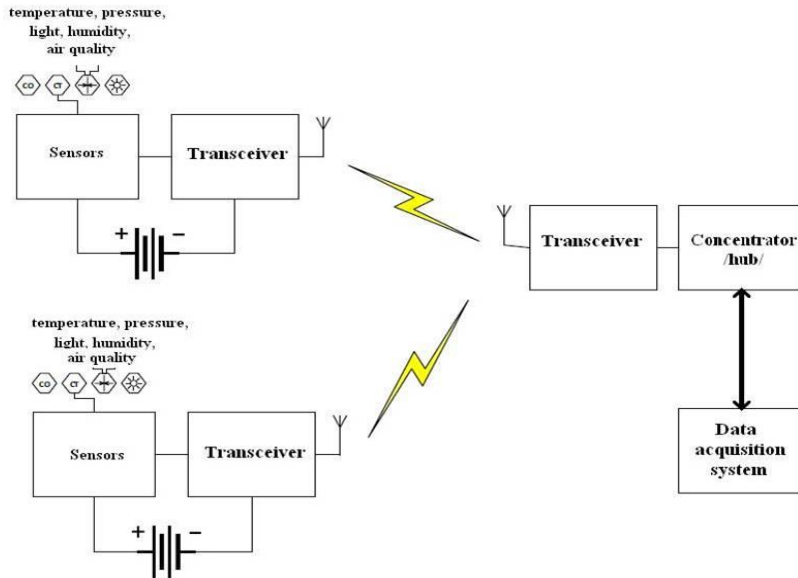
The choice of Bluetooth Low Energy (BLE) is based on its being uniquely applicable for building wireless data transfer modules. The features provided in its specifications – authentication, encryption, and high-speed data transmission – fully meet channel requirements, while its low power consumption, depending on sensor consumption, ensures autonomy, for months, and at higher battery capacities, for years. This, combined with the small size, enables building self-unit networked modules that use a unified standard for data transmission. The fault clearing time is reduced since the module is usually replaced.

In aviation system automation, the wireless communication standard finds practical applicability mainly in the expansion of the capabilities of the sensor network and its rapid upgrade.

To optimize the data transmission channel, different types of sensors are used. The information collected via radio channel (Bluetooth standard) is transmitted to the data collection system. The proposed approach eliminates the need of a wired connection and allows the sensors to be repositioned when necessary.

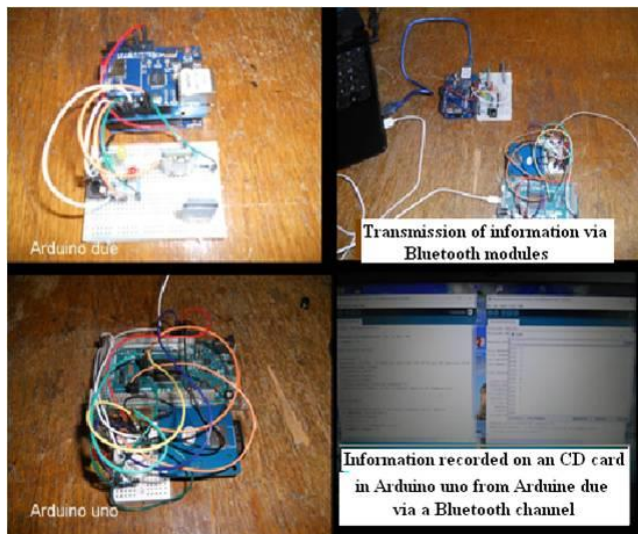
Another advantage is the reduced time and human resources (no need for a skilled specialist to change the position of the sensors) necessary when changing the positioning of the sensors, nor does this require additional infrastructure.

In the proposed approach, the linear structure of the system is preserved, which, when using wireless communication channels, can be changed to star connection, as shown in Fig. 7.



*Fig. 7. Structure of the system is preserved, which, when using wireless communication channels*

In the selected experimental model, all modules are of Arduino specifications, as shown in Fig. 8.



*Fig. 8. Transmission of information via Bluetooth modules*

The block diagram and data exchange principle of the test device are shown in Fig. 9.

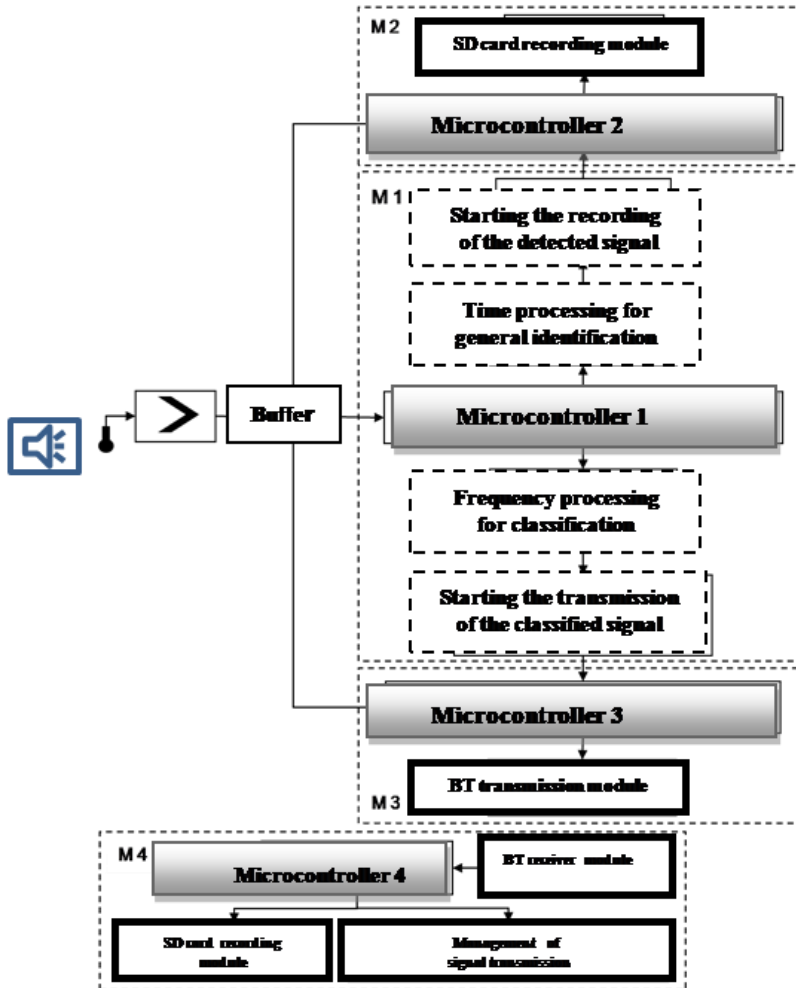


Fig. 9. Block diagram and data exchange principle of the test device

To analyze the capabilities of the Bluetooth communication standard, the sensor selected is an acoustic receiver, which allows qualitative and quantitative comparison (amplitude-frequency characteristics) of the input and output signals, in this case noise and speech. This is achieved by comparing the spectrograms of noise and noise + speech recorded on SD cards after the classification of speech signals (their separation from noise-only signals) and those of noise + speech after BLE communication.

### 3.3. Test results

The verification of the proposed technical solutions was carried out by two types of experiments: to determine the mechanical stability and to evaluate the possibility for wireless communication.

Fig. 6 shows the experimental set-up used to evaluate the resistance of the structure to mechanical stress. For this purpose, air was compressed in the metal cylinder (2) under controlled pressure and monitoring the condition of the plates made of composite materials according to item 3.1.1., 3.1.2., and 3.1.3. Deformation was taken as the percentage of the angle between the tangent to the most convex part of the plate (counting as its beginning the point where the plate is tightened to the periphery of the cylinder with a flange) and the normal to the plate. The test results are shown in Table 2.

Table 2. Test results

No	Composite according to the configuration in item	Deformation of 3% at pressure	Deformation of 5% at pressure	Destruction at pressure
1.	3.1.1.	11.8 bar	12,8 bar	15.6 bar
2.	3.1.2.	9.3 bar	10,1 bar	11.3 bar
3.	3.1.3.	8.9 bar	9,1 bar	10.8 bar

The results regarding the correspondence between the audio signal (speech) before and after its wireless transmission via Bluetooth communication through the plates made of the three composite materials are shown in Fig. 10.

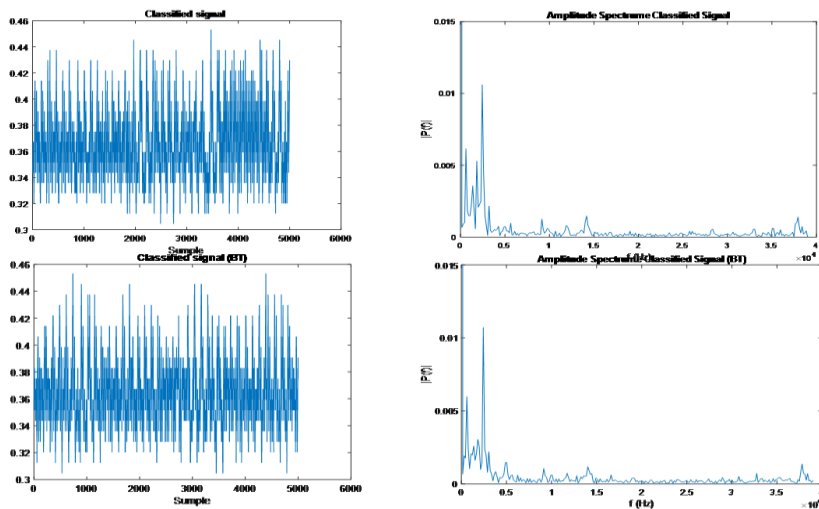


Fig. 10. Correspondence between audio signal (speech) before and after its wireless transmission

## 4. Conclusions

The results of the experiments using the model shown in Fig. 4 for testing the strength properties of the proposed composite plates and the Bluetooth-enabled wireless network for remote sensor data communication and transmission of the collected data to an aviation electronics server using Arduino designed and manufactured open source computer hardware and open source software and microcontroller kits for building digital devices, taking into account the technical, functional and financial requirements, allow the following conclusions to be drawn:

4.1. For spacecraft from the moment of their launch until their orbit positioning it is appropriate that the contact devices between the on-skin and the under-skin wireless communication modules should be provided with screens protecting them from the high dynamic external pressure values. For other aircraft this will not be necessary.

4.2. The proposed composite materials fully meet the requirements for providing wireless communication with on-skin sensors in aerospace vehicles;

4.3. It is advisable to activate the operation of the wireless communication system on a signal, and the easiest and cheapest way is with a pair of light source and light receiver (LED). This requires that the composite material should be transparent, i.e. most suitable is the composite of configuration 3.1.3.;

4.4. The use of wireless communication standards in the construction of sensor networks provides flexibility in their implementation and reduces the time consumption. Another benefit of BLE sensor modules is the possibility to use small-size batteries;

4.5. The construction of sensor concentrators/hubs enables the provision of information on the parameters at different points, thus ensuring the correct operation of the automated systems. It also allows a completely new approach in their implementation. In practice, it is possible for each system to be given individual configurations and to upgrade the sensors used;

4.6. The disadvantages of the presented approach include in the first place the limits on the distances imposed by the Bluetooth standard, though this will be partially overcome in its upcoming fifth version. Another shortcoming is the impossibility to position sensor modules behind metal partitions, which requires placing additional concentrators and the use of “windows” made of radio-transparent materials.

## 5. Acknowledgements

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## **КОМПОЗИТЕН МОДУЛ ЗА БЕЗЖИЧНА КОМУНИКАЦИЯ В АВИОКОСМИЧЕСКИТЕ СРЕДСТВА**

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### **Резюме**

Увеличаването на въздушният трафик, в това число и на космическите полети, количествата пренасяни товари и пътници, както и поставените за решаване сложни научни и научно-приложни задачи, повишават изискванията за получаване на постоянна актуална информация за параметрите на системите и заобикалящата ги среда. С навлизането на платформите за IoT се наблюдава тенденция за използването им във всички сфери на технологиите, като системи за сбор и обработка на информация, което е в пълна сила и за нуждите на въздухоплаването. Един от основните проблеми на изграждането на нови системи или надграждане на съществуващи, съобразени със съвременните тенденции, е високата себестойност и големият период за реализация на настоящите решения. Предлаганият подход на унифицирани модули с голям набор от възможни сензори, работещи по безжичен стандарт за предаване на информацията свързани в единна мрежа с относително ниска себестойност и минимално време за изграждане, надграждане и обновяване, дава възможност за отговаряне на тенденциите в сферата на въздухоплаването.