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ANALYSIS OF ON-BOARD WIRELESS SENSOR NETWORK AS AN ALTERNATIVE TO TRADITIONAL WIRED NETWORK

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Wireless networks based on the principle and technology of Wireless Avionics Intra-Communications (WAIC), that is, wireless avionics or wireless onboard intercom are becoming increasingly widespread on modern aircraft. The development and deployment of WAIC on board is a complex task, as its solution is directly related to ensuring safety of flights. It requires preliminary careful scientific analysis. The article analyzes the on-board wireless sensor network as an alternative to a traditional wired network using the example of a short-haul aircraft. A rough estimate of the length of the electrical harness connecting the sensors of the aircraft systems with the electronic units is carried out in order to determine the possible gain in the length of the wires when switching to a wireless sensor network (WSN). To solve this problem, the aircraft sensors of each aircraft system are placed on a large-scale grid; for each sensor, analyze the feeder circuits by the composition of the plug connectors, the number of occupied contacts and the length of wires for each contact to the corresponding electronic unit. It is shown that the heterogeneous sensor system of the aircraft with wireless sensors can reduce the number of wires by about 1200, the length of the wires of the feeder network by about 15 km. The most promising aircraft systems in terms of switching to wireless sensors are: fuel system (about 3400m), fire equipment system (about 1300m) and hydraulic system (about 1300m). Further scientific research is required to make an informed decision about the technical feasibility and advisability of using a wireless sensor network for each specific aircraft system.

Key words: mathematical models, processes and systems, technical operation, avionics, aircraft, on-board complexes, functional systems.

INTRODUCTION

Wireless networks are being increasingly spread onboard the modern aircraft. These networks are based on Wireless Avionics Intra-Communications (WAIC), i.e. wireless avionics or wireless intra-communication system. The WAIC development and implementation is a challenging task as its solution is directly connected with flight safety. This challenge requires a thorough scientific analyses [1,9]. The recent development of wireless technologies, which are widely used for general computer networks (i.e. not airborne networks), telephones and Internet communications, enable the wireless technologies also to be used in airborne networks [2-5].

Papers [6-8] determine the three stages of airborne wireless system implementation. The first stage (which is currently in progress) the WAICs introduced on board execute the new, compared to traditional networks, functions such as providing Internet access for the passengers. The second stage (which has already started) WAICs implement the functions of the traditional airborne networks. The upcoming third stage implies that the WAICs replace the traditional networks partially or completely.

For example, the wireless flight control function which may replace the fly-by-wire. The fly-by-wire, in its turn, used to replace the mechanical flight control system. The further research requires the development of wireless sensors with self-contained power supply, data hubs, corresponding airborne computer software, WAIC data transition reliability analyses, fail-operational capability and system safety assessment for both the aircraft system in question and the adjacent systems.

The international requirements^{1,2,3} define the WAIC performance properties and provide the airborne implementation guidance. Papers [10-12] analyze and provide wireless solutions for non-aviation areas.

¹ Technical characteristics and operational objectives for wireless avionics intra-communications (WAIC) // M Series Mobile, radio determination, amateur and related satellites services. Report ITU-R M. 2197, 2010. 58 pp.

The present article provides short-haul aircraft WAIC assessment as an alternative to the traditional wired network layout. The paper evaluates the approximate length of the electric wiring harnesses, which connect the aircraft system sensors and probes with their control units in order to determine the possible savings in the wire length in case of transition to wireless sensor network.

The solution supposes the positioning of every aircraft system sensor on the scale grid. Each sensor feeder diagram has to be analyzed for the number of plugs, the number of terminal elements engaged and the wire length from every terminal element to the corresponding control unit.

AIR CONDITIONING SYSTEM WIRELESS SENSOR NETWORK

Figure 1 shows the positioning of the air conditioning system sensors on the aircraft scale grid. The system comprises the following sensors.

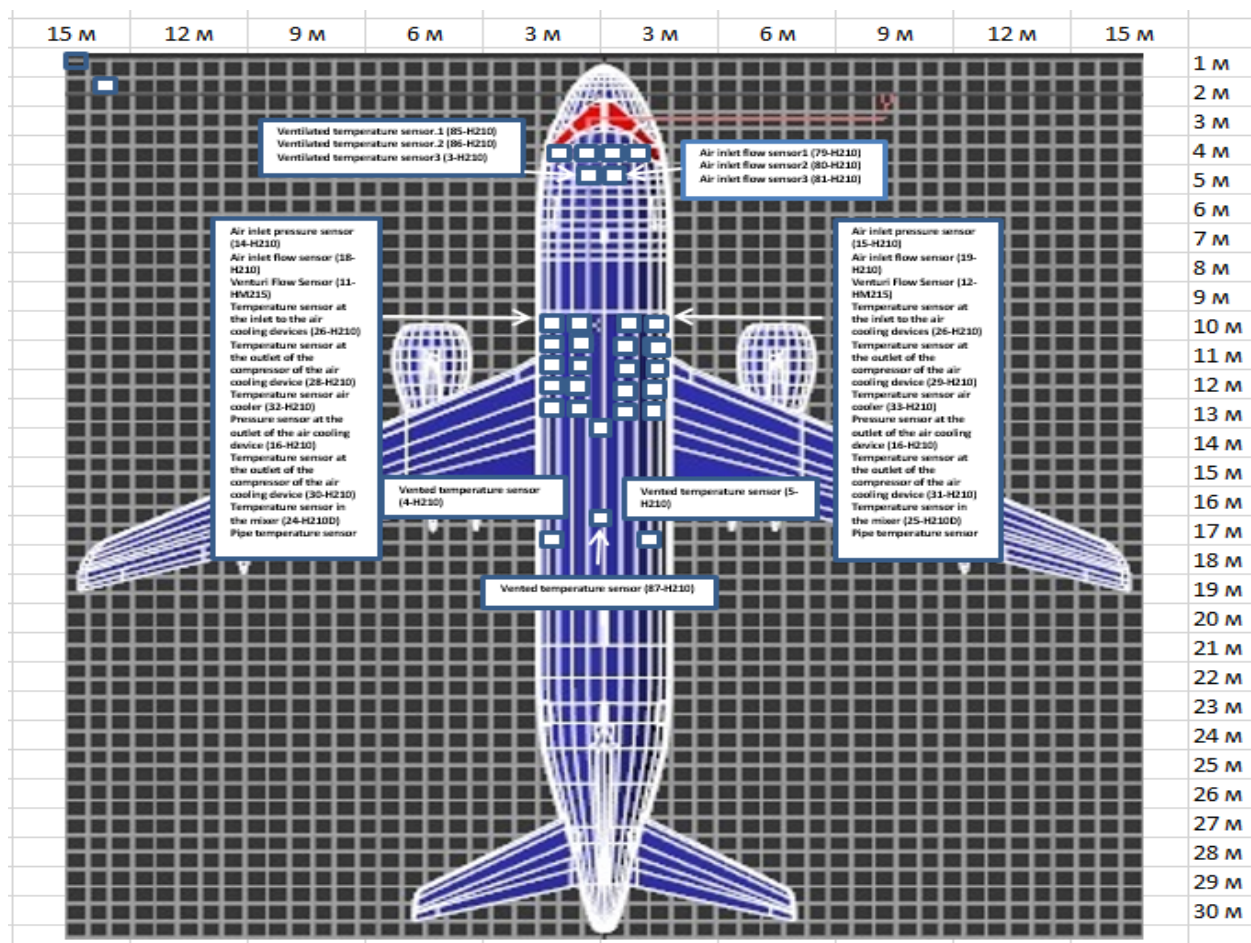


Fig. 1. Location of air conditioning system sensors (SLE) on an airplane

² Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4 200-4 400 MHz . M Series Mobile, radio determination, amateur and related satellite services. Recommendation ITU-R M. 2059-0, 2014. 24 pp.

³ Technical characteristics and protection criteria for Wireless Avionics Intra-Communication systems . M Series Mobile, radio determination, amateur and related satellite services. Recommendation ITU-R M. 2067-0, 2015. 6 pp.

The ventilated temperature sensor has a socket connector with 8 pins, 6 of them engaged. There are three sensors located in the avionics compartment 3 meters away from the conditioning system control units, the overall wire length is 48 meters. There are three sensors in the passenger cabin at the distance of 10 meters. The total number of wires is 36, the overall length is 180 m.

Air cooling (pack) inlet pressure sensor has a socket connector with 4 pins, 4 pins engaged. Two sensors are located within the RH and LH wing fairings 6 meters away from the air conditioning control units. The total number of wires is 8 with the overall length of 36 m.

Air cooling outlet (pack discharge) pressure sensor has a socket connector with 4 pins, 4 pins engaged. Two sensors are located in the LH and RH forward cargo/baggage compartment under floor space 6 meters away from the air conditioning control units. The total number of wires is 8 with the overall length of 36 m.

Pack inlet consumption sensor has a socket connector with 8 pins, 6 pins are engaged. Three sensors are located in the avionics compartment three meters away from the air conditioning control unit. The total number of wires is 18 with the overall length of 48 m.

The compressor outlet temperature sensor has socket connector with 6 pins, 6 pins engaged. Two sensors are located within the RH and LH wing fairings 3 meters away from the air conditioning control units. The total number of wires is 12 with the overall length of 36 m.

The mixing unit temperature sensor has socket connector with 6 pins, 6 pins engaged. Two sensors are located within the RH and LH bottom fuselage below the air conditioning compartment 6 meters away from the air conditioning control units. The total number of wires is 12 with the overall length of 72m.

The pack outlet temperature sensor has a socket connector with 6 pins, 6 pins engaged. Two sensors are located within the RH and LH wing fairings 6 meters away from the air conditioning control units. The total number of wires is 12 with the overall length of 72 m.

The manifold temperature sensor has a socket connector with 6 pins, 6 pins engaged. Three sensors are located within the RH and LH bottom fuselage below the air conditioning compartment 6 meters away from the air conditioning control units. The total number of wires is 18 with the overall length of 108 m.

The pack outlet temperature sensor has a socket connector with 6 pins, 6 pins engaged. Two sensors are located within the RH and LH wing fairings 6 meters away from the air conditioning control units. The total number of wires is 18 with the overall length of 108 m.

The venturi consumption sensor has a socket connector with 12 pins, 9 pins engaged. Two sensors are located within the RH and LH wing fairings 6 meters away from the air conditioning control units. The total number of wires is 18 with the overall length of 108 m.

Thus, the wireless sensor heterogeneous air conditioning system allows to diminish the number of wires by 174 and reduce the wire length approximately to 900 meters.

THE FLIGHT CONTROL SENSOR SYSTEM

Figure 2 shows the location and aircraft scale grid placement of flight control system sensors. The system comprises the following sensors.

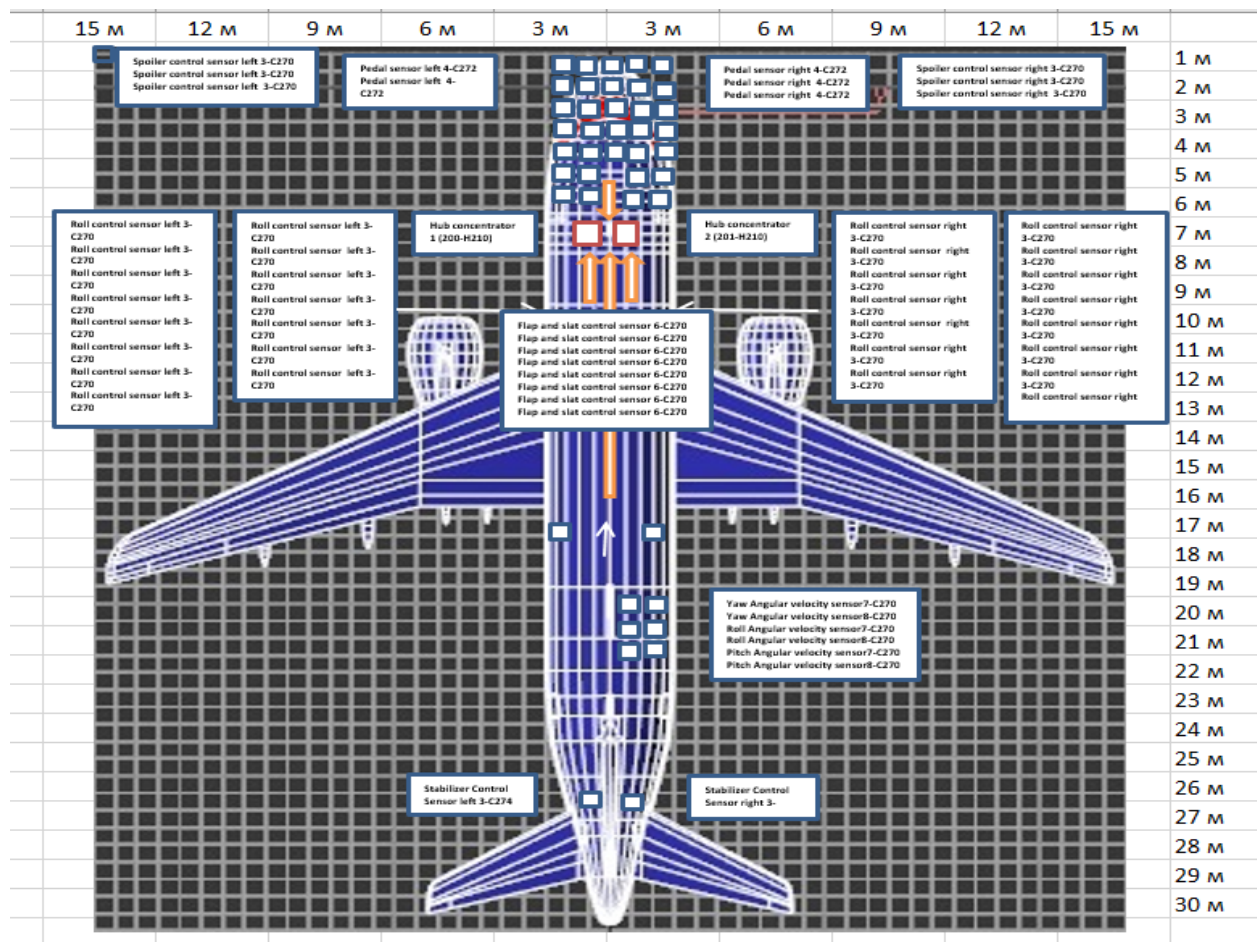


Fig. 2. Location of aircraft control system sensors on an airplane

The roll control sensor has two socket connectors with 32 pins. There are 11 pins engaged on the first socket connector, the second connector has the same number of contacts engaged. The right control stick roll sensors are located 5 meters away from the RH avionics rack. The total number of wires is 22 with the overall length of 110 m. The same is the length of wires for the left control stick, 110m. The total number of wires is 22. The overall length of wires to the left and right control sticks is 220m.

The pitch control sensor has two socket connectors with 36 pins. There are 12 pins engaged on the first socket connector, the second connector has the same number of contacts engaged. The left control stick roll sensors are located 5 meters away from the LH avionics rack. The total number of wires is 24 with the overall length of 120 m. The same is the length of wires for the right control stick, 120m. The total number of wires is 24. The overall length of wires to the left and right control sticks is 240m.

The spoiler control sensor has two socket connectors with 32 pins. There are 5 pins engaged on the socket connector, the remaining contacts are not engaged. The spoiler control sensors for right and left control sticks are located 5 meters away from the LH and RH avionics racks. The total number of wires is 10 with the overall length of 50 m.

The pedal control sensor has one socket connector with 32 pins. The left pedal connector has 5 pins engaged; the remaining pins are free. The same are the numbers for the right pedal connector. The right and left pedal control sensors are located 5 meters away from the LH and RH avionics racks. The total number of wires is 10 with the overall length of 50 m.

The flaps and slats control sensor has one socket connector with 8 pins. The first connector has 5 pins engaged; the remaining pins are free. The same are the numbers for the second connector. The flaps and control sensors are located in the GC area 5 meters away from the LH and RH avionics racks. The total number of wires is 10 with the overall length of 50 m.

The stabilizer control sensor one socket connector with 8 pins. There are 6 pins engaged; the remaining pins are free. The same are the numbers for the second sensor. The stabilizer control sensors are located 5 meters away from the LH and RH avionics racks. The total number of wires is 12 with the overall length of 60 m.

Each angular velocity sensor has one socket connector with 8 pins. The yaw angular velocity connector has 6 pins engaged; the remaining pins are free. The same are the numbers for the roll and pitch angular velocity sensors connector. The angular velocity sensors are located in the GC area 5 meters away from the LH and RH avionics racks. The total number of wires is 18 with the overall length of 160 m.

Thus, the total number of wires is 152, the flight control systems sensors require about 830 m of wires.

THE FUEL SYSTEM SENSOR NETWORK

Figure 3 shows the location of fuel system sensors on the aircraft scale grid.

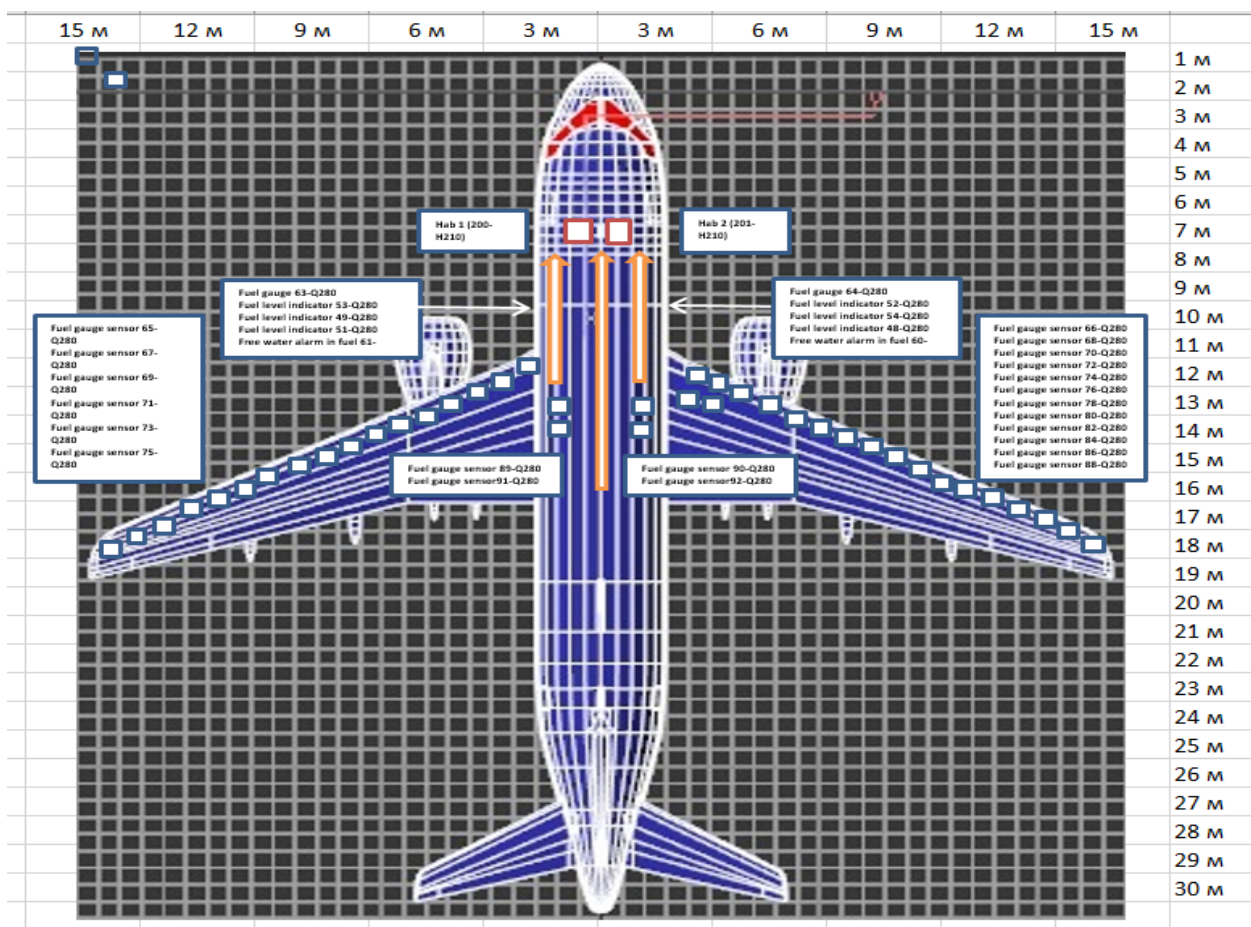


Fig. 3. Placement of fuel system sensors on the scale grid of the aircraft

Fuel quantity indicating probe has a socket connector with 3 pins, 3 pins engaged. Three probes are located in fuel tank compartments 1,2 and 3 and 20, 15 and 10 meters accordingly away from the system control units rack. The total number of wires is 9 with the overall length of 135m.

The water – in fuel indicating probe has a socket connector with 3 pins, 3 pins engaged. The probe is located in fuel tank compartment 3 and is 15 meters away from the system control units rack. The overall wire length is 45m.

Fuel quantity gage has a socket connector with 4 pins, 4 pins engaged. Two gages are located in fuel tank compartments 1 and 3 and are 10 and 15 meters accordingly away from the system control units rack. The total number of wires is 8 with the overall length of 150 m.

Fuel quantity gage (1) has a socket connector with 7 pins, 7 pins engaged. The gage is located in fuel tank compartment 2 and is 20 meters away from the system control units rack. The total number of wires is 7 with the overall length of 140 m

Fuel quantity gage (2) has a socket connector with 10 pins, 10 pins engaged. The gage is located in fuel tank compartment 3 and is 15 meters away from the system control units rack. The total number of wires is 10 with the overall length of 300 m.

All-in all, the total length of wires for the first group LH wing fuel sensors is approximately 770 meters. The same amount of wires is used for the first group RH wing fuel sensors. The total number of wires is 37. The overall length of wires for both first group left and right wing fuel sensors is 1540.

Now let us estimate the second group of LH wing fuel sensors. The fuel quantity gage has a socket connector with 4 pins, 4 of them engaged. There are 8 gages in the fuel tank compartments 1,2 and 3 and are 10,15 and 20 meters away from the fuel control units rack. The total number of wires is 24, the overall length equals 500 m.

The fuel quantity gage has a socket connector with 7 pins, 7 of them engaged. The gage is in the fuel tank compartment 1, 20 meters away from the fuel control units rack. The total number of wires is 7, the overall length equals 140 m.

Thus, the total length of wires for the second group LH wing fuel sensors is approximately 640 meters. The same amount of wires is used for the second group RH wing fuel sensors. The total number of wires is 38. The overall length of wires for both second group left and right wing fuel sensors is 1280.

Let us estimate the center tank sensor groups. The fuel quantity indicating probe has a socket connector with 3 pins, 3 pins engaged. Two probes are located in the center wing fuel tank compartment 10 meters away from the system control units rack. The total number of wires is 6 with the overall length of 50 m.

The fuel quantity gage has a socket connector with 4 pins, 4 of them engaged. There are 3 gages in the center tank compartment, 10 meters away from the fuel control units rack. The total number of wires is 6, the overall length equals 50 m.

The fuel quantity gage has a socket connector with 4 pins, 4 of them engaged. There are 3 gages in the center tank compartment, 10 meters away from the fuel control units rack. The total number of wires is 12, the overall length equals 70 m.

The fuel quantity gage has a socket connector with 7 pins, 7 of them engaged. The gage is in the center tank compartment, 10 meters away from the fuel control units rack. The total number of wires is 7, the overall length equals 70 m.

Thus, the total length of wires for the center tank fuel sensors is approximately 190 meters. The number of wires for the center tank fuel sensors is 25.

The fuel pressure sensor has a socket connector with 4 pins, 3 pins engaged. Nine pressure sensors are located in fuel tank compartments 1, 2 and 3 and center tank compartment and 20, 15 and 10 meters accordingly away from the system control units rack. The total number of wires is 45 with the overall length of 405 m.

Thus, the total number of wires is 138. The wireless sensor heterogeneous fuel system allows to reduce the wire length approximately by 3415 meters.

The consolidated data on the number and the length of wires for the aircraft systems are shown in Table 1.

Table 1

Summary data on the number and length of wires of aircraft systems

№	Aircraft system	Number of wires	Wire length
1.	Air conditioning system sensor network	174	900m
2.	Flight control system sensor network	152	830m
3.	Fire protection system sensor network	91	1334m
4.	Anti-icing system sensor network	98	860m
5.	Landing gear system sensor network	82	800m
6.	Oxygen system sensor network	18	24m
7.	Water supply system sensor network	16	320m
8.	Inerting agent system sensor network	20	200m
9.	APU system sensor network	36	900m
10.	Engine fuel system sensor network	52	1040m
11.	Engine control system sensor network	64	920m
12.	Engine instrumentation system sensor network	56	1120m
13.	Exhaust system sensor network	16	160m
14.	Oil system sensor network	42	840m
15.	Doors and hatches system sensor network	48	480m
16.	Fuel system sensor network	138	3415m
17.	Hydraulic system sensor network	100	1280m
	Total	1203	15423m

CONCLUSIONS

1. The aircraft heterogeneous sensor system with the wireless sensors allows to minimize the number of wires approximately by 1200, the with the feeder network being reduced by 15 km.

2. The most promising aircraft systems for the sake of wireless sensor transformation are: the fuel system (approx.3400m), the fire protection system (approx.1300m) and the hydraulic system (approx.1300m)

3. The possibility of technical implementation and feasibility of WSN for every particular aircraft system is a subject to further research.

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АНАЛИЗ БОРТОВОЙ БЕСПРОВОДНОЙ СЕНСОРНОЙ СЕТИ КАК АЛЬТЕРНАТИВЫ ТРАДИЦИОННОЙ ПРОВОДНОЙ СЕТИ

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На современных воздушных судах все большее распространение получают беспроводные сети, основанные на принципе и технологии Wireless Avionics Intra-Communications (WAIC), то есть беспроводной авионики или беспроводной бортовой внутренней связи (ББВС). Разработка и внедрение на борт воздушного судна (ВС) ББВС (WAIC) – сложнейшая задача, так как ее решение непосредственно связано с обеспечением безопасности полетов. В статье проведен анализ бортовой беспроводной сенсорной сети как альтернативы традиционной проводной сети на примере ближнемагистрального самолета. Проведена приблизительная оценка длины электрожгутов, соединяющих датчики самолетных систем с электронными блоками, с тем, чтобы определить возможный выигрыш в длине проводов при переходе на беспроводную сенсорную сеть (БСС). Для решения этой задачи самолетные датчики каждой самолетной системы размещены на масштабной сетке, для каждого датчика проведен анализ фидерных схем по составу штепсельных разъемов, количеству занятых контактов и длине проводов по каждому контакту до соответствующего электронного блока. Показано, что гетерогенная сенсорная система самолета с беспроводными датчиками позволяет сократить количество проводов примерно на 1200, длину проводов фидерной сети примерно на 15 км. Наиболее перспективными самолетными системами с точки зрения перехода на беспроводные датчики являются: топливная система (около 3400 м), система пожарного оборудования (около 1300 м) и гидравлическая система (около 1300 м). Для принятия обоснованного решения о технической возможности и целесообразности использования беспроводной сенсорной сети для каждой конкретной самолетной системы требуется проведение дальнейших научных исследований.

Ключевые слова: бортовые беспроводные сети, беспроводная бортовая внутренняя связь, беспроводные сенсорные сети, бортовые гетерогенные сети, электродистанционные системы управления полетом.

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СВЕДЕНИЯ ОБ АВТОРЕ

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