External Wireless System for Ultimate Flight Control in Contingency Situations

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ABSTRACT

This paper presents an External Wireless System (EWS) which is completely independent from any other system of the aircraft including the power supply. The EWS is used when the electrical, mechanical and hydraulic control systems of the aircraft fail concomitantly and the pilots lose control of the aircraft completely or partially. A EWS unit consists of a solar cell, independent control surface, battery, electrical wires, and stepper geared motor with planetary gears. The battery is charged continuously by solar cells, and the stepper drives the control surface through the planetary gear. The control surfaces have a very slow motion due to the low available power. The role of EWS is only to stabilize the aircraft flight and to direct it to the closest tarmac or acceptable landing place. The EWS units are placed on aircraft wings and tail. All the EWS units are controlled by an independent control unit with the dimension of a mobile phone. Both the pilots dispose of such independent control units. In case of ultimate contingency situations, when the electrical power system, the mechanical, electrical and hydraulic control systems and engines of aircraft fail, the pilot activates the independent control unit (ICU) of the EWSs and directs the aircraft to the closest airport or to an appropriate field for emergency landing.

KEYWORDS: *Wireless System for Aircraft, Flight Control, Flight in Contingency Situations*

NOMENCLATURE

EWS – External Wireless System;
ICU – Independent Control Unit;
1,2,3 L – 1,2,3 Left;
1,2,3 R – 1,2,3 Right;
AWN – Aircraft Wireless Networks;
PED – Personal Electronic Device;
QoS – Quality of Service;
ATN – Aeronautical Telecommunications Network;
L – length, [m]
S – surface area, [m^2]
M – torque, [N·m]
P – power, [W]
p – pressure [Pa]
v – speed. [m/s]
W_s – wing span, [m]
w – width, [m]

Greek

α – angle, [rad]
τ – time, [s]
η – stepper efficiency, dimensionless
Ω – rotation speed of control surface, [rad/s]
ρ – density, [kg/m^3]

1 INTRODUCTION

Although the control systems of modern aircrafts are highly reliable, such hazardous situations when the electrical, mechanical and hydraulic control systems fail concomitantly have been recorded in the past. These situations can happen, for instance, due to failure of other aircraft systems of relatively lower reliability or due to incorrect maintenance or exploitation. For example, in some cases, turbine disc failure caused the cutting of both electrical wires and hydraulic control lines. Taking into account that the modern passenger aircraft became larger and larger, and the air traffic increases day by day it is important for the reliability of flight control systems to be even further improved.

The paper presents an External Wireless System (EWS) which is completely independent from any other system of the aircraft including from the power supply. The EWS is used when the electrical, mechanical and hydraulic control systems of the aircraft fail concomitantly and the pilots lose control of the aircraft completely or partially. Such a system is useful even when all the aircraft engines fail. Implementing a EWS based system leads to low additional costs and weight due to the fact that the system is wireless. The presence of EWS is justified even by the fact that modern aircraft have become so complex, that dangerous events could occur from multiple sources. Being impossible to find the cause in due time, a simple and independent system as EWS can save the aircraft. EWS has another advantage as well: in case the pilots are injured and cannot fly the aircraft, this one can be remotely controlled from another aircraft or from a satellite and directed to an emergency landing location.

2 GENERAL PRESENTATION OF EXTERNAL WIRELESS SYSTEM (EWS)

The EWS unit consists of a solar cell, independent control surface, battery, electrical wires, and stepper geared motor with planetary gears. The battery is charged continuously by solar cells, and the stepper drives the control surface through the planetary reducer. The control surfaces have a very slow motion due to the low available power. The low speed of the motion is not important because the role of EWS is only to stabilize the aircraft flight and to direct it to the closest tarmac or acceptable landing place. There are more EWS units, which are placed on the aircraft wings and tail. All the EWS units are controlled by an independent control unit with the dimensions of a mobile phone. Both the pilots dispose of such independent control units.

The EWS is designed for a maximum mass of 3.5 kg and volume of maximum 1000 cm^3 each. In case of ultimate contingency situations, when the electrical power system, the electrical, mechanical and hydraulic control systems and engines of aircraft fail, the pilot activates the independent control unit of the EWS and directs the aircraft to the closest airport or to an appropriate field for emergency landing (each EWS works independently).

The EWS will be presented in connection with a small passenger aircraft as Airbus A 318. This is a short/medium range, narrow-body, commercial & passenger twin-engine A 318 aircraft has a capacity of 132 passengers and its maximum range is 5,700 km. It entered into service in July 2003. Some characteristics of A 318 aircraft are given below in Table 1:

Table 1: The general characteristics of A 318 aircraft

Length	31.44 m
Wing span	W_s=34.10 m
Wing area	122.40 m^2
Wing sweepback	25°
Tail height	12.56 m
Cabin width	3.70 m
Fuselage width	3.95 m
Maximum take-off weight	68,000.00 kg
Cruising speed	829 km/h
Ceiling	11900 ÷ 12500 m
Engines	2 x [CFM56-5B or PW6000A]
Total thrust of the two engines	2 x (96 ÷ 106 kN)

Several pictures of this aircraft and the positioning of solar cells and independent control surfaces are presented in Figure 1:

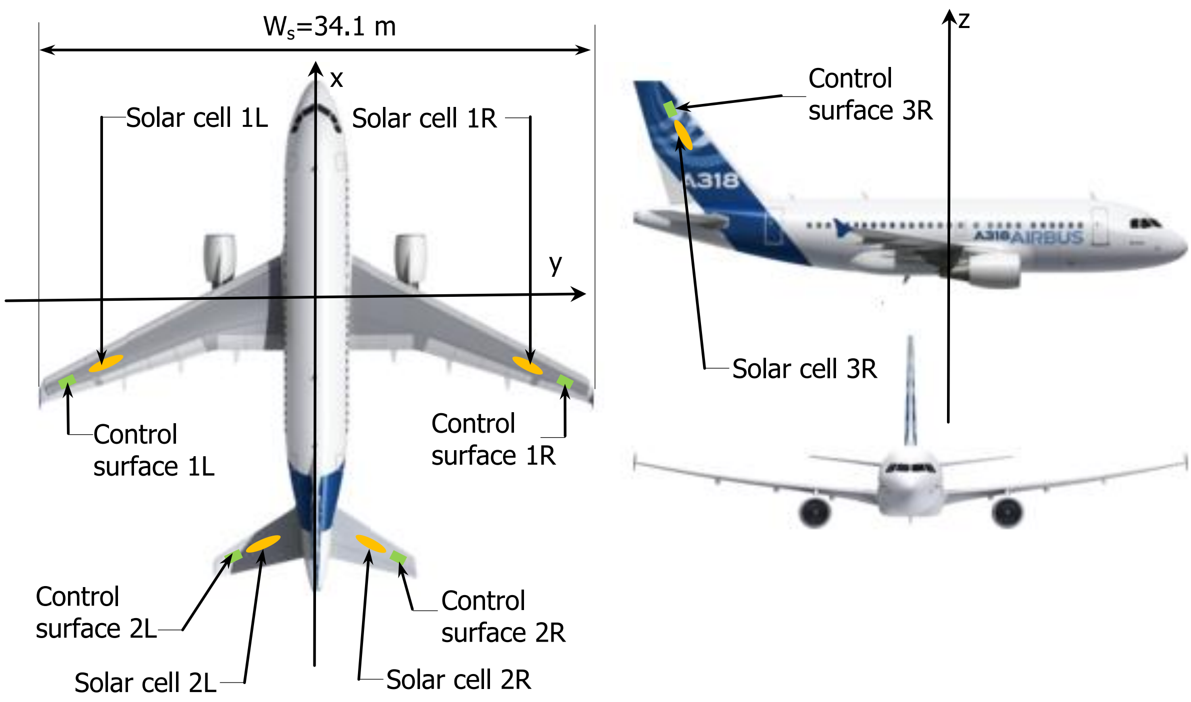


Figure 1: Positioning of solar cells and control surfaces on A318 aircraft

The solar cells 1L and 1R are used for charging the batteries for actuating of independent control surfaces of wing 1L, 1L' and 1R, 1R' (left side and right side of aircraft wing, suction side and pressure side of wing airfoil). The solar cells 2L and 2R are used for charging the batteries for actuating of independent control surfaces of horizontal tail 2L, 2L' and 2R, 2R' (left side and right side of horizontal tail, suction face and pressure face). The solar cells 3L and 3R are used for charging the batteries for actuating of independent control surfaces of vertical tail 3L and 3R (left side and right side). Note: The control surfaces 1L', 1R', 2L', 2R', 3L', 3R' are not represented.

The diagram of a EWS is presented in Figure 2:

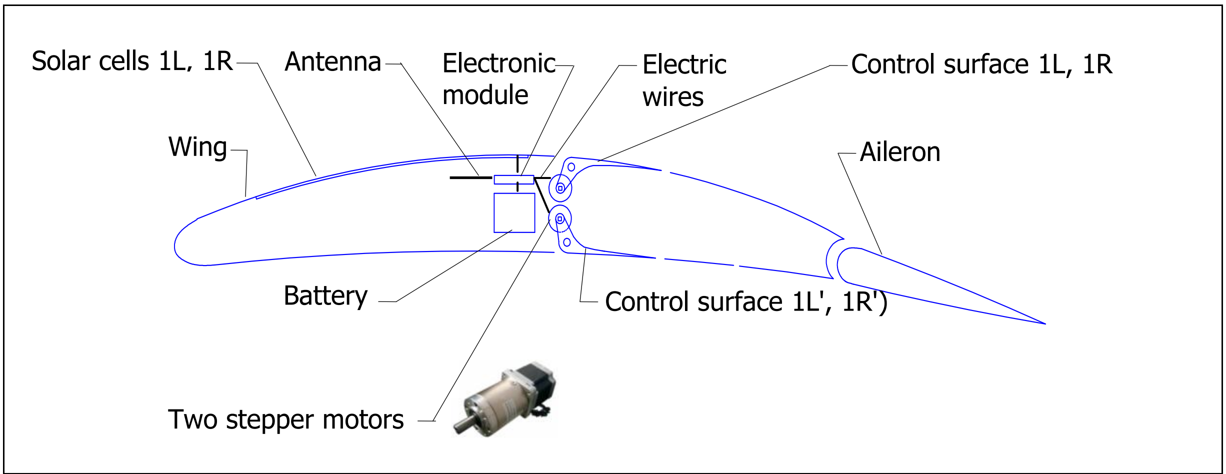


Figure 2: EWS diagram

As one can see in Figure 2, the solar cells are placed on the extremities of the left and right wing and the rest of EWS components (battery, electronic module, antenna, connecting wires and steppers) are placed inside the wing. The control surfaces are articulated on the wing by means of bearings actuated by the planetary gears of the stepper motors.

Opening of the upper control surface A (1L, 1R) is presented in Figure 3:

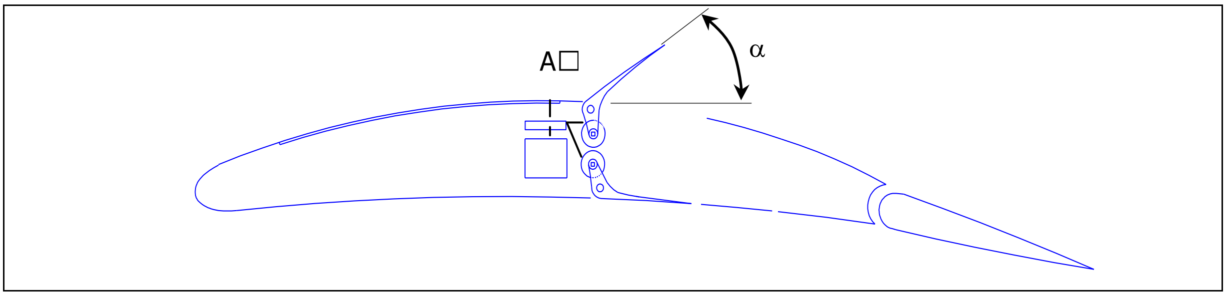


Figure 3: Opening of the upper control surface

Opening of the lower control surface B (1L', 1R') is presented in Figure 4:

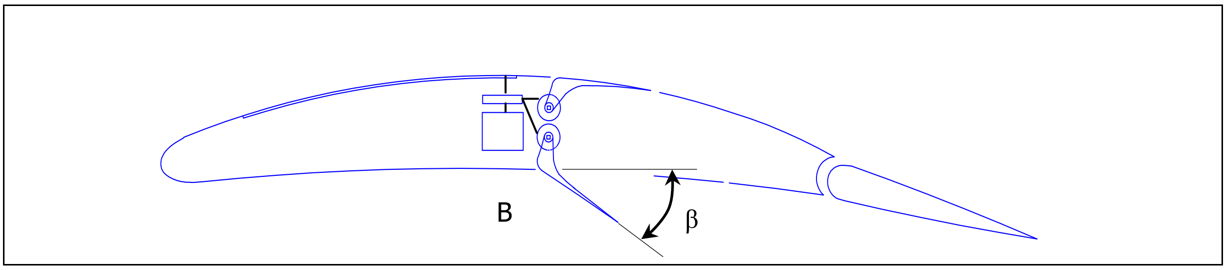
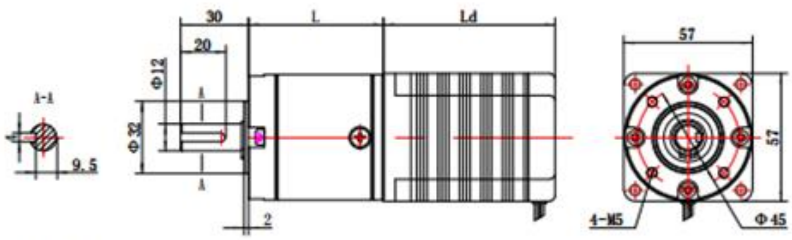


Figure 4: Opening of the lower control surface

The batteries are charged by solar cells placed on the wing extremity (left or right) through the electronic module. The electronic module supplies the upper stepper motor for rotating of the control surface 1L or 1R and the lower stepper motor for rotating of the lower control surface 1L' or 1R' when a signal from the pilot is received through antenna. An example of stepper motor that can be used is a planet gear stepper motor as presented in Figure 5, [1]. One can see that the stepper motor together with its planetary gear can produce a torque of 400 kgf·cm, which is sufficient for the actuation a small control surface.

● Mechanical Dimensions



● Gear Box Data

Reduction Ratio	X:1	3.6	4.25	12.96	15.3	18.063	46.656	55.08	65.025	76.766
Number of gear trains	#	1	1	2	2	2	3	3	3	3
Max Permissible Torque	kg.cm	200	200	300	300	300	400	400	400	400
Moment Permissible Torque	kg.cm	400	400	500	500	500	600	600	600	600
Gear Box Length	mm	49.5	49.5	64.5	64.5	64.5	79.5	79.5	79.5	79.5

● Motor Specifications

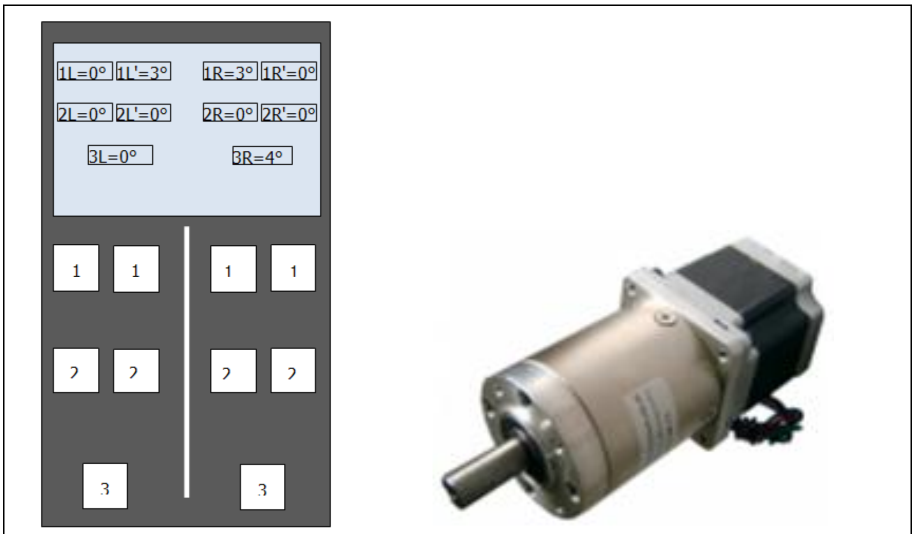
Model	Step Angle	Length (Ld)	Phase Voltage	Phase Current	Phase Resistance	Phase Inductance	Holding Torque	Lead Wire
	°	mm	V	A	Ω	mH	kg.cm	#
57BYGH41(M)-144-4A/B	1.8/0.9	41	4.1	1.44	2.85	5.4	4	4
57BYGH51(M)-144-4A/B	1.8/0.9	51	4.74	1.44	3.3	8.2	9	4
57BYGH56(M)-100-6A/B	1.8/0.9	56	7	1.00	7.6	10	9	6
57BYGH56(M)-280-4A/B	1.8/0.9	56	2.52	2.80	0.9	2.5	12.5	4
57BYGH76(M)-200-6A/B	1.8/0.9	76	5	2.00	2.25	3.6	13.5	6
57BYGH76(M)-280-4A/B	1.8/0.9	76	3.16	2.80	1.13	3.6	18.9	4

Figure 5: Planetary gear stepper motor 56PA/57BYG, [1].

The planetary gear stepper motor has overall dimensions:

57 mm x 57 mm x [30+76+41] mm= 57 mm x 57 mm x 147 mm,

which make it suitable to be mounted inside the wing. It also has a low mass, of only 2.5 kg.
See Figure 6. b). An image of the independent control unit (ICU) of EWS is presented in Figure 6. a).



a) ICU b) Planetary gear stepper motor for EWS

Figure 6: ICU of EWS

For example, when the ICU is programmed by the pilot according to Figure 6, the aircraft turns to right as presented in Figure 7:

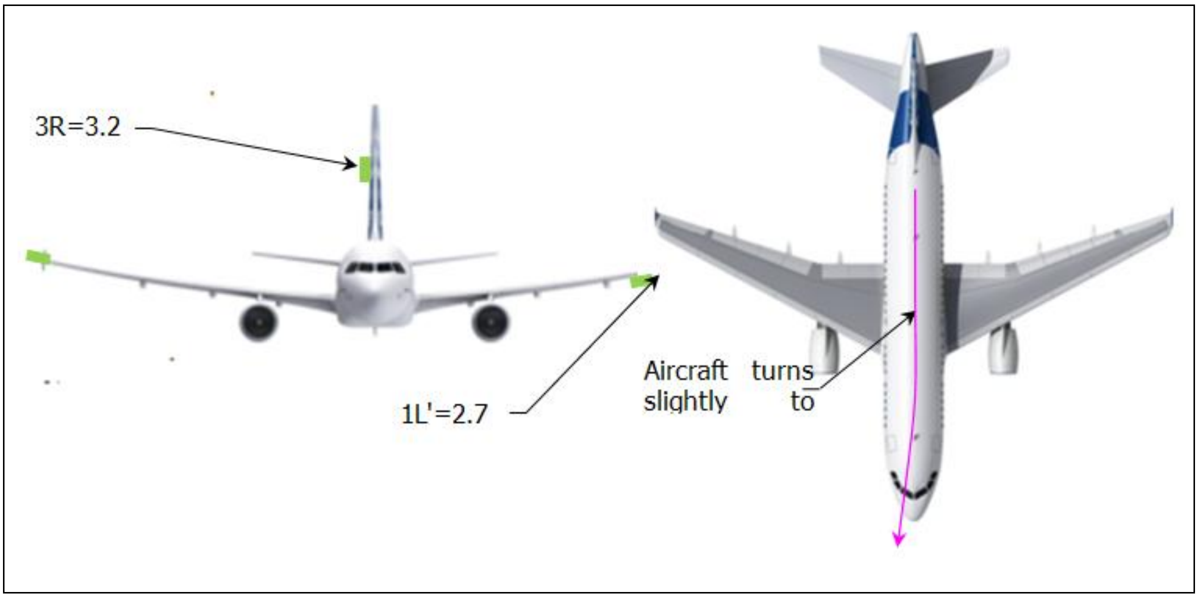


Figure 7: Turning of aircraft to right for ICU programming given in figure 6

Considering that the step is taken to be 0.9° (see again Figure 5), for programming the ICU, the pilot presses 3 times the button 1L' , 3 times the button 1R and 4 times the button 3R. Considering that the stepper is doing 400 steps for a complete rotation (360°), and taking α_{max} =27.7° for maximum opening of control surface, in case that planetary gearbox reduction ratio is i_{pg}=12.96 for the opening at the control surface from the wing at 3°, the stepper must move 43 steps and for opening at the control surface from the wing at 4°, the stepper from vertical empennage must move 58 steps. Flying the aircraft to the landing field or tarmac is achieved in a similar manner as in the case when the current control surfaces are used. Only the equivalent of flaps is not applied because of complications raised by the large area of the surface needed.

3 GLOBAL EVALUATION OF CONTROL SURFACE AREAS

For reducing the mass and volume of the EWS to a minimum, the power necessary has to be minimal. For this reason the control surfaces areas must be reduced to a minimum and their actuation has to be done at a low speed. As it was already mentioned, the EWS is used a limited time only for directing of aircraft to a tarmac or landing field for forced landing. Assuming Airbus A318 is flying at speed V = 829 km = 230 m/s at an altitude of 10 000 m when both engines, electrical and hydraulic control fail. At 10 000 m, the air temperature is t = -50 °C, the air pressure is p = 0,26 bar and the air density is ρ = 0,413 kg/m^3. The dimensions of Airbus A318 are given in chapter 2 and Figure 1. Assuming that the dimensions of the control area are width = w = 0.2 m and length = L = 0.6 m. The control surface area is then S = w x L = 0.12 m^2 (i.e. about a quarter of a spoiler area).

The dynamic pressure of air is:

$$p_d = \rho \cdot V^2/2 = 0.413 \cdot 230^2/2 = 10924 \text{ N/m}^2 \tag{1}$$

If the maximum incidence angle for cruise is taken α=10° (Figure 3) then the torque M_{step} applied by stepper motor around articulation point A is:

$$M_{step} = \sin \alpha \cdot p_d \cdot S \cdot w/2 = 0.174 \cdot 10924 \cdot 0.12 \cdot 0.2/2 = 22.8 \text{ N}\cdot\text{m} = 232 \text{ kgf}\cdot\text{cm} \tag{2}$$

It can be seen that the necessary torque M_{step} is smaller than the maximum permissible torque $M_{stepmax}$ of planet gear stepper motor (see again Figure 5):

$$M_s = 232 < M_{stepmax} = \text{Holding torque x } i_{pg} = 18.9 \cdot 12.96 = 245 \text{ kgf}\cdot\text{cm} \tag{3}$$

The torque on wing which rotates the aircraft around x axis when 1L' and 1R are at incidence angle of α=10° is:

$$M_x = (\sin \alpha \cdot p_d \cdot S) \cdot \cos \alpha \cdot W_s = 0.174 \cdot 10924 \cdot 0.12 \cdot 0.985 \cdot 34.1 = 7607 \text{ N}\cdot\text{m} \tag{4}$$

Obviously, such a torque can produce a slight rotation of aircraft around X axis.
If the motor is driven during τ=3 seconds, the angular speed of rotation of control surface is:

$$\Omega = (\alpha \cdot \pi/180)/\tau = (10 \cdot \pi/180)/3 = 0.058 \text{ rad/s} \tag{5}$$

The mechanical power produced by one stepper is:

$$P_{sm} = M_s \cdot \Omega = 22.8 \cdot 0.058 = 1.32 \text{ W} \tag{6}$$

For a total efficiency of stepper evaluated at η = 80% the electrical power P_{se} needed by stepper is:

$$P_{se} = P_{sm}/\eta = 1.32 /0.8 = 1.65 \text{ W} \tag{7}$$

It can be observed that this power can be supplied by the stepper presented in Figure 5.
On the other hand, taking into account a solar cell area S_{sc} = 0.15 m^2, for the irradiance at the Earth's surface I_{ES} = 1000 W/m^2, the electrical power P_{sc} supplied to batteries by solar cells (taking the efficiency of solar cells η_{sc} = 20%) is:

$$P_{sc} = \eta_{sc}\, I_{ES} \cdot S_{sc} \cdot = 0.20\ 1000 \cdot 0.15 = 30 \text{ W} \tag{8}$$

Obviously, with this power it is possible to supply directly the stepper motor during day time. For the night time, a battery having energy E_b = 0.15 Ah (mass of battery $m_b \approx$ 100g) can be considered as sufficient because the total energy E_{cs} consumed for moving of surface once (for opening and closing) is:

$$E_{cs} = 2 \cdot P_{se} \cdot \tau = 2 \cdot 1.65 \cdot 3 = 9.9 \text{ J} \tag{9}$$

For the given energy, the control surface can be actuated over 54 times during night by battery because the total energy incorporated in battery is:

$$E_b = 0.15 \text{ Ah} = 0.15 \cdot 1 \cdot 3600 \text{ A}\cdot\text{s} = 540 \text{ J} \tag{10}$$

This energy allows the opening and closing of the control surface by n_{ot} operating times which is:

$$n_{ot} = E_b/E_{cs} = 540/9.9 = 54 \text{ times} \tag{11}$$

This number of actuations can be considered to be sufficient, taking into account that the EWS is intended only for the turning of the aircraft to the closest tarmac or to an appropriate field for emergency landing. If the mass of one control surface is estimated at m_{cs}=0.5 kg, the mass of the solar cells m_{sc}=0.25 kg,the mass of the battery m_b=0.1 kg, the total mass of an EWS can be calculated:

$$m_{EWS} = m_b + m_{step} + m_{cs} + m_{sc} = 0.1 + 2.5 + 0.5 + 0.25 = 3.35 \text{ kg} \quad (12)$$

For the 10 EWSs placed on the wings and on the vertical and horizontal empennages, the total mass is M_{tEWS}≈33.5 kg. This mass is rather insignificant in comparison with the mass of a modern passenger aircraft (tens of tones).

4 ELECTRONIC DESIGN OF EWS AND ICU

4.1 Electric/Electronic design of EWS

The main components of the electrical diagram for EWS are show in the following Figure 8:

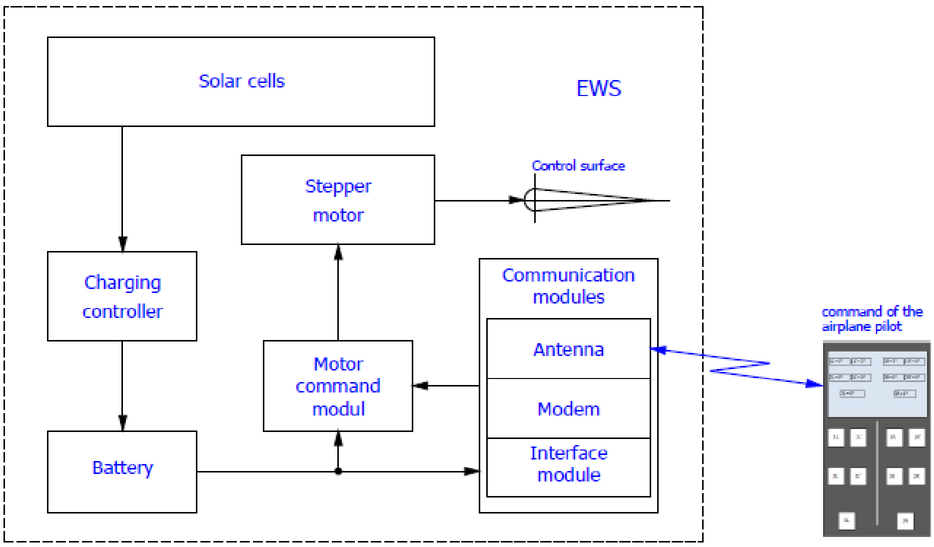


Figure 8: Schematic block for EWS system

The signal emitted by the remote is transmitted wireless and received by the 5 emergency electronic control modules located on the wings and airplane amps. They are encoded and protected from interference so that when the buttons for a module are actuated that module responds to commands. The signal received by the module's antenna is decoded and transformed into the electric control for the stepper motor that acts on the upper or lower control surface mechanism. The electrical assembly is powered by a battery with sufficient capacity to drive the stepper engine for several hours. The battery is charged from solar cells with enough power to keep the battery charged when the electrical system is in standby mode.

4.2 Electric/Electronic design of ICU

One application domain in which wireless networks are of far greater practical use is aviation, since planes are scattered all over the world. In commercial aviation, the major goal is to provide in-flight Internet connectivity. An objective is to focus on research concerning network connectivity from ICU within an aircraft trough a Wi-Fi connection. The major issues in AWN (aircraft wireless networks) research are interoperability, interference, mobility, and quality of service (QoS).

Interoperability is important because the EWS system requires the use of multiple different networks. Two of the key networks considered are Internet for EWS satellite ground control and Wi-Fi connectivity for ICU. To provide the Internet and Wi-Fi connection required for the EWS system, an aircraft must have an access point for receiving both kinds of wireless signals and be able to transmit traffic from EWS system to the ground via the satellite link and to the ICU. Interference comes into play because it is undesirable for these transmissions to interfere with the navigational and communications systems needed for operation of the aircraft.

The general use of radio transmitter equipment remains banned on board aircraft, due to the danger of an uncontrolled radio transmission directly affecting the aircraft's communications or flight control electronics. However, the use of mobile phones is becoming relaxed, as they are a much more controlled radio transmission, and the behaviour of the phone can be managed to such an extent that it does not cause a problem for the aircraft.

Personal electronic devices (PEDs) emit two kinds of radiation: intentional and spurious. Intentional emissions are those with the purpose of transmitting data in the allocated frequency bands of the PED. Only devices which communicate via wireless links have these. Spurious emissions are those which are unintentional, and contribute to the Radio Frequency Noise Level. Although all PEDs have these, they are more significant in wireless PEDs. Intentional transmissions are normally not a concern because their frequency bands are limited and do not overlap the frequencies of airline systems, as shown in Table 2. However, if the power level of a spurious emission is high enough at a receiving frequency of an aircraft nav / comm system, it could interfere with aircraft operations.

Table 2 - Frequency ranges of wireless communication equipment and aircraft nav/comm systems [2]

Omega navigation 10 - 14 kHz	ADF 190 - 1750 kHz	HF 2 - 30 MHz	Marker beacon 74.85, 75, 75.-5 MHz	VOR/LOC 108 - 118 MHz	VHF COM 118 - 136 MHz	Glide slope 328 - 335 MHz
GSM 400 450 - 496 MHz	GSM 850 824 - 894 MHz	GSM 900 876 - 950 MHz	DME 960 - 1220 MHz	TCAS/ATC 1030, 1090 MHz	GPS 1575 MHz	SATCOM 1529, 1661 MHz
GSM 1800 1710 - 1880 MHz	European UMTS 1880 - 2025, 2110 - 2200 MHz	GSM 1900 1850 - 1900 MHz	IMS band: 802.11b, Bluetooth 2446.5 - 2483.5 MHz	Low-range altimeter 4.3 GHz	Microwave landing system 5.03, 5.09 GHz	802.11a 5.15 - 5.35 GHz
Weather radar 5.4 GHz	802.11a 5.725 - 5.825 GHz	Weather radar 9.3 GHz	Sky radio 11.7 GHz	DBS TV 12.2 - 12.7 GHz	-	-

The EWS communication frequency with satellite ground control and the Wi-Fi connectivity for ICU must not reach the ranges described in Table 2. Interference of an intentional or unintentional EWS system with a passenger PED should be also avoided.

The physical movement of the aircraft makes mobility and QoS issues of concern. Aircraft and ground stations with which EWS system communicates must be mobility-aware, as the aircraft is basically a moving network. As it moves, an aircraft must register with each new ground station it encounters in order to establish a path for traffic to and from the EWS system. The ground station must also handle routing to the multiple nodes which reside on each aircraft connected to it. The process of switching between satellites and/or ground stations can cause a loss or degradation of EWS communication. The architecture of the communication system should be such that the impact of handovers on QoS is minimized.

On the aircraft, a wireless access point can be used to provide connectivity to EWS system. The satellite link provides a connection to the ground station, which is connected to the Internet network. Using the Internet network, an authorized operator can control a malfunctioning plane through an application that connects to EWS plane system. Architecture for this purpose is presented in Figure 9.
The Aeronautical Telecommunications Network (ATN), developed by the International Civil Aviation Organization was imagined as a way to provide ground to ground and air to ground data communications services in the aviation industry. ATN is based on the seven-layer Open Systems Interconnection (OSI) model. This is a private network with its own addresses, and a scheme for providing network mobility for aircraft. These ones' mobility solution relies on a large address space

and backbone routers updating path information in the network. When an aircraft is connected to a new access point, the associated backbone router transmits the routing information for that aircraft's network back through the ATN backbone. The ATN also has specifications for managing different QoS levels.

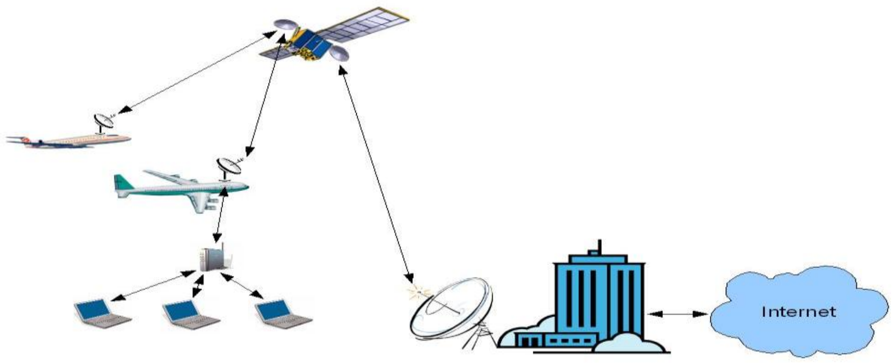


Figure 9: Commercial airline network topology [2]

5 CONCLUSIONS

In the future, air traffic will increase considerably especially due to the emergence of low cost operators on market. The number of aircrafts and flights is expected to record a high increase. As a result, contingency situations will increase accordingly. For this reason, EWS controlled by ICU as totally independent units will be necessary for a minimal control of the aircraft when the electrical/hydraulic control systems and engines of aircraft fail.

EWS controlled by ICU permit manoeuvring of aircraft only for orientation of aircraft to the tarmac or an appropriate field for emergency landing. EWS is composed of a small area solar cells, small area control surface, battery, connecting wires, planet gear stepper motor. The planet gear stepper motor can directly drive the control surface due to the high torque produced by the planetary gear. EWS are placed at wings extremities, in vertical empennage and at the two extremities of horizontal empennage (10 EWS units). The evaluated weight of a EWS unit is around 4 kg. A total mass of the 10 EWS is 40 kg which is small in comparison with take-off weight of current passenger aircraft.

The EWSs are controlled by ICU. These units, which are similar with phone cells, transmit signals for EWSs actuation and display the position of each control surface. On ICU are provided buttons for opening and closing of each surface from wings and from vertical and horizontal empennage.

Two ICUs are kept permanently charged in pilot cabin for use by any pilot in case of emergency situation. Interference of ICU equipment with aircraft navigation communication systems and passenger personal electronic devices (PEDs) are to be avoided.

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