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Potential Problems Related to EMC Caused by Low-altitude Flying Powerful Electrical Rotorcrafts in Urban Environment

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Abstract – **Mass electrification of personal transportation vehicles creates prerequisites for massive mobile sources of electromagnetic interference. These is especially strong in dense urban environments. The problem with the introduction of 3D drone traffic will create a number of problems associated with the generation of unacceptable interference in communication and navigation aids. The EMC problems for this type of transport are justified but not well addressed in the publicly available literature, as the regulations currently required typically cover non-urban passenger aircraft and some general radio regulations concerning autonomous transportation.**

Keywords – **drones EMC, 3D urban mobility.**

I. Introduction

Aircraft vehicles for 3D urban mobility and transportation fall into the two main categories of semi-automatic aircraft (Unmanned Aerial Vehicles - UAV) and aircraft intended for recreational use. Therefore, most countries, including the EU, are unable to come to a common regulation, both for their use and for the requirements for implementing such transport services. In addition to these purely formal requirements regarding the safety of users of such services and the protection of the health and life of citizens and the integrity of urban infrastructure, few authors address the issue of electromagnetic compatibility (EMC), which is the main attribute which largely determines the quality, reliability, functional safety and radio electronic protection of the UAV. Violation EMC of avionics that is included into UAV, can lead to lower quality of functioning or irreversible failure. Under the EMC of avionics is meant, how it operates in accordance with the required specifications in the real electromagnetic environment (caused by electromagnetic interaction or by impacts), without creating inacceptable electromagnetic disturbances in other equipment of UAV. The densely populated urban environments does not allow drones larger than the two-seats passenger models to be deployed. Nevertheless, such aircraft will be predominantly electric or hybrid powered. A number of companies have already introduced fully automatic shipping services for the delivery of small consignments that use fully electric propulsion vehicles (Amazone, Google, etc [1]). But when it comes to transporting people, it is necessary to use a hybrid type of drive. The use of turbojet engines in dense urban environments cannot be justified due to noise standards, environmental and ecology issues and physical problems associated with the high velocity of the leaking hot gases. Therefore, concept implies the introduction of hybrid type drones [2] with an internal combustion engine-generator pair, redundant battery unit and fully electrically driven multi-rotor elevation modules. The use of this type of dual power supply for electric cars relatively well adapted to the production of electric and hybrid vehicles. Most of the problems of electromagnetic compatibility have been solved by suitable shielding, RF filtering and shunting. Typically, the electric vehicle has maximum power consumption when starting, stopping and climbing slopes, which rarely exceed 15% in urban environments (maximum trust of 580 kW Tesla Model S), while the rest of the time the energy is used mainly to overcome rolling resistance and resistance in the air. In addition, sufficiently reliable shielding is applied to the electromechanical and control modules. Unfortunately, in the case of air transport, the use of standard automotive controllers, mainly based on IGBT industrial modules, cannot be considered for reasons of minimum mass and low energy losses and cooling problems. This does not allow the use of standard car shielding solutions and electrical power filters to be used in aviation because of their weight. Nevertheless, the typical power supply of such aircraft is between 45-80 kW, with almost 80% of the time electric power being loaded at 70-90% of its maximum trust. The typical electric drive of the rotors generating a lift is through twin-stator brushless sensor-less motor, which requires the use of dual synchronized impulse controllers (2x4 for typical drone).

Moreover, the length of the cables between the main battery, speed controller and the electric motors exceeds 2-3 m. in larger models. This makes these wires an ideal pulsed power supplies for electric aircraft, but the cost of implementing light enough and temperature-resistant modules increases their cost by up to 30 times, including low resistance high amps wiring (120-600 V/150-200 amp per motor).

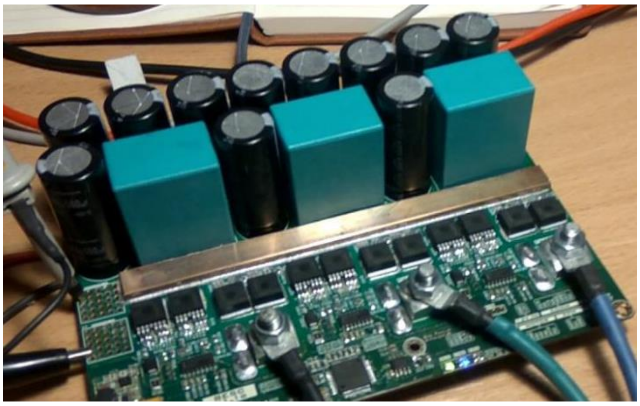

Fig. 1. Compensation capacitor battery near CMOS switching fabric

These circumstances make the typical single or double seat drone an ideal mobile source of radio frequency and EMP interference, which would have a negative impact on the communications and navigation infrastructure in urban areas as well as on potential problems of the flight control and control systems within the drone itself. Intensification plans for 3D urban transport suggest that more than 8-10% of it will be airborne in next 5-10 years, which, for a city like Sofia, represents more than 50,000 simultaneously flying drones in the city's airspace. Another problem is the powerful industrial interference in an extremely wide spectral range up to several dozen MHz generated by power supply. The typical electric motor of a woodworking or metal-cutting machine operates at a fixed speed (rpm) and has a rated power between 2.5-10 kW powered by a three-phase network. In comparison a single seat drone uses 8 to 10 times more pulse-generated power. A comparative analysis of interference levels and frequency bands with those specified in EN 61000-6-4 for the emissions in industrial environments should be done. Typically, interference mitigation in industrial systems is achieved through quality chokes and capacitor batteries (Fig.1). These measures are also applicable to voltage, and should also be protected from accidental collision with high-voltage power grids and lightning, ever more common in densely populated and polluted cities. In the following sections, we will look at some basic regulations applicable to human transportation drones regarding the provision of EMC & safety standards, protection of flight systems against electromagnetic radio frequency interference, as well as lightnings. Studies show, that there is an increasingly complex regulatory environment around drone certification with national and international aviation and product safety regulations, developed to cover these products.

II. Intrasystem Electromagnetic Compatibility

Electromagnetic compatibility means the ability of rotocrafts to operate correctly in accordance with the required specifications in the real electromagnetic environment (that is caused by the electromagnetic interaction and impacts) without causing excessive electromagnetic interference to anything in that environment [9]. The intrasystem EMC is limited by interaction of interference sources and receptors on a single object. At present, the problem of ensuring EMC of moving objects acquires the greatest relevance that is due to the some of the following major causes:

- wide frequency range of intrasystem electromagnetic interferences that complicates the real electromagnetic environment during aircraft operating and is due to a large amount of radio-electronic, computing and aircraft equipment.
- production of rotocrafts from composite materials - leads to complication of the problem of predicting and providing intrasystem EMC

2.1 Aircraft EMC certification – emissions

Historically, radio interference problems were first encountered during the Second World War. In 1940, some of the first recommendations for the protection of radio communication and navigation equipment in aircraft came out mainly related to the interference caused by the on-board electrical system and generators. First US military standard MIL-I- 6181 [3] was issued in 1950. It covers both emissions and susceptibility limits and testing. The corresponding standards were published in UK. In 1968 US civil aircraft equipment and environment test standard was published as RTCA (Radio Technical Commission for Aeronautics) DO138. In 1975 EUROCAE (European Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments) published fist recommendation taking in to account ISO/TC 20/SC1 & SC5. USA DO138 suppressed old document. After 1980 DO160/ED14 has been adopted and is still in force today. In case of small men-driven electric-gasoline hybrid rotorcraf a family of standards EN 55011 and EN 55032 must be taken into account for radiated and conducted emissions. In accordance with European regulation [10]. Directive 2014/53/EU [11] should apply to unmanned aircraft that are not subject to certification and are not intended to be operated only on frequencies allocated by the Radio Regulations of the International Telecommunication Union for protected aeronautical use, if they intentionally emit and/or receive electromagnetic waves for the purpose of radio communication and/or radiodetermination at frequencies below 3 000 GHz.

Directive 2014/30/EU [12]. should apply to unmanned aircraft that are not subject to certification and are not intended to be operated only on frequencies allocated by the Radio Regulations of the International Telecommunication Union for protected aeronautical use, if they do not fall within the scope of Directive 2014/53/EU.

EMC tests

To demonstrate compliance with limits for emissions and immunity to interference two types of tests should be conducted:

Ground tests are conducted with rotorcraft engines and generators running, and with all electrical, electronics and radio navigation equipment operating at full assigned frequency spectrum. The normally running equipment should not exceed interference limits applicable to any other system. Because small rotorcrafts are designed to operate in dense urban and building infrastructure a typical 30 m distance between aircraft and other systems should be reduced to 3 meters from outside infrastructure and 1 meter specified in ED14 [13] for internal electronics and inside electronic bay.

Flight tests are conducted with all equipment that normally running at flight and applicable EMC parameters must comply with the relevant EMC standards.

Booth measurements are similar but because measurements may be done in different conditions and environment two types of measurements are used:

Quasi peak versus peak measurements

Difference in measurement bandwidth in EN and ED14 is shown in Table 1.

TABLE 1. FREQUENCY BANDS AND MEASUREMENT BANDWIDTH

FREQUENCY BANDS

Frequency Bands	EN	ED14
0.15 – 30 MHz	9 kHz	1 kHz
30 – 400 MHz	120 kHz	10 kHz
400 – 1000 MHz	120 kHz	100 kHz
1000 – 6000 MHz	1 MHz	1 MHz

In practice, the interference measured in this frequency range could be a mixture of all types, including narrow band, impulsive and broadband noise, with impulsive and broadband noise more likely to be encountered at lower frequencies. The commonly used distances for EN are 30 metres, 10 metres and 3metres. The ED14 aeronautical standard specifies a distance of 1 metre. The EN deal with electromagnetic compatibility between several apparatus not necessarily installed in close proximity. These are measured at distances between 3 metres to 30 metres on open area test sites on a nonconductive pad but over a ground plane.

2.1.1 Radiated emissions

To demonstrate compliance with the EMC Directive, the electromagnetic emission characteristics must be in accordance with those specified in the EN 61000 -6-4 “Generic Emission limits for the industrial environment”.This generic emission standard generalizes the limits existing in the product family standards EN 55011 and EN 55032 for nonintended RF emitters industrial environment (Group 1, class A equipment).

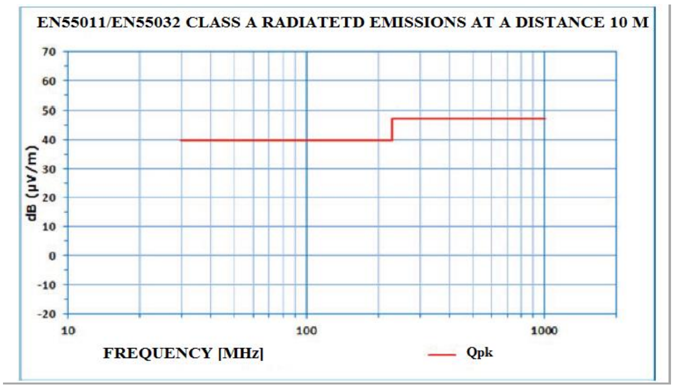

Fig. 2. European Norm EN 61000-6-4 (EN 55011, 55032) – radiated emissions

For a measurement distance of 3 m, the norms for the respective frequency sub-bands are 10.5 dB higher. We are interested in the emission limits from an aircraft but only have the emission limits of each electronic box which is embodied within the aircraft. Therefore, the assessment of the electromagnetic compatibility of the rotocraft shall take into account the cumulative effects of the emissions of each piece of equipment.

2.1.2 Conducted emission on the power supply

The EN conducted emission limits are given in EN 61000-6-4, based on the product family standards EN 55011 and EN 55032. The only possible electrical link between the aircraft and other external system is, on ground, connection to external power supply. This power is supplied to the aircraft by fixed or mobile installation. This power supply is providing a 115V/400 Hz current specific for aircraft. The aircraft is never directly connected to the industrial or public power supply network. Therefore the conducted emission of an aircraft through this link will have no impact on the external world. It is not an external EMC issue and as such, no extra requirement is needed. If we consider the aircraft as a single apparatus, all the aircraft electrical equipment could be functioning when the aircraft is plugged to its power supply and every piece of equipment emit the conducted emission in compliance with the limit specified in the Fig. 3.

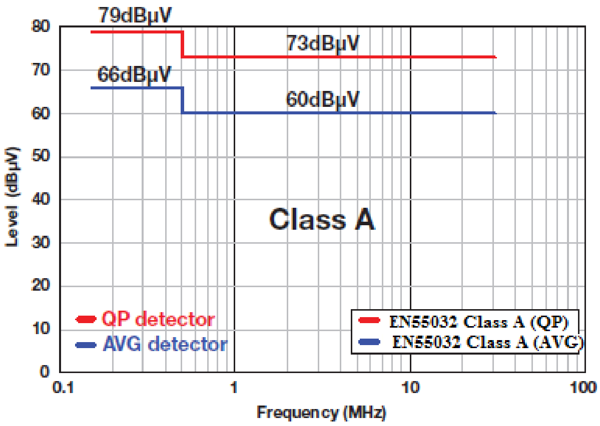

Fig. 3. European Norm EN 61000-6-4 (EN55032) – conducted emissions, mains port

The limits specified in the EN55011 for Group 1 equipment are the same.

2.1.3 Pulsed electromagnetic interference

Typical Characteristics of Pulsed EMI is given in Table 2.

2.2 Transient problems

Lightnings, electrostatic discharge and inductive switching transients have large magnitude (>100V to >1000V). These transient voltages can be reduced in significant factor by design, but can't be entirely removed and they result in short data communication disruption. Some well known methods can be used to avoid significant noise levels including: twisted pair cabling (magnetic induction is reduced by -60dB) with shielding (-30dB), balanced isolated design reject common mode -40dB, coaxial cabling (for RF equipment) or fiber optics (susceptible only on lightnings).

TABLE 2. TYPICAL CHARACTERISTICS OF PULSED EMI

	ESD	EFT	Surge
Waveform	See the next page		
Feature	Superfast rise time	Fast rise time, repetitive pulses, and box-car integration	Relatively slower rise time, large energy concentrator
Rise time	less than 1 ns	~ 5 ns	µs
Energe	low (mJ)	medium (mJ)	high (J)
Duration	ns	ns, and repeating	ms
Peak voltage (into high impedance)	up to about 15 kV	kV	several kV
Peak current (into low impedance)	medium (A)	low (A)	high (kA)
Sources	accumulation of static electricity	activation of gaseous discharge, make / break of electrical circuits	lightning, power switching

3. Lightning strike protection

An ordinary metal aircraft is hit by lightning once or twice a year, because entire surface of most passenger and cargo aircraft are built from aluminum the flash seamlessly crosses the structure causing no significant damage except at the point of direct contact [*DOT/FAA/AR-04/13 Office of Aviation Research Washington, DC 20591 General Aviation Lightning Strike Report and Protection Level Study, August 2004 Final Report, U.S. Department of Transportation Federal Aviation Administration].

Fig. 4. Metal expanded mesh - damaged.

In cases where the aircraft is made of carbon or fiberglass, which does not conduct or is difficult to conduct electrical current, direct lightning strikes an electric current of about 200000 amps, passing through the entire structure of the aircraft, finding the path with the lowest resistance causing direct and indirect effects on the aircraft structure and on-board electrical and electronic equipment. In most cases direct effect cause vaporization of resin around the strike area and may lead to possible burn of entire structure Fig. 4.

The indirect effects is associated with the induction of transient voltages which can damage or destroy unprotected and unshielded electrical and electronic systems of the aircraft. Approximately 20% of unprotected aircraft that have no any type of lightning protection reported major electrical failure compared to 3% of protected planes. Corresponding problems are covered by ACJ 29.610 (Lightning and Static Electricity Protection - Interpretative Material and Acceptable Means of Compliance). JAR 27 [*Joint Aviation Requirements JAR–27 Small Rotorcraft, Amendment 6 December 2007] covers the small rotorcrafts of maximum weights of 2730 kg that can be applicable for multirotor drones as it is:

- **JAR25X899** Electrical Bonding and Protection Against Lightning and Static Electricity (ACJ 25X899)
- **JAR 25.581** Lightning Protection
- **JAR 25.953** Fuel System Lightening Protection

There are not many usable ways to fight against these problems. Traditionally aircraft designers are using different types of lamination of the entire structure with aluminum foils, or directly incorporation of aluminum or cooper mesh to the aircraft structure. In mass practice two types of meshes are used: woven and micro expanded mesh

[*Martin Gagné Daniel Therriaul, Lightning strike protection of composites, Progress in Aerospace Sciences, Volume 64, January 2014, Pages 1-16, https://doi.org/10.1016/j.paerosci.2013.07.002].

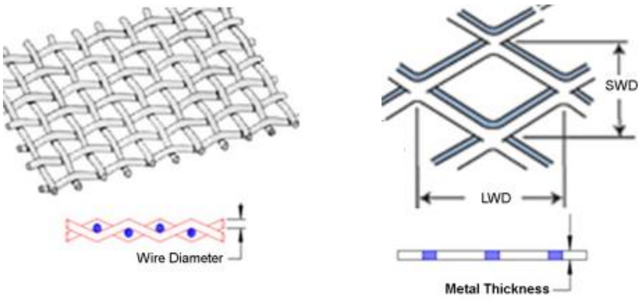

Fig. 5. Metal mesh types: woven (typical thickness is 3 times diameter of wire) and expanded (less than non expanded thickness and have better molding properties on curved surfaces)

There are some new designs that use especially conductive painting, but this protection layer should be placed in clear and computer controlled environments because if we apply less of the necessary paint the electric conductivity will not be sufficient, in other case the weight of the coating will seriously increase. In case of powerful electrical drones prepared to operate in dense urban arias lightning strike danger can't be escaped so the use of expanded aluminum foil mesh inside ducked propeller and entire body of a drone seems to be an easier construction procedure. The major effort should be taken to a conductive path between different joint bolts; a proper protection for the passenger should be made. The use of new generation metallized fabrics and fibers is not a good option because it needs specialized procedures during fiber plastic creation and its price.

III. Conclusion

Testing and certification can minimize the risk of noncompliance and product liability. Radiated emission limit of an aircraft in the frequency band of radio communication and navigation system, have to be in conformance with the EN limit. Aircraft manufacturer and equipment manufacturer must take the necessary measures so that the equipment does not emit above a level that would cause interference to radio receiving equipment (e.g. navigation and communication systems). There are several trends that will affect the future potential for aircraft system electromagnetic interference. These trends are:

a) Proliferation of handheld computing, communication and entertainment electronics, which will include RF voice and data transmission, RF local area network interfaces imbedded in devices, and faster clock and data rates.

b) More comprehensive lighting protection on aircraft systems.

c) Transition to more sophisticated, higher frequency aircraft RF communication, navigation and surveillance systems, and decommissioning earlier-generation RF communication and navigation systems.

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