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Conceptual Design of the Low-Cost Environmental Temperature Test Chamber System

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Unmanned robots being remotely controlled or autonomous are spread worldwide and used in different purposes. Inhabited robots are brought very close to users and accessibility to these tools is very high, moreover, at very low costs. Regardless to emphasize the increasing popularity of these robots. However, any robot system being electrically driven and controlled has bottleneck in the amount of the electrical energy stored aboard in the battery packs. In other words, due to limited amount of the electrical energy available special issues related to use energy best way with maximum effectiveness are needed and considered. Additionally, the battery management system is needed to control the processes of the discharge and the charge ensuring technical data and parameters set by the manufacturer. This paper addresses robot applications in regions out of the calculated when special environmental testing is needed to confirm battery pack technical data. Among those of the environmental tests required the temperature test is in the focus of attention. The main idea and purpose of this paper is to set up new concept of the low-cost environmental temperature test chamber, to define its technical parameters and other properties needed for its preliminary design and prototype manufacturing.

Keywords: environmental temperature test and control, conceptual design, battery pack, UAV/UAS, UGV

Introduction

Environmental testing is in the focus of attention of the scientists and engineers since many decades. Environmental tests carried out for analysis of behaviour of materials, mechanical, electrical and electronic systems have extremely high level of importance. This kind of system or material analysis allows modelling how the environmental conditions like temperature, humidity, air density, moisture, pressure, e-smog etc. affect properties of the system or materials being subjected to thorough analysis and inspection.

Unmanned vehicles like unmanned aerial vehicle (UAV), unmanned ground vehicles (UGV), unmanned underwater vehicles (UUV), and unmanned surface vehicles (USV) gained more and more attention in the past decade due to advantages shown and proven in their in-situ tests. Such inhabited vehicles require different forms of the energy available aboard, among those the widely spread electrical energy harvested and stored in on-board batteries. Unmanned vehicles often lean on and use electrical propulsion system due to their advantages.

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Moreover, the on-board sensorics, controllers, computers, the communication links and finally the telemetry also require electrical energy. The amount of electrical energy stored in battery packs must be considered and calculated when to plan any kind of the robot mission ensuring both successful robot missions and safe return to home.

Recent days there is a global trend to bring closer as it is possible to the users robots listed above and does not matter their nature. Unmanned robots are widely used in several kinds of both governmental (like military applications, police applications, firefighter applications, border guard applications, different inspection applications etc.) and non-governmental (industrial applications, precise agriculture applications, construction industry applications, safety and security applications, film industry applications, hobby and entertainment applications etc.) purposes.

There are numerous COTS-offered UAVs are available on the market when the UAV buyer and user has to select between the offered UAV platforms not going into deep details with system technical parameters. Such approach often reflects the UAV type selection as a budgeting problem skipping to discuss system technical data regarding the circumstances robots will operate inside. However, any underestimation of the importance of such technical data evaluation and decision making might lead to drastic reduction in system properties like operation time, or operation range threatening the overall functionality of the robot system used.

Furthermore, UGVs are often considered and applied in 3D (Dirty-Dull-Dangerous) missions like industrial catastrophes, natural disasters etc., when any human action represents threat to the health and to the life of people, at all.

The impetus for this paper was the emerging need for small unmanned aircraft (UAs) applied in several different missions being not limited to good delivery in smart cities, cargo delivery, precise agriculture applications.

This paper addresses the challenge of the battery pack test and selection for the newly designed UAVs and UGVs in terms of being subjected to environmental temperature test. Leaning on references different operation scenarios of the unmanned aerial and unmanned ground vehicles will be fabricated, and the operation environment both for the UAVs and UGVs will be identified. Regarding recent diversity of the UAVs, authors will limit research to the small UAVs and UGVs applied in different purposes at different locations worldwide. Concerning UAVs the small category representatives will be subjected to discussions and further evaluations. The basic concept of the environmental temperature test chamber will be laid down. Finally, technical data and design specification parameters for a brand-new environmental temperature test chamber will be derived to test battery packs used in different kinds of inhabited robots.

1. Related works

Lefcourt A.M. et al. in their early work discussed the design of the large environmental chamber used for test of the gaseous emissions in agricultural facilities. Authors gave specifications for the chamber housing, controllers, supply and exhaust fans, and the airflow itself. [1]

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Cole, O. et al. presented the battery test chamber design defining basic steps in design process, like conceptual design, embodiment design. Further Cole et al. introduced the detailed test chamber design procedure. Ezike, S. C. et al. presented the design of the low-cost environmental test chamber built for testing different materials. Jung et al. discussed the problems of the optimal battery pack design used aboard of the delivery UAVs . [2] [3] [4]

Boukorberine, M.N et al. addressed the UAVs power system and energy management system design introducing different UAV solutions like hybrid architecture of the UAV electrical system based upon fuel cell, chemical battery and the supercapacitor. The temperature test chamber design is thoroughly depicted by Zhang et al., Ashara et al. , and Mensah et al. . Moreover, Zhang et al. has been used the MPC technique to control test chamber internal temperature. Ashara et al. addressed the temperature control of the test chamber using the fan speed control system. Mensah, K. et al. introduced test chamber able to vary, control and test both temperature and humidity simultaneously. [5] [6] [7] [8] [9]

The UAV battery pack design and selection are thoroughly analysed and introduced by Zwol V., and by several Internet web references [10-16].

The military facilities, mission equipment and gear, as the main rule, are subjected to more severe environmental conditions than any non-military ones. Thus, for normal functionality and proper reliability in their design phase they must be thoroughly tested. For testing airborne electronic and associated equipment following environmental tests are required: temperature/altitude test, vibration test, shock test, humidity test, salt fog test, explosion test, sand and dust test, fungus test, and finally, temperature shock test. [17]

The climatic environmental conditions were thoroughly analysed and parameter variations were introduced for different continents worldwide with rigorous classification. The methodology of the climatic environmental tests is given in military standard. The environmental tests required were extended to the following ones: high temperature, low temperature, thermal shock, solar radiation, humid heat, immersion, mould growth, salt fog, rain/watertightness, icing, low pressure, sand and dust, contamination by fluids, freeze/thaw, explosive atmosphere, temperature/humidity/altitude, vibration/temperature/altitude, acidic atmosphere. [18] [19]

The ADS-71-SP aeronautical design standard deals with environmental airworthiness and qualification requirements for electronics, avionics and mission equipment installed on army aircraft. [20]

2. Problem formulation

The small UGVs and UAVs are widely applied recently in numerous applications. More and more hobbyists spend their entertainment time with running vehicles designed and built by different approaches just to have fun. Such non-governmental private purpose robot applications are very popular ensuring satisfaction of the robot owners. On the contrary, in governmental robot applications either being military or a non-military one there is a predefined and motivating goal to reach a given purpose and functionality, like public transport control, air pollution control, border control, migration control, firefighter purposes, good delivery, postal delivery, natural disaster relief etc.

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The UGV is a vehicle being non-habited and serving many different tasks like industrial production support, logistic support, good delivery etc. Regarding the class of the unmanned aircraft (UA) it is crucial to design the on-board electrical energy supply system able to supply users with electrical energy flying in the entire flight envelope. Additionally, it is important to organize UAV flight when minimum flight conditions are met. Occasionally, some less-trained hobby UA operator might not consider the environmental climatic conditions, which may lead to the abortion of the flight mission. Moreover, this negligence might lead to emergency landing, when the only goal is to land the UA safely.

Regardless of the propulsion system of the small UA it requires electrical energy aboard to supply the communication system, telemetry systems, sensors and controllers with electrical energy. The COTS UAs available on the market for free sale have properly designed and airworthiness certified on-board electrical systems with technical data provided by the manufacturer for given environmental and climate minimums. It is well-known that any degradation in climate minimums (e.g. temperature) might drastically degrade technical parameters (i.e. flight time, flight radius, flight range) of the UAV.

Secondly, in the average lifetime of any UAV it might happen that types of the battery packs used as recommended ones are out of the production, and new battery packs must be implemented. However, in common public general use new types of the batteries rarely tested by the UAV users. Commonly, the battery packs can be used by different vehicles run in fully different climatic and meteorological conditions degrading capabilities and technical data of the batteries and battery packs, too.

The goal of the authors is to identify environmental meteorological conditions for UAVs used in hobby purposes with the aim to define environmental conditions used in design of the temperature test chamber. Additionally, flight scenarios and different flight missions for small UAVs will be fabricated to be able to model electrical loads on UAV's battery packs.

3. Environmental worldwide climatic categories

The environmental testing domain includes several kinds like natural, induced, constructed and conflicts. Further, authors will focus only on natural climate tests. Leaning on data gained by several thousands of world meteorological land stations and measured from 1983-2001 worldwide, climatic categories has been identified as they are depicted in Figure 1, Figure 2 and Figure 3. The climatic categories, their properties and main data are tabulated in Table 1. [21] [22] [23]

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Climatic categories	Meteorological Conditions		Applies to
	Temperature (ºC)	Relative Humidity (%)	
'A1': Extreme hot, dry	(+32 ÷ +49)	(8 ÷ 3)	North Africa, Western Australia, Middle East, Central Asia, South Western USA, Mexico
'A2': Hot dry	(+30 ÷ +44)	(44 ÷ 14)	Australia, Middle East, Central Asia, India, North Africa, South USA, North Mexico, South American Continent, Southern part of Europe
'A3': Intermediate	(+28 ÷ +39)	(78 ÷ 43)	Europe, Canada, Northern USA, Australia
'B1': Wet warm (7 days)	+24	100	Congo, Amazon Basin, South East Asia, Madagascar, Caribbean Islands
'B1': Wet warm (358 days)	(+23 ÷ +32)	(88 ÷ 66)	
'B2': Hot warm	(+26 ÷ +35)	(100 ÷ 74)	Northern Australia, Gulf of Mexico, Eastern China
'B3': Humid hot costal desert	(+31 ÷ +41)	(88 ÷ 59)	Read Sea, Persian Gulf
'C0': Mild cold	(−6 ÷ −19)	Tending to saturation	Western Europe, South East Australia, New Zealand,
'C1': Intermediate cold	(−21 ÷ −32)		Central Europe, Japan, Central USA
'C2': Cold	(−37 ÷ −46)		Northern Europe, Scandinavia, Canada, Tibet, Russia
'C3': Severe cold	−51		North America, Greenland, Siberia
'C4': Extreme cold	−57		

Table 1. Worldwide climatic categories

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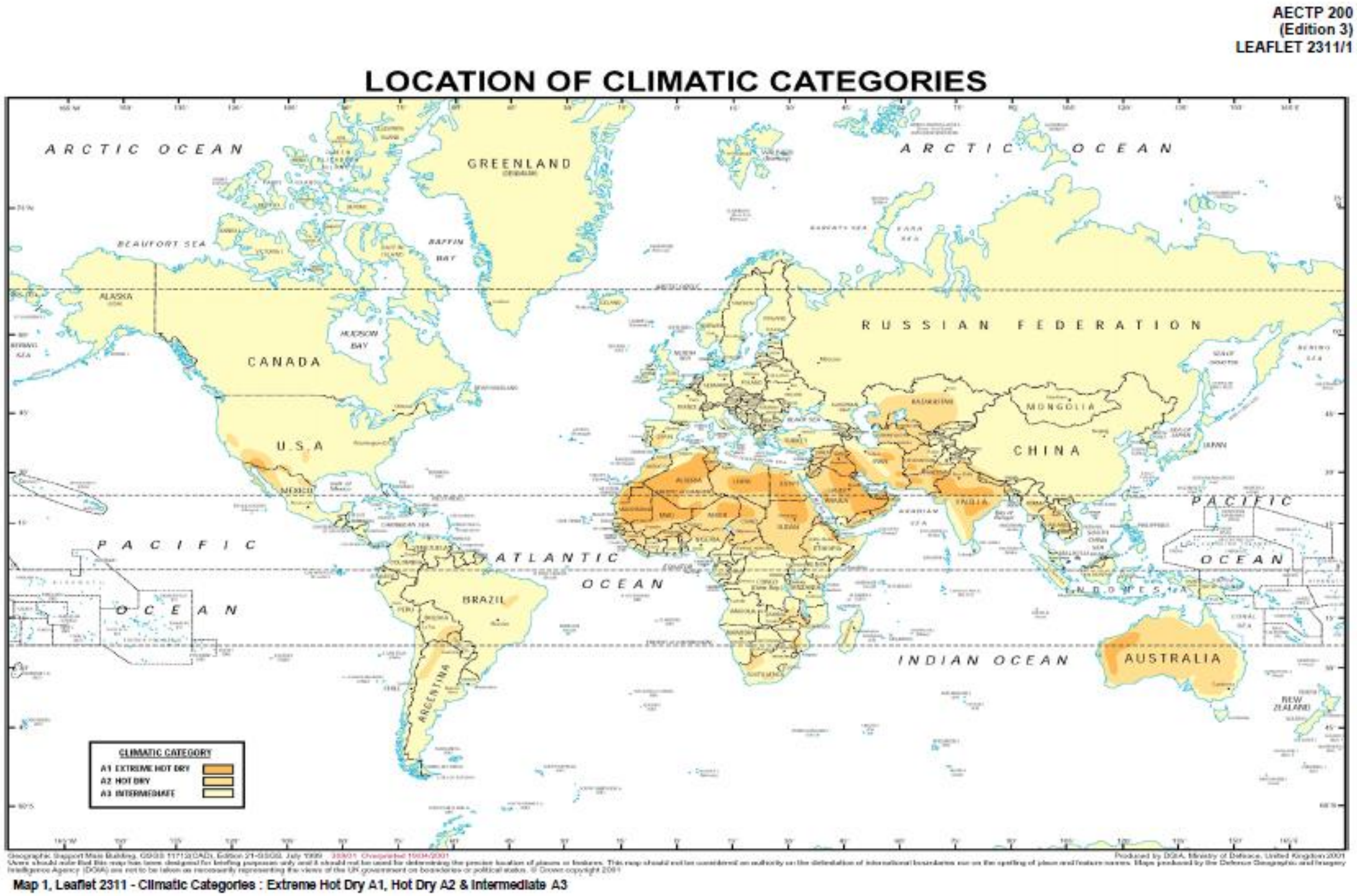

Figure 1. Climatic 'A' Categories (High Temperature) [24]

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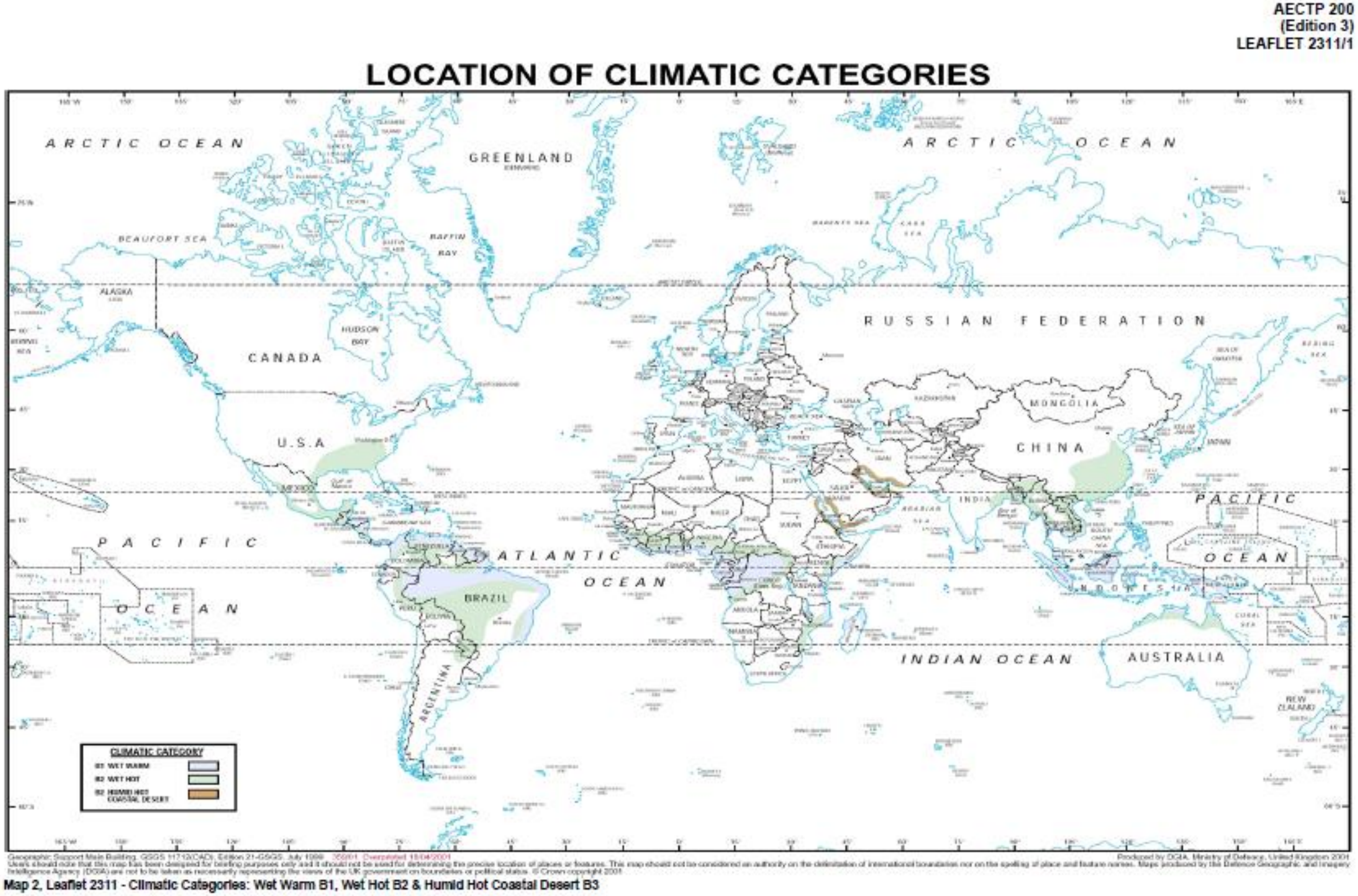

Figure 2. Climatic 'B' Categories (Humidity) [25]

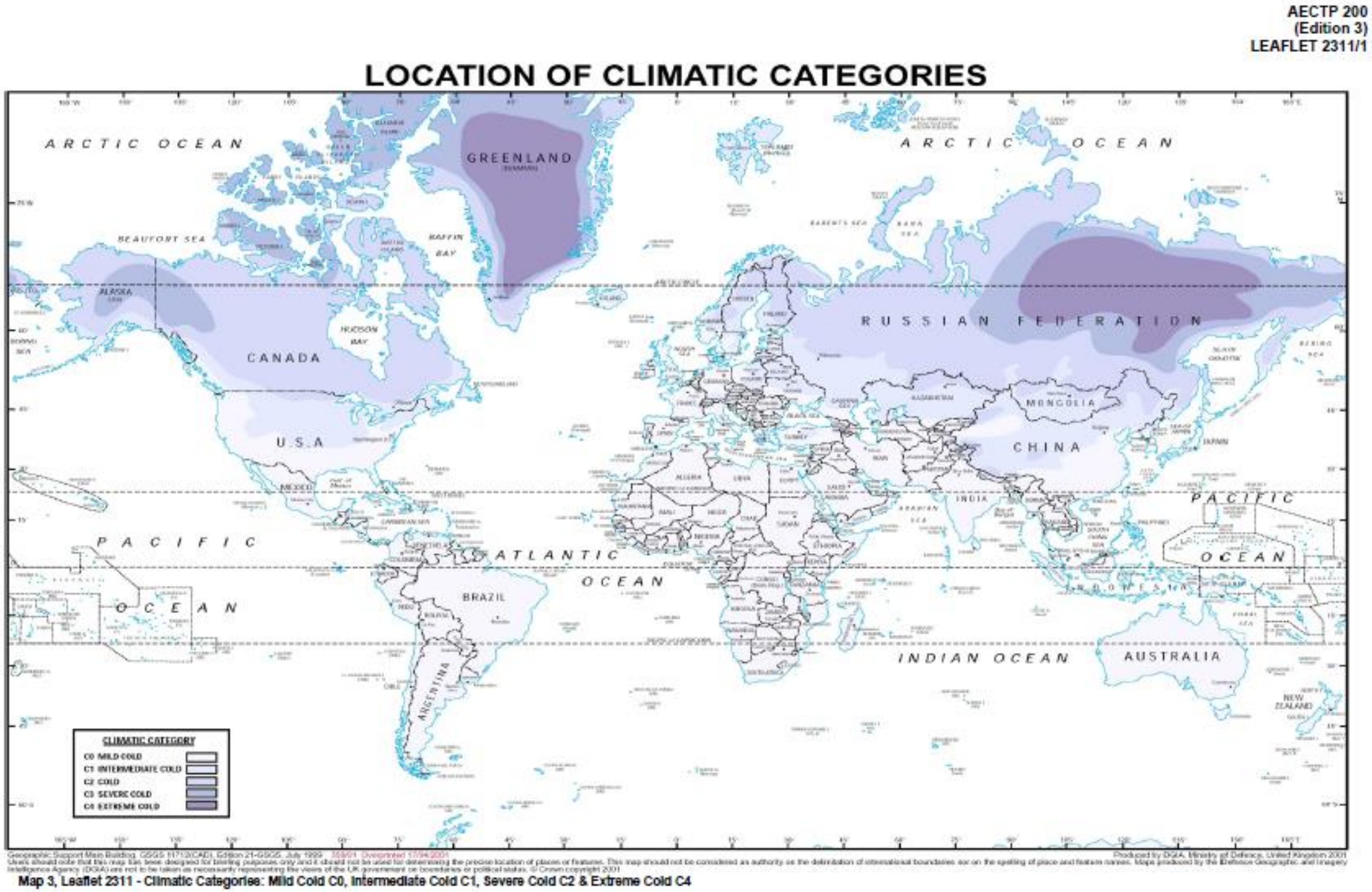

Figure 3. Climatic 'C' Categories (Low Temperature) [26]

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From Figures 1, 2 and 3, and from Table 1 it is easy to see that meteorological conditions like temperature and humidity might vary in a very large scale. Leaning on data compiled into Table 1 Hungary is dedicated to 'A1' (intermediate, (28 ÷ 39) ºC) and to the 'C1' (intermediate, (−21 ÷ −32) ºC) climate categories. Thus, the ambient temperature range might vary between (−32 ÷ +39) ºC measured at the ground level.

Considering the data acquisition time range of 1983-2001 introduced before, one must doubt about reliability of the data available and still not updated. Consequently, the temperature range defined for any country must be subjected to thorough review leaning on data from the past two decades of the 21st century.

Namely, the worst cases must be identified both for the high and low temperature ranges. Using data given for the UAV flight temperature range is set for the worst case UAV flight scenarios with expanded temperature range of (−39 ÷ +47) ºC. The UAS airworthiness full qualification environmental test requirements mostly focusing on climatic tests are thoroughly detailed. [27] [28] [29]

4. UAV Flight Mission Scenarios

The UAV is a technique widely used in different flight missions and purposes like good delivery, medicine and medical equipment delivery, postal delivery, pipeline monitoring, firefighter, police and disaster relief purposes, safeguarding, movie industry, and although in hobby purposes. In military missions they widely used both in combat (e.g. A/A, A/G, A/S) and in non-combat (e.g. reconnaissance, patrolling etc.) missions.

From our point of view and our mission, there is no mismatch between flight missions. The only goal is to identify meteorological flight minimums at which UAV battery packs must keep their potential and ability to supply users with electrical energy not threatening the entire flight mission execution.

The small UAV – due to their propulsion systems' properties – has limited flight performance and limited flight envelope, too (Figure 4.)

Trainer 60 SUAV *Ultrasick-40 UAV*

Figure 4. Small UAVs used in hobby purposes (Accessed at www.google.com on 15 May 2021.).

Regarding latest EASA regulations they might be flown lower than 120m in the UAS 'Open' operations category. This concerns only those operators and remote pilots flying their UAV in this 'open' category

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[23]. In 'Specific' and in 'Certified' categories of the UAV operations the altitude limit can be eliminated. However, the UAV flight envelope is still limited and bounded by the UAV propulsion system performances. Thus, flight envelope of the small UAV being considered is as follows:

$$H_{max} = 1000\ m,\ v_{max} = 50\ m/s. \quad (1)$$

The vertical thermal gradient of the lower atmosphere is -6ºC/1km, approximately. Consequently, the climatic temperature test chamber test range must be selected to consider ambient temperature at given height of the UAV flight. Thus, the expanded temperature range is (−45 ÷ +47) ºC.

In spite of the wide range of the small UAV applications authors will consider further only the hobby and entertainment purpose applications. Thus, this statement yields to drastic limitation of the UAV flight envelope defined above to be:

$$H_{max} = 100\ m,\ v_{max} = 50\ m/s, \quad (2)$$

The environmental temperature is supposed to be limited with the following range:

$$-15°C \le T \le +50°C. \quad (3)$$

Additionally, weather conditions for the flights are considered in-line with the hobby operators expectations and wish like good visibility, very small winds, proper air pressure and no precipitations are allowed. It is supposed that in the flight envelope determined before the UAV executes free flight manoeuvres serving development of the flight skills of the UA users with further improvement in their ground handling skills.

Regardless to emphasize that the UAV requires electrical energy aboard to supply sensors, controllers, telemetry and the radio remote control, too. Recently there are many battery types available for use aboard of UAVs. Thus, making difference between batteries leaning on the data harvested to test and to identify their technical parameters leaning on tests organized especially for this purpose is a crucial point both for the flight maintenance and ground handling.

5. UGV Mission Scenarios

UGVs are very popular platform and tools to carry heavy loads in production, to carry passengers in the transportations. Moreover, in governmental military missions they widely used in reconnaissance missions, in counter insurgency missions and also in demining tasks, too. Further authors will limit their discussions to the hobby UGV applications when the only goal of the users is to entertain themselves and the audience, too. Figure 5 depicts few RC car models applied by the hobbyist in different circumstances in different scenarios.

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On-road clear racing *Off-road dirty racing* *Off-road clean racing*

Figure 5. Small UGVs used in hobby purposes (Accessed at www.google.com on 15 May 2021.).

By the common sense, climatic conditions and limits for the UGVs being remotely controlled are as follows:

$$-10°C \le T \le +50°C. \quad (4)$$

Additionally, weather conditions for the missions are considered in-line with the hobby operators expectations and wish like good visibility, proper air pressure, and few precipitations (small rains creating mud) are allowed.

It is supposed that the UGV executes free and high loaded manoeuvres (e.g. race on asphalt or concrete) serving development of the skills of the UGV users with further improvement in their ground handling skills. Additionally, the model UGV can be tested for its survivability in a severely sludge terrain roughness, additionally giving an opportunity for the drivers to improve their manual skills in car driving.

The small UGVs own electrical drives to move the model car. Further, these model cars require RC telecommunication system for transmission of the command signals. In some model car applications, the telemetry system is used to broadcast the image captured by the on-board camera, and such technical abilities of the car also require electrical energy, which is mostly stored in batteries. Amount of the electrical energy remaining for the model car missions is driving and informing the driver about mission feasibility, and, in case of necessity, the driver can terminate the mission of the vehicle.

Summing up main conclusions of the previous chapters we can underline that source of the electrical energy like batteries are key elements and their recent technical status and predicted status are very important questions requiring thorough measurement and data evaluation after.

6. Test Chamber Conceptual Design

As it was discussed before, authors will subject batteries and battery packs used aboard UAVs and UGVs to environmental temperature test. For this purpose, authors will design a temperature test chamber via following concept and main idea:

1) Volume of the test chamber: the volume of the test chamber shall be such that any item (battery) under the temperature test will not interfere with the heat generation and maintenance system elements. Thus, regarding a standardized size of a LiPO COTS-battery used in model vehicles, the test chamber size is recommended to be selected for 300mm*300mm*400mm, as the minimum. If the battery pack is planned to be tested the chamber size is modified to that of 500mm*500mm*600mm.
2) Heat source: the heat source of the test chamber shall be located such that radiant heat will not hit directly the test item unless this is a matter of the measurement. Heat source itself is a heating unit using resistive element to generate heat and a ventilator to dissipate this heat amount inside the chamber fast and proper way. The rate of change of the heat increase inside the chamber is 0,5°C/s, with maximum 1 s of the dead time.

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3) Location of the temperature sensors: temperature sensors utilized are thermistors, due to their temperature ranges and high level of sensitivities. The thermistor must be located centralized where possible, and must be shielded from direct heat both from heating element and the test element, too. The temperature sensor must be selected for the operating temperature range of -15°C≤T≤+50°C.
4) The cooling system: the cooling system shall be able to reduce temperature inside the test chamber aggressively although able to model rapid changes in the test chamber temperature. The cooling device must be able to reduce the test chamber temperature with rate of 0,1°C/s.

The test conditions unless otherwise specified are the standard ambient conditions, as they are listed below:

1) ambient temperature: -23°C±10°C;
2) ambient air relative humidity: (50%÷40%);
3) atmospheric pressure: 725 +50/-115 mm of mercury (Hgmm).

The test conditions inside the test chamber shall have following allowable tolerances:

1) temperature drift: ΔT=±1,4°C at the sensor location. Unless specified otherwise the test chamber temperature stabilization system will have been attained if and only if when the test item considered to have the longest thermal lag does not change more than 2°C per hour.
2) temperature gradient: at any cross-sectional area occupied by the test item shall not exceed 0,3°C;
3) ambient air relative humidity drift: +5% - 0%;
4) atmospheric pressure drift: 5%, or ±1,5 mm of mercury (Hgmm);
5) vibration level drift: ±10% (if it is defined and considered);
6) vibration frequency drift: ±2% (if it is defined and considered).

Leaning on data, conditions and criteria formulated above one might design test equipment able to test batteries or battery packs in different simulated ambient environmental conditions. Authors will limit themselves to temperature test, however, understanding and not downplaying importance of other meteorological and climatic issues being omitted in this study.

7. Results, Discussions, Closing Remarks, Future Work, and Outlook

This paper addressed the concept and basic idea of the conceptual design of the low-cost temperature test chamber leading to several technical parameter and data will have been used in detailed preliminary design targeting a prototype test chamber system. The reachable standards used in the conceptual design were mostly military standards, due to their more complex feature and more rigorous content than other standards openly available.

The test chamber is planned to be equipped with data measurement and data acquisition system able to sense, measure, store and evaluate data harvested from the test item, which might be batteries and battery packs.

The test item (i.e. batteries or battery packs) shall have an external electrical load system discharging the batteries tested for voltage drops. The external load system shall imitate how the vehicle drives and other users of the electrical energy will finally decrease the battery voltage level. Thus, the voltage level measurement might serve purpose of the optimal use of the energy preventing deep discharges leading to less lifecycle of the batteries.

Future work is dedicated to design test chamber with the original temperature range found ensuring more precise imitation of the ambient conditions inside the temperature test chamber.

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References

[1] Lefcourt, A. M., Buell, B., Tasch, U.: Large Environmental Chamber: Design and Operating Characteristics. *Applied Engineering in Agriculture*, 2001, 17, pp (691-701), DOI: 10.13031/2013.6915.

[2] Zhang, E.; Yuan, H.; Fu, J.; Jiang, X.; Hu, D. The design of temperature control system of test chamber based on the predictive control algorithm. *Proceedings of the Fourth International Conference on Instrumentation and Measurement, Computer, Communication, and Control*, Harbin, China, 18–20 September 2014.

[3] Ashara, G.S.; Vyas, D.S. Design, and simulation of temperature control of chamber based on automatic fan speed control. *Proceedings of the National Conference on Emerging Trends in Computer, Electrical & Electronics* (ETCEE-2015), Rajkot, Gujara, India, 14 March 2015.

[4] Mensah, K.; Choi, J.M. Energy Consumption and Stability Investigation of Constant Temperature and Humidity Test Chamber. *Int. J. Air-Cond. Refrig*. 2017, 25, 1750010.

[5] Van Zwol, J. Design Essentials: for UAVs and Drones, Batteries are included. 2017. https://www.machinedesign.com/mechanical-motion-systems/article/21835356/design-essentials-for-uavs-and-drones-batteries-are-included (Accessed on 11 March 2021.)

[6] Jung, S., Jeong, H. *Optimal Battery Pack Design for the Delivery UAV*. Journal of the Korea Convergence Society, Vol. 8. No. 6, pp. 219-226, 2017. https://doi.org/10.15207/JKCS.2017.8.6.219.

DOI: 10.21791/IJEMS.2022.3.8.

[7] Sabastine Chinedu Ezike, Aderemi Babatunde Alabi; Amarachukwu Nneka Ossai; Adebayo Olaniyi Aina: A Low-Cost Temperature-Controlled Chamber Fabricated for Materials Testing. *MDPI Desings*, 2018, 2, 25; DOI:10.3390/designs2030025.

[8] Cole, O., Purdy, N., Happ, J. "Battery Test Chamber" (2018). *Honors Research Projects*. 656. http://ideaexchange.uakron.edu/honors_research_projects/656 (Accessed on 11 May 2021).

[9] Boukoberine, M.N., Zhou, Z., Benbouzid, M. *A Critical Review on Unmanned Aerial Vehicles Power Supply and Energy Management: Solutions, Strategies, and Prospects*. 2019, https://www.sciencedirect.com/science/article/pii/S0306261919315107 (Accessed on 11 May 2021.)

[10] https://www.grepow.com/page/uav-battery.html (Accessed on 11 March 2021).

[11] https://www.amicell.co.il/uav-drone-battery-packs/ (Accessed on 11 March 2021).

[12] https://www.eaglepicher.com/markets/aviation/unmanned-aerial-vehicles/ (Accessed on 11 March 2021).

[13] https://uavfpvbattery.com/ (Accessed on 11 March 2021).

[14] https://www.custompower.com/markets-served/unmanned-aerial-vehicle/ (Accessed on 11 March 2021).

[15] https://www.kokam.com/module-aviation-uav/ (Accessed on 11 March 2021).

[16] https://www.genstattu.com/tattu-uav-battery.html/ (Accessed on 11 March 2021).

[17] MIL-STD-810H. Environmental Engineering Considerations and Laboratory Tests. Department of Defense Test Method Standard. Department of Defense, USA, 2019 (Accessed at www.everyspec.com on 11 March 2021).

[18] MIL-T-5422F(AS) Military Specification: Testing, Environmental, Airborne Electronic and Associated Equipment. Naval Air Systems Command, Department of the Navy, USA, 1971 (Accessed at www.everyspec.com on 11 March 2021).

[19] NATO STANAG 4370 Environmental Testing - AECTP (Allied Environmental Conditions and Test Publications). AECTP 200: Environmental Conditions, MoD, USA, 2006 (Accessed at www.everyspec.com on 11 March 2021).

[20] NATO STANAG 4370 Environmental Testing – AECTP (Allied Environmental Conditions and Test Publications). AECTP 300: Climatic Environmental Tests, MoD, USA, 2006 (Accessed at www.everyspec.com on 11 March 2021).

[21] ADS-71-SP. Aeronautical Design Standard. Standard Practice for the Environmental Airworthiness and Qualification Requirements for Electronics, Avionics, and Mission Equipment Installed on Army Aircraft. Department of Defense, USA, 2009 (Accessed at www.everyspec.com on 11 March 2021).

[22] https://hu.wikipedia.org/wiki/Magyarország_hőmérékleti_rekordjainak_listája (Accessed on 12 May 2021).

[23] https://www.easa.europa.eu/document-library/regulations/commission-implementing-regulation-eu-2019947 (Accessed on 12 May 2021).