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Medium Size UAV as Test Platform for New Technologies

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Abstract

Aerospace seeks constant optimization and innovation. To introduce these advances, first new technologies have to be developed and tested, which requires suitable test equipment and work resources. One of the possible ways to do it efficiently, is to utilize UAV platform as a testbed. This paper describes manufacturing of such a platform in flying wing configuration and its capabilities. A variety of new technologies, that can be investigated on the platform are discussed, including alternative propulsion systems, new avionics solutions, and new aerodynamic devices.

Keywords: UAV, test platform, new technologies, flying wing

1. Introduction

Creating and testing new technologies in aerospace is a natural process. Trying to push development beyond the current state of the art to make aircraft even more functional and greener. Communication and transport of goods are among basic human needs. While today's community is already used to travel at an affordable ticket price, air transport needs to grow constantly. Due to the recent popularity of UAV, new areas of use for the airborne equipment are becoming regular. For example, already common areas of usage are aerial photography, pollution sensing, terrain recognition, situational control from the air, inspection of the pipeline and packages delivery. On the other hand, all this increased activity has impact on the natural environment regarding air communication safety, pollution, and noise. These are well known challenges to address, but its importance rises with this increased activity.

Using UAV platforms may be a good solution to introduce safely and efficiently new technologies. It gives opportunity to conduct tests cost-effectively of new devices in real life conditions. Moreover, new UAV technology itself is often the target for the testing and later for commercialization.

This paper describes creation of such a platform and discusses in the following paragraphs the potential of this solution. All kinds of new technologies have to be constantly improved and tested, e.g.: alternative propulsion systems, new avionics solutions, new aerodynamic devices, as that will become near future.

2. Test Platform UAV description

Developed and fabricated UAV test platform is shown on Figure 1. The UAV is designed as the flying wing configuration and was developed specifically to achieve excellent handling qualities and dynamic stability properties [1]. Obtaining good flying qualities for an unconventional configuration was possible thanks to the application of MDO methods with the use of dynamic stability constraints [2]. The aircraft has wingspan of 4.3m, it can take up to 10kg of payload with MTOW of 50kg, and has the design cruise speed of 25m/s. Great performance enables it to fly over 24h with range of 2000km. It has modular configuration where the center body (fuselage) can be easily exchanged for another one with different cargo configuration. Already built aircraft has three exchangeable center bodies equipped with three types of propulsion systems: piston engine, hybrid (fuel-electric) and jet engine. The following paragraphs present variety of different tests possible to make on the platform.

Figure 1 – UAV test platform.

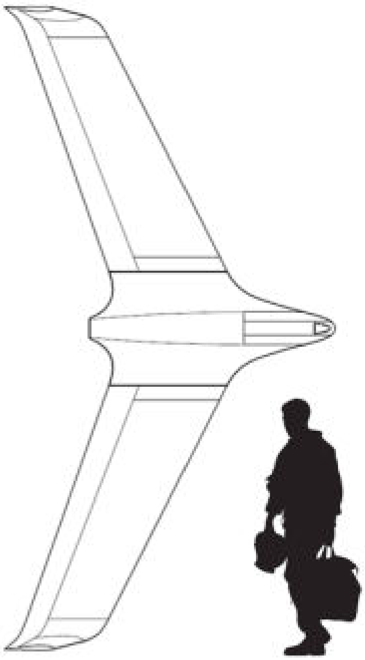

Figure 2 – UAV test platform layout.

3. Alternative Propulsion Systems

Propulsion systems need advancements to make them even more efficient, less pollutant and noisy. Electric propulsion seems to be promising because of no pollution and its relative simplicity. Power supply still remains challenging for the aircrafts with this type of propulsion. However, alternative sources of power supply can be proposed: batteries made with new technologies, hydrogen fuel cells, photovoltaic cells and hybrid engines solutions. Modular structure of the designed UAV, with exchangeable center body (fuselage), supports efficient testing of different propulsion systems.

3.1 Power Sources

Different power sources have their own advantages and disadvantages. To obtain best performance engineers seek for alternative power sources. Electric propulsion seems to be one of the most promising [3][4][5]. It's clean and efficient, except that current batteries weigh is much heavier than fossil fuels, due to their lower energy density. The extension of this concept is implementation of photovoltaic cells, which may provide unlimited power supply [6]. Such aircraft potentially could fly endlessly, assuming batteries capacity is big enough to fly over night in the 24h cycles. Wider capabilities come with the consequence of even more additional weigh, leaving less space for the payload. Another power source is hydrogen [7][8][9][10]. It has high energy density but occupies large volume, which generate the need for large tanks. Hydrogen in the gaseous phase is also very explosive and dangerous. All promising technologies related to power storage still demand farther development. To test them in real conditions technology testing platforms are needed. Middle size UAV proves to be a very good solution.

3.2 Engines and Motors

The modular design of the UAV test platform allows the interchangeable use of three types of propulsion: piston engine, hybrid (fuel-electric) and jet engine Figure 3. This makes it possible to optimize the aircraft's performance for different types of missions.

Figure 3 – UAV alternative propulsion systems.

Using a conventional piston engine in an unmanned aircraft is so far, the most proven solution. Despite the technological revolution taking place in the field of propulsion, piston engines still remain the best choice for a number of applications and demonstrate a great potential. UAV with internal combustion engine propulsion systems mainly use standard aviation fuels. The relatively high volumetric energy content of these fuels along with their wide range of operating conditions offers significant weight savings over gaseous fuels [11] and energy storage in the form of batteries.

Due to the growing demand for creating environmentally friendly solutions, the development of zero-emission or reduced-emission powertrains is important. An example of such a solution is a hybrid (fuel-electric) propulsion. The development of hybrid drive technology in recent years, especially in the automotive field, has proven the great potential of the use of hybrid engines. UAV used for civilian and military missions could benefit from the same technology [12]. This type of system is more efficient than conventional internal combustion engine, allowing for longer flight range and lowered emissions. At the same time, it is easier to install it in an aircraft originally designed to use a piston engine, than to install it in one designed for all-electric system. In a hybrid drive system, depending on the mode of operation, the electric motor can serve as the driving force increasing the power of the whole system, as well as a generator which recharges the batteries. During an aircraft mission, the greatest power demand is at the takeoff, which is when there is a particular need for additional power from the electric motor. During cruise well-optimized aircraft use only a small fraction of the power that the internal combustion engine is capable of generating. In this case, the excess engine power can be taken up by a generator, which simultaneously charges the batteries and, by appropriate loading, allows the internal combustion engine to run at optimum conditions. The main disadvantages of implementing a hybrid propulsion are the complexity of the system and the need to install heavy batteries as an additional power source.

Jet engine is an alternative solution in UAV propulsion compared to piston engines and its derivatives. Jet propulsion can be realized by using micro turbines. Interest in such propulsion is taken by professionals such as military institutions and research and development centers. Relatively small dimensions and high value of power makes micro turbine engines the attractive alternative for UAV propulsion [13]. Jet engines are designed for applications where the speed of the aircraft is the most important parameter. However, due to high fuel consumption, the range of an aircraft with this type of propulsion is very limited.

3.3 Propeller

Alternative propulsion systems work in different conditions then traditional piston and jet engines. Unique combination of flight conditions: altitude, flight speed, RPM, thrust to power ratio demands for new propeller types design. New solutions have to be efficient, adaptable for the all flight conditions, support the loads and weight less. Moreover, they have to be sufficiently resistant to wear, capable for maintenance and repair. To test such new designs adequate test platform is needed.

4. New Avionics Solutions

Popularity of UAV created new scenarios of usage. Technology of the image recognition matured significantly. But to develop it further new data collection from air is required. Also, alternative protocols of communication are investigated especially in urban sites where cell phone network is present. Recently attempts to utilize 5G network is taken into account. Increased air traffic also demands solutions for robust sense and avoid systems as well as integration of UAV traffic in the segregated airspace. This also calls for real world simulations and tests before incorporation into the standard flight procedures.

4.1 Image Collection and Processing

Data collection from air already has become standard UAV usage case. Automation of the process is getting mature and gives new extended possibilities. New types of electro-optical EO sensors [14] and advanced SAR radars [15] are introduced, which are capable to gather data at night in cloudy and low visibility conditions, or follow multiple observation targets. Vast amount of data is produced, which has to be processed, often in the real time to make appropriate decisions.

4.2 New Communication Systems (5G)

As more and more UAV systems are going to be deployed in the urban environment, the usage and capability of 5G wireless network can provide reliable aerial networking and safe integration of UAV into air traffic. There are as many new benefits and applications of UAV-enabled wireless networks as challenges, which have to be addressed and successfully solved.
On the one hand, the 5G platform will provide communication and networking for UAV swarms, which enables coordination of multiple vehicles, team behavior, and autonomous operation. On the other hand, UAV can enhance existing 5G network coverage, serving as moving base stations, increasing its capacity, reliability, and wireless efficiency Figure 4.

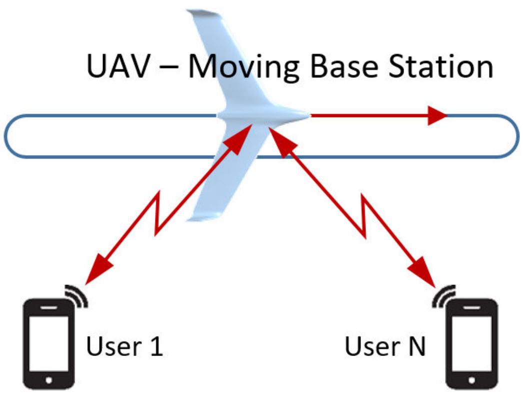

Figure 4 – UAV as moving 5G Base Station.

Based on such UAV networks, many applications can be based, such as real-time high rate video streaming, information dissemination, localization, item delivery, or flying mobile terminals, to name a few.
However, successful deployment of new capabilities of such air and ground integrated networks relies heavily on reliable tests of UAV platforms, and investigation of existing communication technologies. Many of these issues can be only tested on airborne UAV platform, such as optimal 3D placement, channel modeling, flight time constraints, performance analysis, interference management, and many others. Such necessity for real-live testing is imposed by the physical characteristic of electromagnetic waves propagations from moving aerial platforms and their changing patterns and configuration in 3D space.

4.3 Sense and Avoid Systems

To ensure conducting UAV operation in BVLOS (Beyond Visual Line of Sight) a proper set of sensors and systems must be integrated with UAV. Two types of hazards can be listed: air collision and collision with terrain/obstacles. To mitigate those hazards UAV must be able to detect, keep separation and if necessary perform an evasive maneuver. This can be only achieved by UAV with an adequate level of technology maturity as well as a sufficient size and power of the platform, which provides capabilities to power and accommodate the necessary set of sensors and systems.

To ensure the autonomous flight, the UAV platform must be equipped with autopilot. The position of UAV can be tracked by GNSS system. Moreover, the aircraft orientation and acceleration can be determine by inertial sensors. The UAV must be also equipped with pressure sensors (for speed and altitude). The terrain and obstacles can be detected by a sensors such as a classic radar, LIDAR, elector-optical sensors or infrared sensors. In case of flight in non-segregated, airspace transponder might be required. Also the UAV operator should be equipped with VHF radio to mitigate probability of collision [16]. While, example of a concept of the Detect & Avoid Ecosystem is presented in [17].

Many of potential applications of the presented UAV platform is associated with ability to perform autonomous missions. A proper equipment is an important milestone to success. The presented UAV, can be used as a test platform to carry out experiments with different sets of sensors and systems. A big volume of the payload compartment allows for an easy integration of variety sensors and if necessary installation of additional batteries. Moreover, thanks to different propulsion system that are integrated the same platform (keeping the identical size and location of the payload bay) can be used in validation of the proposed set of sensors and systems on UAV which can represents different class of UAV (in terms of propulsion system type). A fleet of proposed UAV can be utilized in testing a scenario of an operation with multiusers, including case that each UAV is equipped with different type of propulsion system.

4.4 UAV Operations in Segregated Airspace

Accessibilities and continuous grow of new applications of UAV causes, that this category of the aircraft has a significant contribution in the air traffic. Moreover, size of objects as well as the need to perform flights in BVLOS (Beyond Visual Line of Sight), is increasing probability of crash with other airspace users, including manned aircraft. Therefore, there is a high demand on unmanned traffic management (UTM) system and establishment of dedicated zones within the airspace. There are a few organizations that work on such concepts including EU [18], ICAO [19], FAA and NASA [20]. However, so far there is no implemented comprehensive regulations or traffic system that would allow for UAV operations for instance across several countries. One of the examples of a segregated airspace concept is the U-Space which is developed within EU program [21]. Currently FAA and NASA is conducting filed tests of their traffic management system [22]. But those tests are associated with flights below 400 ft.

The presented UAV can be a great platform to conduct tests on how to safely perform operations in the segregated airspace on higher flight levels and using a mid-size UAV. The presented UAV can be used to create guidance regarding certification and UAV operators training of mid-size UAV. Thanks to excellent handling qualities of the presented UAV, operators can focus on procedure of how to operate in airspace with other users without being too much distracted by controlling the aircraft itself.

While, operation in non-segregated airspace is associated with bigger risk of collision as well as is required to integrate more advanced electronics and avionics to ensure that UAV is able to perform evasive maneuvers. Moreover, in some countries flying in BVLOS in none-segregated airspace required a special permission and the platform must demonstrate a high technology maturity [23]. Due to variety of design, applications and missions creating a harmonized certification process is quite a challenge. The presented UAV can be used to create guidance regarding certification and pilots (operators) training of mid-size UAV systems.

5. New Aerodynamic Devices

Better flight efficiency and aircraft handling qualities requires development of new aerodynamic devices tailored to the specific aircraft configuration. This can be various control surfaces, airbrakes Figure 5, or winglets, see an example in Figure 6. Such aerodynamic devices [24] can be safely tested on UAV platforms without taking the risk of human health and life. Also, this could be a great opportunity for UAV operators to learn how to handle the aircraft in different configurations [25].

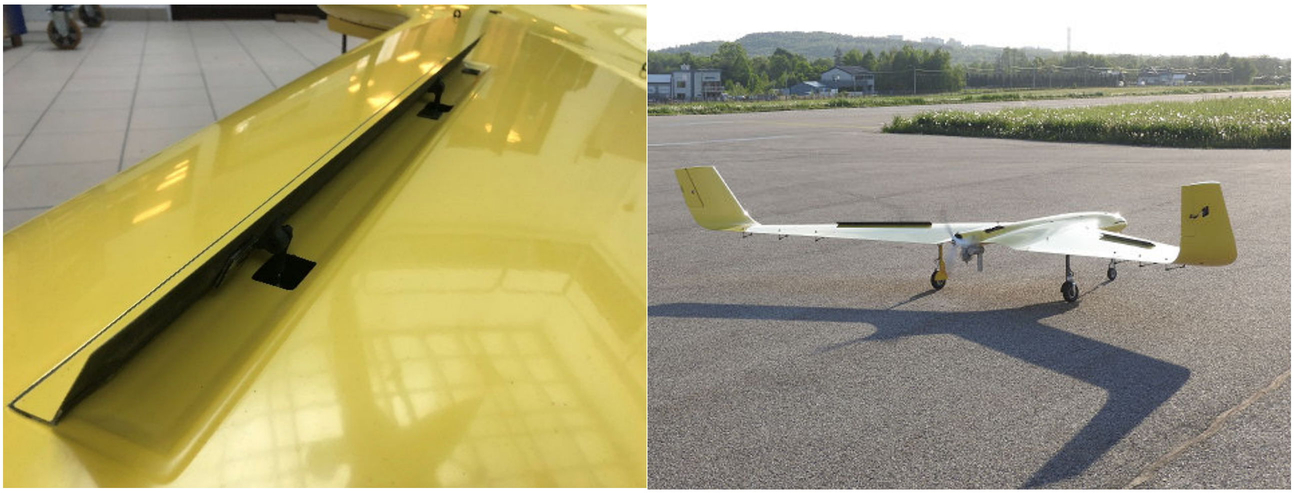

Figure 5 – The UAV airbrakes.

Figure 6 – Control surfaces and winglets tailored for aircraft's optimum performance and stability.

The presented UAV test platform has been equipped with three different aerodynamic devices to test and optimize aircraft behavior in different flight regimes:

- Multi-element elevons – test for redundancy in case of one or more servomechanism failure; simulation of different flaperons configuration; adverse yaw prevention technics; minimum aileron/elevon size determination;
- Rudders on winglets – side wind take-off and lending technics and requirements, wind gust alleviation;

- Airbrakes – ground effect reduction during landing; airbrakes deflection angle tests; wind gust alleviation;

New manufacturing technologies also can be tested on the UAV platform. Figure 7 shows pressure port, which was designed and manufactured with 3D printing technology. It allowed to easily incorporate complicated air channels into the pressure port structure. It is a single peace object. Assembly requires only to glue in three additional tubes, one for total pressure input and two for silicon tubs connecting pressure sensors. The solution is aerodynamically clean and easy to manufacture.

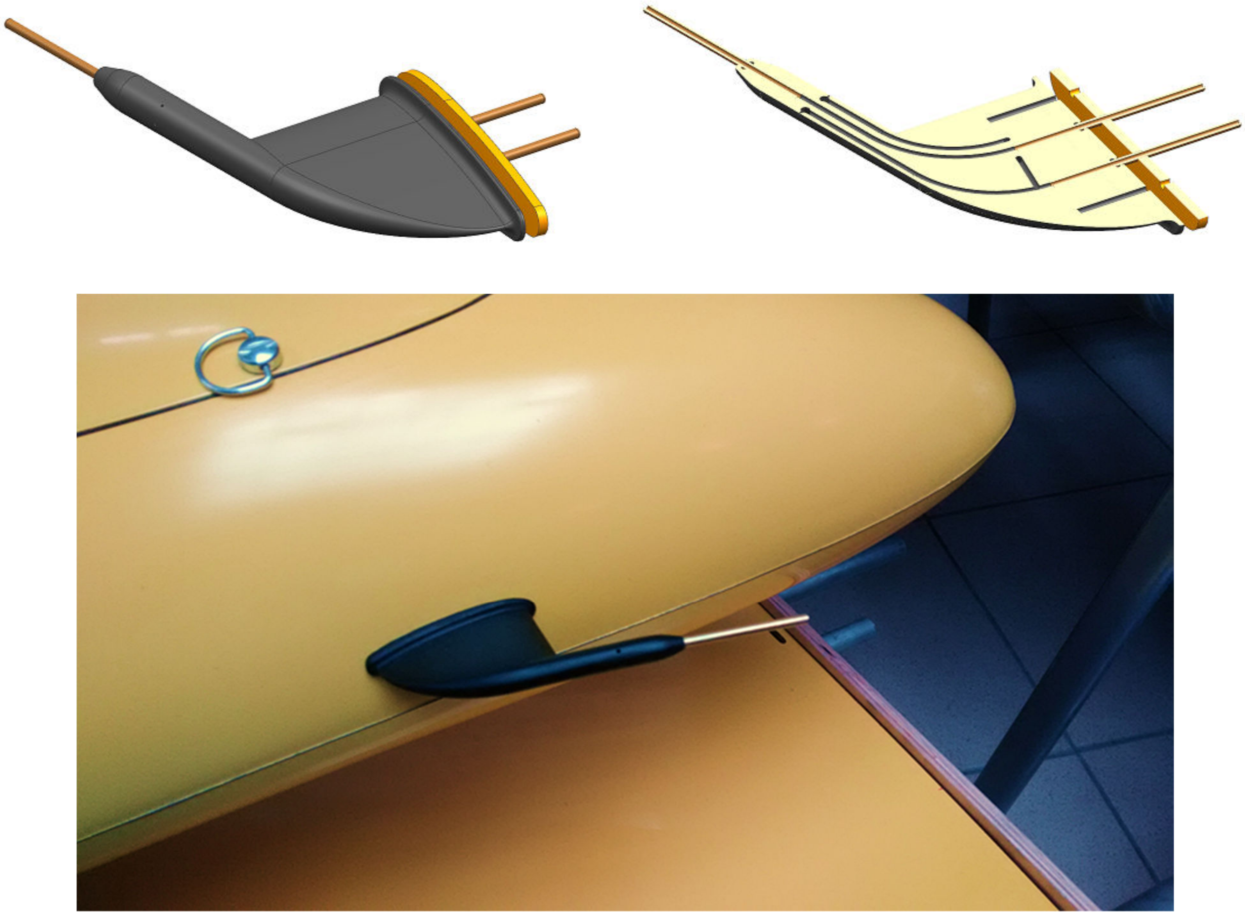

Figure 7 – Pressure port designed for 3D printing technology.

6. Summary

This paper describes concept of using medium size UAV for research purposes in aerospace sciences. The specific UAV designed and built for this purpose was presented. Possible fields of scientific investigation were introduces, like: alternative propulsion systems, new avionics systems, and new aerodynamic devices. The list of possible new technologies requiring testing was described, but is by no means closed. During the development and progression of aerospace knowledge new ideas on how to use new technologies will emerge.

7. Copyright Statement

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References

[1] Mieloszyk J., Tarnowski A., Tomaszewski A., Goetzendorf-Grabowski T. "Validation of flight dynamic stability optimization constraints with flight tests", Aerospace Science and Technology, Vol. 106, 2020, https://doi.org/10.1016/j.ast.2020.106193

[2] Mieloszyk J., Goetzendorf-Grabowski T., "Introduction of full flight dynamic stability constraints in aircraft multidisciplinary optimization", Aerospace Science and Technology: An International Journal, Vol. 68, 2017, https://doi.org/10.1016/j.ast.2017.05.024

[3] Epstein A. H., O'Flarity S. M., "Considerations for Reducing Aviation's CO2 with Aircraft Electric Propulsion", Journal of Propulsion and Power, Vol. 35, No. 3, May–June 2019, doi: 10.2514/1.B37015

[4] Mellor P. H., Heath C., Collins S., Simpson N., Bond I., "Addressing the Challenges of Lightweight Aircraft Electric Propulsion through Electrical Machines with Air-gap Windings", Proceedings of IEEE Energy Conversion Congress and Exposition – ECCE, Baltimore 2019, doi: 10.1109/ECCE.2019.8911841

[5] Del Pizzo A., Di Noia L. P., Rizzo R., "Energy Storage System Sizing for a Twin Engine Four-Seat Aircraft Electrical Propulsion", International Review of Aerospace Engineering, 10(6):315, 2017 doi: 10.15866/irease.v10i6.11841

[6] Safyanu B. D., Abdullah M. N., Omar Z., "Review of Power Device for Solar-Powered Aircraft Applications", Journal of Aerospace Technology and Management, 7 (4.25), 131-135, 2018, doi: 10.5028/jatm.v11.1077

[7] Mukhopadhaya J., Rutherford D., "Performance Analysis of Evolutionary Hydrogen-Powered Aircraft", International Council on Clean Transportation, 2022, doi: 10.13140/RG.2.2.34487.60329

[8] Petrescu R. V. V., Machín A., Fontánez K., Arango J. C., Márquez F. M., Petrescu F. I. T., "Hydrogen for aircraft power and propulsion", Volume 45, Issue 41, pp. 20740-20764, 2020, https://doi.org/10.1016/j.ijhydene.2020.05.253

[9] Zhang F., Maddy J., "Investigation of the Challenges and Issues of Hydrogen and Hydrogen Fuel Cell Applications in Aviation", TechRxiv, 2021, doi: 10.36227/techrxiv.14958057

[10]Mangold J, Silberhorn D, Moebs N, Dzikus N, Hoelzen J, Zill T, Strohmayer A., "Refueling of LH2 Aircraft — Assessment of Turnaround Procedures and Aircraft Design Implication", Energies, 15(7):2475, 2022, https://doi.org/10.3390/en15072475

[11]Depcik Ch., Cassady T., Collicott B., Burugupally C. P., Li X., Alam S. S., Arandia J. R., Hobeck J., "Comparison of lithium ion Batteries, hydrogen fueled combustion Engines, and a hydrogen fuel cell in powering a small Unmanned Aerial Vehicle", Energy Conversion and Management, Volume 207,2020,112514, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2020.112514

[12]Harmon F. G., Frank A. A., Joshi S. S., "The control of a parallel hybrid-electric propulsion system for a small unmanned aerial vehicle using a CMAC neural network,Neural Networks", Volume 18, Issues 5–6,2005, pp. 772-780, ISSN 0893-6080, doi: 10.1109/IJCNN.2005.1555856

[13]Dutczak, J., "Micro turbine engines for drones propulsion", IOP Conf. Ser.: Mater. Sci. Eng. 148 012063, 2016 doi: 10.1088/1757-899X/148/1/012063

[14]https://uavfactory.com/en/products/stabilized-payloads, visited: 30.05.2022

[15]https://www.imsar.com/, visited: 30.05.2022

[16]Clothier R. A., Williams B. P., Fulton N. L., "Structuring the safety case for unmanned aircraft system operations in non-segregated airspace", Safety Science, Volume 79, 2015, Pages 213-228, https://doi.org/10.1016/j.ssci.2015.06.007

[17]https://publicapps.caa.co.uk/docs/33/CAP%201861%20-%20BVLOS%20Fundamentals%20v2.pdf, visited: 30.05.2022

[18] https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-integrated_atm.pdf , accessed 31.05.2022

[19] https://www.icao.int/safety/UA/Documents/UTM%20Framework%20Edition%203.pdf, accessed 31.05.2022

[20] https://www.nasa.gov/utm, visited 31.05.2022

[21] https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20research%20innovation%20results.pdf, visited 31.05.2022

[22]https://www.faa.gov/uas/research_development/traffic_management/field_test/media/Presentation-UTM_Field_Test_UFT_Industry_Day.pdf, visited: 30.05.2022

[23]https://publicapps.caa.co.uk/docs/33/CAP%201861%20-%20BVLOS%20Fundamentals%20v2.pdf, visited: 30.05.2022
[24]Tarnowski A., Goetzendorf-Grabowski T., Mieloszyk J., “Morphing wing with surface discontinuity - comparative tests”, Proceedings of 31th INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES, Belo Horizonte 2018
[25]Goetzendorf-Grabowski T., Mieloszyk J., “Unconventional configurations - design and optimization”, Proceedings of 30th INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES, Deajeon 2016