ACTA TECHNICA JAURINENSIS

Vol. 16, No. 4, pp. 167-173, 2023

10.14513/actatechjaur.00717

Research Article

Challenges of the visual line of sight operations of unmanned aerial vehicles

Zsolt Sándor*

Drone Operations Hungary Ltd.
Váci utca 10., 1052 Budapest, Hungary
*e-mail: zsolt.sandor1@gmail.com

Submitted: 17/10/2023 Accepted: 03/11/2023 Published online: 24/11/2023

Abstract: The following question often emerges: what is the maximum distance during a visual line of sight (VLOS) operation between the remote pilot and the unmanned aerial vehicle (UAV)? The answer is complex, and there is no particular number because it depends on several factors that have to be jointly taken into consideration. The generally mentioned 1 km rule is not applicable for all cases. In some cases, 1 km means the absolute maximum. However, it should be considered that in certain situations, the operation can get out of the VLOS operation limits, even if obstacles and other factors do not hinder the view of the UAV.

Keywords: unmanned aerial vehicle, UAS, UAV, visibility, beyond visual line of sight operation, drone

I. INTRODUCTION

This article presents the challenges and limits of the visual line of sight and beyond visual line of sight operations of unmanned aircraft systems based on European regulations. These factors have a significant influence on the execution of a single operation. The article is based on European regulations, but some American solutions are also presented as best practices or meaningful outlooks. Moreover, the article presents the challenges of BVLOS and VLOS operations from the aviation safety viewpoint.

The topic is current and controversial due to the complex reading of the regulations and the diverse applicable solutions. The topic has not yet been researched, and there is only one empirical result, which is the basis of the German national regulation.

This is the reason why the references of the article consist of only regulations. The topic and the domain of the use of unmanned aircrafts are continuously evolving, and its basis is experience and empirical-based. Thus, the detailed scientific background of the usage is still waiting for. Some technical aspects and use-cases (even post flight evaluation of the captures images and videos) are already well-researched (like datalink communication, structural mountings, aerodynamic elements, batteries, video analysis for infrastructure monitoring, etc.) [1], [2], [3], [4], but usage-related questions regarding the fulfilment of the UAS operations are still open. This results that the standards are constantly changing based on the user experience and the accident and incident data.

In the article, the author presents the results of the regulation in a practical way and shows the difficulties of the usage. Moreover, it reveals a possible future way that may influence the usage and extend the potential technical means.

This article is considered a review of the current regulations in a technical way with operational examples, future implementation and development outlook.

Reviewing the following definitions and the connected explanations is essential for a better understanding of the subject.

- **Visual line of sight operation (VLOS):** Based on the Commission Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft, Article 2, point 7: „*means a type of UAS operation in which, the remote pilot is able to maintain continuous unaided visual contact with the unmanned aircraft, allowing the remote pilot to control the flight path of the unmanned aircraft in relation to other aircraft, people and obstacles for the purpose of avoiding collisions*” [5]. Based on the definition, it is provided that the remote pilot can see and eye the UAV and its surroundings with his/her eyes during the whole period of the operation. Compared to the EU definition, the American rule specifies much better because it defines what should the remote pilot continuously detect during the execution of the operation: current position, trajectory, course, altitude, orientation of the UAV, and affected airspace for the identification of any potential danger [6]. During the operation, the UAV cannot endanger the physical integrity of anyone, assets, or any other natural formation.

- **Beyond visual line of sight operation (BVLOS):** Based on the Commission Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft, Article 2, point 8: "*means a type of UAS operation which is not conducted in VLOS*" [5]. Based on the definition, all operations that are not able to fulfil the requirements of VLOS are BVLOS operations. BVLOS operations can be divided into more solutions, depending on the physical execution of the operation.
- **Visibility:** It is a horizontally measured distance where a landmark or an artificial non-illuminated object during daylight conditions fuse with the background but can only be recognised. To measure this, the measurer uses well-known dimension references on the spot. Measurement can be carried out at night, but the comparison is based on well-lit objects located at a known distance. In the case of UAS operations, flight visibility should be considered, which can be different occasionally than the visual range (measured on the ground). The maximum visibility can be set at 5 km, in accordance with VFR (Visual Flight Rules) flight rules. When the sight is ensured beyond this distance, this 5 km limit must be taken into account in all further calculations [7]. Further guidance is given in ED Decision 2022/002/R GM1 UAS.STS-02.020(3) [7].
- **Spatial perception limit of the UAV:** It is a horizontally measured maximum distance until the remote pilot is able to perceive the position, trajectory and orientation of the UAV. The remote pilot can control the trajectory of the UAV and detect its actual altitude and position by visual perception until the UAV reaches this distance. The precise value is determined by an empiric formula, taking the structure (fixed-wing or multicopter) and maximum characteristic dimension (diagonal wheelbase – CD measured in meters) of the UAV into consideration [8]:
  - In the case of multirotor UAV: 327 × CD + 20 meter
  - In the case of fixed-wing UAV: 490 × CD + 30 meter
- **Detection limit:** the distance until other aircraft can be visually detected and enough time is available to execute avoidance manoeuvres. This limit is always 30 per cent of the actual visual range measured on the ground [8]. During night or limited visibility, other limits can be determined experimentally.
- **VLOS limit:** The maximum allowed distance of the UAV from the remote pilot until the circumstances of VLOS can exist. This distance value is the lower value of the spatial perception limit of the UAV or the Detection limit and corresponds to a given operation.

II. Factors that have to be taken into consideration during the UAS operations

The VLOS or BVLOS feature of a single operation significantly emphasises the risk assessment and fulfilment of the operation. When the operation is fulfilled according to BVLOS, it can be conducted according to the rules of the Specific category only. The operational method like BVLOS or VLOS determines the ground risk class, the applicable risk mitigation measures and the compliance evidence that should be submitted to the civil aviation authority. Based on the presented information, the authority assesses the safe and secure fulfilment of the proposed operation – even with the assessment of the UAS-operator and the remote pilot – during the authorisation process.

The remote pilot's responsibility is to observe the rules and regulations during the operations.

1. Conditions for the Open category

In the Open category, only and exclusively VLOS operations can be conducted. It means that the conditions of the VLOS should always be satisfied. Otherwise, the remote pilot should abort the operation (UAS.OPEN.060(2)(b)). The Acceptable Means of Compliance (AMC) issued by EASA submitted to the (EU) 2019/947 regulation says that the remote pilot should control the UAV at a maximum distance from where he/she is able to detect it and determine its distance from the obstacles. If there is no obstacle, then the maximum distance of the UAV from the remote pilot is the visibility limit of the UAV (maximum distance from where it can be fully detected – spatial perception limit). In case of obstacles, this maximum distance should ensure that the remote pilot can assess the relative distance between the UAV and the obstacles.

In the Open category there is no limit for the VLOS border in the regulations. That originates from the fact that several factors jointly determine the VLOS border as a distance limit for the operations. They are the following.

Technical and environmental factors:

- Size of the UAV: the bigger, the better perceptible.

Table 1. *VLOS limits for multicopter UAVs [own edition]*

Type of UAV	diagonal wheelbase (m)	Spatial perception limit of the UAV (m)	Detection limit (m)			VLOS limit (m)		
			Visibility: 5 km	Visibility: 3 km	Visibility: 1 km	Visibility: 5 km	Visibility: 3 km	Visibility: 1 km
DJI Agras T10	2,68	896	1500	900	300	896	896	300
DJI Agras T30	2,98	994	1500	900	300	994	900	300
DJI Matrice 300	0,9	314	1500	900	300	314	314	300
DJI Mavic 3	0,38	144	1500	900	300	144	144	144
DJI Mini 3 Pro	0,25	101	1500	900	300	101	101	101
DJI Mini 2	0,21	90	1500	900	300	90	90	90
DJI Phantom 4	0,35	134	1500	900	300	134	134	134
DJI Air 2	0,3	119	1500	900	300	119	119	119

- Colour and painting of the UAV: UAV with flashy paint and pattern has better perceptibility. It must be considered that a UAV that fuses with the cloud's colour cannot be seen even from a few 10-meter distance (e.g. white or light grey UAV in cloudy weather).
- Actual weather and atmospheric effects: cloudage, cloud base, mist, dust, fog, smoke, sand, etc.
- Illuminance and its degree: sunshine, position of the sun, direction and degree of illumination, night, twilight and day conditions.
- The nature of the built or artificial environment, the location of any obstacles: Which part of the horizon is visible and to what distance?
- Trajectory, course and speed of the UAV: Is the remote pilot able to follow the movement of the UAV based on the intensity of the 3D trajectory of the UAV – considering the actual mental and physical situation of the remote pilot?
- Reference points, shadows: Are there any significant points that support the accurate position detection of the UAV?
- Visibility-enhancing equipment: They are fitted to the UAV to provide a better perception (lights, strobes, etc.).

Human factors:

- Actual physiological condition of the eye, as a sense organ: This is a continuously changing status, partly subjective, but objective standards can measure some elements. Several factors influence this, like age and momentaneous lighting effects (sensitivity and accommodative ability of the eye, etc).
- Actual mental status of the remote pilot: The tasks' complexity, the remote pilot's actual stress level and other emerging external disturbing effects may hinder the remote pilot's effective perception and decision-making.
- The routine of the remote pilot: The effective management of the tasks and perceptions may be a considerable challenge for a beginner or inexperienced remote pilot.

Based on the listed factors, it can be seen that there are situations when the VLOS limit is only a few 10 meters. It has to be considered during the flights.

Table 1. presents the maximal distance (VLOS limit) in meters (round for integers) for multicopter UAVs, considering the spatial perception limit of the UAV in case of different visibility.

Table 1 shows that it is impossible to reach the maximum 1 km distance in VLOS, even with the biggest DJI Agras T30 spraying UAV (Authorised and available in Europe).

It has to be considered if an unmanned aircraft observer (UAO) supports the remote pilot, the operation should be regarded as a VLOS operation because the UAO stands directly alongside the remote pilot, and this person assists the remote pilot in keeping the UAV in VLOS and safely conducting the flight. The UAO does not use aids to visually observe the UAV (like binoculars, electronic devices that present live video or other status stream, etc.), even correction spectacles.

2. Conditions for the Specific category

In the case of Specific category operations (and within it, even in the case of STS [5] or PDRA [5] based operations), the regulation conditions for the maximal distance of VLOS should be taken into consideration, and it has to be assessed uniquely for each operation. VLOS limits indicated in the STSs and PDRAs are absolute distances in all cases, which should not be exceeded even in optimal weather or environmental circumstances. When the Specific calculation regarding a single operation results in a lower VLOS limit than the indicated value, the maximum VLOS distance will be lower, even if the STS or PDRA has a greater limit. The reason is simple: the perception of the UAV is not provided from such a distance due to its size or other limiting conditions.

Therefore, the 1 km (or other indicated) maximum distance is just a guidance. This 1 km can be used only with proper-size UAVs and in optimal weather and environmental circumstances. The 1 km maximum distance originates from STS-02 conditions [5], [7] (UAS.STS-02.020 (6) (c)), because the UAV can move away from the nearest airspace observer only by a maximum of 1 km.

III. The specialities of beyond visual line of sight operations

When the remote pilot conducts an operation where the distance between the remote pilot and the UAV is greater than the VLOS limit, it can only be performed according to the BVLOS operational regulations.

The BVLOS operations have two types – the differentiation is analysed only from an operational viewpoint, and other legal specificities related to the operation are not part of the present analysis, like an assistant person during plant protection operations or other people who are not uninvolved in the operation, etc. [9]:

- **EVLOS - extended visual line of sight:** The operation is conducted with one or more trained airspace observers. An observer is a person who assists the remote pilot by performing unaided visual scanning of the airspace in which the unmanned aircraft is operating for any potential hazard in the air.
- **Single pilot BVLOS – conventional BVLOS**: Airspace observers and other supporting people are not supporting the operations (even the flying). A single remote pilot performs it. The remote pilot has no direct visual contact with the UAV by his / her eyes. However, the remote pilot is able to control the UAV by the help of the available technical equipment and the transmitted data and live video stream. Comprehensive safety solutions enable the single pilot operation.

During the fulfilment of the operations, the remote pilot or the UAS-operator (depending on who is responsible for the planning of the operation) should consider these factors, and based on them, he/she should determine the maximum distance to provide the VLOS (in case of EVLOS).

During the preparation phase, the maximum distance between the remote pilot and the UAV should be determined for all Specific category operations. This distance depends on the dimension and the environment in the case of VLOS operations, and in BVLOS, it depends on the applied technical mitigations and solutions. For all Specific category operations, the issued operational authorisation always determines the mode of operations (VLOS or BVLOS) and other significant conditions that influence the execution (like weather). In the case of BVLOS operation, the operator has the possibility to choose from several operational modes, which limit the maximum distance. They are the following:

- **Operations conducted by pre-defined risk assessment (PDRA):** PDRA provides a framework comprising predetermined risk mitigation measures, which must be used during the operations. The core of the solution is its simplicity. As long as the UAS-operator complies with the measures indicated in the PDRA, it is ensured that that the operations will remain under a given root risk (operations will have SAIL II, which are operations with low risk in the Specific category). Several PDRAs have been elaborated [7], and the UAS-operator can choose the best-fitting variant for his / her operations. The responsibility of the UAS-operator is to build the operational limits according to the PDRA, and it will be the basis of the requested operational authorisation. These limits define in detail the operational scenario (VLOS or BVLOS) and the maximum distance between the remote pilot and the UAV according to the size of the operational staff. PDRAs contain risk mitigation measures as general provisions. This offers flexible working conditions for the UAS-operators to elaborate their limits fitting the characteristics of their intentional operations.
- **Operations conducted by standard scenario (STS):** STSs provide UAV usage under the Specific category without operational authorisation, with the submission of an operational declaration if the operation fits to the framework defined by the regulation [5], [7] and it is performed with UAS that has the proper class identification label (C5 or C6). STSs specify the operational mode (VLOS or BVLOS) and the maximum distance between the remote pilot and the UAV in detail according to the size of the operational staff.
- **Operations conducted by specific operational risk assessment (SORA):** When the UAS-operator would like to perform an operation not covered with an STS or PDRA, then the compliance should be proved using the SORA risk assessment method. Based on the root risk of the operation, the necessary robustness levels should be satisfied by proven methods. In this

case, according to the risk assessment, the maximum distance between the remote pilot and the UAV can be determined, considering the conditions based on the root risk rating.

In the case of BVLOS operation, the physical characteristics and the result of the operation should be considered because they jointly define unambiguously the environment that is essential for the operation. From a technical aspect, the maximum range of the command and control and the video stream have to be considered beyond the performance (maximum flight time, speed, etc.) of the UAV and the vision enhancement solutions. The range is influenced by the built and the artificial environment. Previously known locations should be considered (like high voltage pipelines) where signal loss phenomena may occur and where the transmission of the command and control link becomes unreliable. When the operation should be executed alongside these infrastructures, supplementary risk mitigation measures may be required (redundant antenna system, satellite data communication system, etc.).

BVLOS operations are especially risky because the UAV and its environment are not able to be observed visually. The remote pilot only knows about it through the transmitted video stream watched on the remote controller. This fact justifies the application and availability of further safety enhancement measures.

IV. The future of the beyond visual line of sight operations

BVLOS operations will spread in the future. Detect and avoidance (DAA) systems support the operations. These systems were initially developed for conventional aircraft like transponder. However, smaller, lighter and further developed equipment with a shorter range can be used for the UASs (e.g. ADS-B in, Flarm, etc.). With the help of this equipment, the remote pilot has the possibility to detect the other airspace users (conventional aircraft or other UAVs) that may potentially danger the UAS operation at the given time. Advanced systems and solutions like remote identification can present relevant flight data about other users on the remote controller. Thus, potential incidents (collisions and near-miss events) can be avoided. It is essential that the presented flight information about the other airspace users supports the remote pilot in the correct decision-making. It is not possible that information coming from UAVs may cause unnecessary disorder for conventional airspace users (manned aviation). Therefore, only ADS-B In equipment can be used on the UAVs.

Direct remote identification function named in the EU regulations (similar to remote identification function, which is mandatory in the US) supports these goals [10], [11]. UAVs with certain class identification labels (C1, C2, C3, C5 and C6) should provide this function. The function supports safer operations even in the Open and the Specific category.

The usage area of UASs is broadening. Thus, new use cases are emerging that can be executed only with BVLOS operations. These operations are value-added solutions because conventional living labour can be replaced even in critical areas where human labour is extremely dangerous, slow or expensive. Good examples of this replacement are infrastructure monitoring at high altitudes above the ground (like high-voltage cable or transmission towers), surveying dangerous infrastructures, monitoring linear infrastructure or even the border patrol services.

Autonomous operations will be essential to effectively operate future services like drone delivery. With autonomous operations, the UAV is able to identify potential dangers and solve any kind of conflict on its own without any human intervention, modifying the course if necessary. Autonomous operations can be solved only with such DAA systems. They are capable of detecting obstacles in the air and even on the ground by the joint operation of different sensors.

BVLOS operations will be supported by the emergence and widespread of services like conventional air traffic management functions: UTM – Unmanned Aircraft System Traffic Management, and U-Space – an airspace elaborated by a combination of safety measures where specific requirements must be met by users. With these solutions, the traffic management of unmanned aerial vehicles will be available, and traffic control can also be solved. The latter can significantly reduce the potential collisions and near-miss events that originate from large-scale UAS usage.

Technical development has a significant impact on all areas of UASs. New upcoming technical solutions may trace and transform the future of BVLOS operations, and new standards and regulations may also influence the development. The emergence of increasingly powerful devices will also impact telecommunications and data transmission solutions. Thus, many innovations in telecommunications are also expected in the near future regarding UAS. The range of remote controls cannot be extended indefinitely, nor do environmental obstacles allow unlimited signal transmission, so alternative solutions are needed for longer-range BVLOS operations.

The topic should be further researched from psychology and ergonomic viewpoint because those experimentations can adequately answer operational-related questions. Based on these results, the current regulations may be evolved and cover the reality in a better (enforceable) way to comply it and value-added services can be available more reliably and effectively.

V. Summary

For the identification of the maximum distance between the remote pilot and the UAV in the case of VLOS operations, several factors should be considered jointly. The most important are the size of the UAV and the actual visibility. When the operations cannot be performed in VLOS, it must be considered a Specific category operation. This requires further risk mitigation measures by the UAS-operator that increase the safety of the operation.

Several technical solutions can increase the safety of the BVLOS operation. In the future, further technology developments that can be used even in the Open category operations will also emerge. They are the complex application of different sensors, new data transmission solutions which offer active communication, information display and collision avoidance for the users, thus enhancing aviation safety.

Maximum distance is important for safety or technical; moreover, it significantly influences the applicable operations in VLOS. The technical developments may widen the opportunities due to the emergence of much safer and more reliable mitigation measures that support the fulfilment of the UAS operations.

Author Contributions

Zs. Sándor: Conceptualization, Writing, Review and editing.

Disclosure Statement

The author declares that has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

Zsolt Sándor https://orcid.org/0000-0001-7117-9069

References

[1] Sz. Kocsis Szürke, N. Perness, et al., A Risk Assessment Technique for Energy-Efficient Drones to Support Pilots and Ensure Safe Flying, Infrastructures, (2023), 8(4):67. https://doi.org/10.3390/infrastructures8040067

[2] G. Chen, Z. Yan, et al., A Bridge Vibration Measurement Method by UAVs based on CNNs and Bayesian Optimization, Journal of Applied and Computational Mechanics, (2023) 9(3), 749-762. https://doi.org/10.22055/jacm.2022.41858.3823

[3] A. Alkamachi, E. Ercelebi,, Modelling and control of h-shaped racing quadcopter with tilting propellers. Facta Universitatis, Series: Mechanical Engineering, (2017) *15*(2), 201-215. https://doi.org/10.22190/FUME170203005A

[4] M. Banić, A. Miltenović, et al., Intelligent machine vision based railway infrastructure inspection and monitoring using uav. Facta Universitatis, Series: Mechanical Engineering, (2019) 17(3), 357-364. https://doi.org/10.22190/FUME190507041B

[5] Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, Official Journal of the European Union L 152, 62. 2019. June 11. Online: http://data.europa.eu/eli/reg_impl/2019/947/oj

[6] FAA regulation: Code of Federal Regulations. Title 14 - Aeronautics and Space, Subchapter F - Air Traffic and General Operating Rules, Part 107 - Small Unmanned Aircraft Systems, § 107.31 Visual line of sight aircraft operation.

[7] European Union Aviation Safety Agency, Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Commission Implementing Regulation (EU) 2019/947. 2022. September. Online: https://www.easa.europa.eu/downloads/110913/en

[8] Luftfahrt-Bundesamt (LBA) Guideline: Guidance for Dimensioning of Flight Geography, Contingency Volume and Ground Risk Buffer. 2023. February. Version 1.5 Online: https://www.lba.de/SharedDocs/Downloads/DE/B/B5_UAS/Leitfaden_FG_CV_GRB_eng.pdf?__blob=publicationFile&v=8

[9] Joint Decree 44/2005 (6 May 2005) FVM-GKM-KvVM on aerial work in agriculture and forestry. https://njt.hu/jogszabaly/2005-44-20-82

[10] Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, Official Journal of the European Union L 152, 62. 2019. June 11. Online:

http://data.europa.eu/eli/reg_del/2019/945/oj

[11] Direct Remote ID – Introduction to the EU reopen UAS Digital Remote ID Technical Standard. 2021. Belgium Online. Aerospace and Defence Industries Association of Europe Standardization. https://asd-stan.org/wp-content/uploads/ASD-STAN_DRI_Introduction_to_the_European_digital_RID_UAS_Standard.pdf