drones

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Correction

Correction: Mohamed et al. Gusts Encountered by Flying Vehicles in Proximity to Buildings. *Drones* 2023, *7*, 22

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Text Correction

In the original publication [1], [13] was not cited. The citations has now been inserted in Section 1, Paragraph 1 and should read:

It is well documented that aircraft of all sizes are adversely affected by turbulence and gusts; as identified by the Federal Aviation Administration (FAA) and the US Transportation Safety Board as a leading cause of accidents—costing over USD 100M p.a. [1]. Severe injuries are reported, such as those in the 2015 Air Canada flight AC088, which injured 21 passengers, including three children [2]; and 2019 Qantas Flight QF108 whereby 3 cabin staff had head and neck injuries [3]. Accidents still continue to occur with more recent ac-cidents that resulted in injured passengers [4] and even a passenger death [5]. As the size, mass and speed of aircraft decrease, the susceptibility to turbulence and gusts increases [6,7]; or in sum, due to lower wing loading [8]. Smaller general aviation aircraft and helicop-ters also tend to fly more at lower altitudes within the Atmospheric Boundary Layer (ABL) which is dominated by high turbulence intensities from ground protruding structures [7,9]. This has led to reported accidents directly relating to turbulence [10–13]. Even the tran-sition through the ABL can be detrimental to aircraft that are designed to fly at very high altitudes such as Facebook's Aquila Uncrewed Air Vehicle (UAV) and Airbus' Zephyr UAV, whereby both had fatal crashes due to turbulence and/or gusts [14,15].

In the original publication [1], [17–21] were not cited. The citations have now been inserted in Section 1, Paragraph 3 and should read:

The most relevant aspect of aviation to AAM is the operation of helicopters which also fly in urban environments, albeit less frequently and with a human pilot onboard. Landing on buildings poses a specific challenge in some cases, warranting further aerodynamic studies and field wind measurements being prudent [17]. From a vehicular design standpoint, the AAM vehicles' design and flight dynamics are different from the conventional helicopter and airplane design which warrants an exploration into novel design features and technologies that enable lower sensitivity to turbulence and precise maneuvering [1]. From a vertiport standpoint, the existing heliport infrastructure can potentially support AAM; however there is a need for purpose-built buildings (for ease of public access and to account for the autonomy of UAVs). The characterization of the flow fields for different wind conditions around vertiports is warranted, similar to those conducted for heliports [18–21]. New research is, thus, required to characterize the temporal and spatial variation in the flow fields around buildings and vertiports. This will inform vertiport design and site selection to minimize the risk imposed by the local wake of the building from affecting flight safety as well as passenger ride quality.

In the original publication [1], [80–83,86,87] were not cited. The citations have now been inserted in Section 7.4, Paragraph 1 and should read:

Considerable recent published work has considered the alleviation of gust loads on aircraft [72–76] and in some cases even harvesting it [77–79]. Severe gusts around buildings

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can pose a major challenge for flight of different vehicular scales and configurations. Smaller UAVs are more sensitive to the disturbances, however larger UAVs are still affected albeit to a lesser extent. The latter will depend on the relative magnitude and scale of a gust with respect to the aircraft's scale. Also, the UAV configuration (rotary vs fixed wing) will respond differently to the disturbances. Hybrid configurations which have a combination of lifting surfaces (i.e., fixed wing) and an array of thrusting disks (i.e., rotary wing) are well suited for close proximity flight to buildings. However, there is a spectrum of design possibilities which require careful design choices to truly alleviate the disadvantages of both fixed and rotary wing. Further research is required to identify the intrinsic aerodynamic deficiencies of these hybrid configurations and what are they particularly susceptible to. For example, fixed-wing craft will stall if flown too slow, while rotary wing craft are susceptible to the vortex ring state and weather cock stability. Some deficiencies may be resolved with hybrid configurations while others may persist or even give rise to new deficiencies especially during hover. Vehicles with large surface areas facing the wind direction (e.g., tilt wings) will experience significant attitude control and flight-path tracking challenges due to the relatively large forces generated by these surfaces. Such designs should be avoided where possible if a UAV is expected to fly at low speeds near buildings and gust-generating infrastructure. The frontal projection area of the UAV regardless of the configuration needs to be minimized most critically during proximity flight. This may be even achieved through active wing area reduction, but the structural and mechanical challenges of an airframe capable of reducing area or changing its wing planform. This design challenge is complex but not impossible. There are also other means of mitigating turbulence and gusts through the control systems [80–82], aerodynamic configuration [68,83–86], and novel sensors [66,67,87]. Counteracting such flow disturbances comes at the cost of increased weight and power demands which will affect range and battery consumption. The question then becomes, how smooth of a flight will the passenger demand? How much control will we need to give to the pilot and/or the system?

A correction has been made to Section 7.4, Paragraph 4, we delete ref [76] in the previous version and should read:

Helicopter certifications requirements rely on the presence of human pilots on board that can assess hazardous situations. Regulations for autonomous UAV operations in cities (especially large air taxis) will be different and rely on measurable numerical thresholds, which are used by the flight control system for automated decision making and planning, given there is no human-in-the-loop to make such rapid judgments.

In the original publication [1], [88–93] were not cited. The citations have now been inserted in Section 7.5, Paragraphs 1–4 and should read:

Currently, a small body of knowledge exists around specific heliport requirements that deal with the surrounding turbulence levels from nearby buildings [13,88,89]. There also exists some regulations that can be used as a basis to guide the design and location of vertiport landing infrastructure [20,89]. A turbulence criterion was introduced for helicopters to ensure safe flight is maintained [89]. The criterion sets a threshold on the standard deviation of the vertical flow velocity, which results in a high helicopter pilot workload. Mentzoni and Ertesvåg [88] later suggested the use of turbulence energy instead as a criterion, arguing its benefits over the standard deviation of vertical velocity. Similarly, a new criterion or threshold is needed for the autonomous operation of AAM vehicles, which relies on the limitations of the flight control system instead of the workload of human pilots. The results presented here have implications for vertiport design and a similar analysis can be used to identify thresholds for such a criterion.

Most of the research on building aerodynamics presented in the literature focuses on surface pressure measurements for predicting facade loadings. However, the advent of AAM requires a unique understanding of the velocity field induced by the interaction of the wind with the building on which UAVs will be operating from. Specifically, the shear layers that form and their impact on flight. A thorough characterization of the flow field for different wind directions is essential for each vertiport to be designed since each one will have a unique flow environment. Similar methods and tools, such as those used in the field of wind engineering, can be used.

Vertiport designers will need to avoid design features that generate turbulence or sharp gusts of high amplitude and of length scales that are detrimental to UAVs. A few studies explore this area [13,19,21,90]; however, more research is needed, with full-scale validation. There exists a body of knowledge on designing wind sheltering systems (such as porous fences) for road and rail vehicles which will be relevant. Similarly, building design features, such as round corners and porous deflectors near rooftops, can help reduce the sharpness of the perceived gust, which translates to a lower actuation requirement, thus providing a UAV's flight control system with more time to react and counter the flow disturbance. Another key parameter is the unobstructed air gap below the landing platform, which will also influence the severity of the shear layer by allowing more air to flow underneath the platform. The ideal height of the air gap will be different for each building since it is a function of the building's geometry. A 1.8 m minimum air gap is cited by the FAA in the Heliport Design Advisory Circular AC 150/5390-2D [91]. The document points to research published in FAA/RD-84/25 [19], but it is unclear how the 1.8 m criteria were derived. Regardless, there is enough justification for exploring a new threshold for AAM vehicles. The new US Federal Aviation Administration (FAA) guidelines for vertiport design has a small section on turbulence with high-level recommendations on using turbulence-mitigating design measures [92]. As technology matures and more research is conducted in this area, specific metrics and criterion can be included in future revisions of the guidelines providing design standards, which will need to be met. It is also strongly believed that aviation authorities should provide their own guidelines and regulations on turbulence and gust thresholds around vertiports instead of relying on existing building guidelines and regulations (e.g., [93]), which focus on reducing adverse wind effects that affect the quality and usability of outdoor spaces and pedestrian comfort. The modeling and measurements for the latter are very different from that required for AAM flight paths around the buildings from a probe placement and mesh refinement perspective.

Modelling building aerodynamics and the local flow fields can be performed using classical wind tunnel methods on scale buildings, or utilizing CFD similar to that presented here. There is a need to provision for the surrounding wind environment and its interaction with not only the vertiport structure but also neighboring structures which will have an impact on the local flow field [19] and can result in overspeed regions which are difficult to predict. An additional analysis, which can complement wind tunnel testing and CFD, is full scale measurements using airborne wind anemometers such as the one developed by Prudden, Fisher [94]. A swarm of such sensors are ideal for rapid simultaneous measurements that can map out the flow field accurately at full scale and later used for validation of CFD or comparison with scale experiments to account for any Reynolds number effects. Given the mobility of such systems, it can also be used to measure the perceived gust along the flight paths of UAVs.

Section 8 has been reworded to reflect the newly added citations and should read:

UAVs used for both delivery and human carrying systems are being introduced internationally and are intended to integrate into various civil domains. Urban and city environments provide the greatest operational challenge due to the safety considerations of operating in highly populated environments. Under even moderate winds, landing and take-off maneuvers are subjected to high levels of turbulence intensities and gusts that will impact the stability and control of these vehicles. Furthermore, the integral length scale of turbulence may be such that they are similar to the scales of UAVs; these will provide considerable control challenges in holding relatively steady flight. We are guided by existing literature on helicopter landing and take-off procedures, which is not extensive and is lacking in terms of autonomous operation. Minimization of turbulence and gusts via building or vertiport design are limited and warrant further research.

In this paper we used a CFD simulation of the ambient wind field around a nominally cuboid building in a suburban atmospheric boundary layer. Unperturbed flight paths near the building's roof were superimposed onto the simulated wind field. A possible worst-case gust for the specified wind speed and building geometry was identified when the flight path traverses the shear layer from the building's top leading edge, resulting in significant lift force variations. The analysis showed that UAVs would experience a substantial increase in angle of attack over a relatively short period of time (<1 s) as they fly through shear layer at a representative forward velocity, which can be well above typical stall angles. Due to the slow flight speeds required for landing and take-off, significant control authority of rotor systems is required to ensure safe operation due to the high disturbance effects caused by localized gusts from buildings and protruding structures. The analysis is then flowed by regulation and certification recommendations for AAM vehicles and vertiports.

CFD simulation of atmospheric flows is challenging and warrants experimental validation via collection of careful gust measurements either in a wind tunnel environment or by flying aircraft, which should be fitted with responsive anemometers capable of resolving turbulence length scales smaller than a UAV's characteristic length [94]. The resulting datasets, both computational and experimental, should be interrogated to identify two- and three-dimensional severe gusts. Subsequent work should include furthering the understanding of the transfer functions between a gust flow and the resulting aerodynamic response of the UAV, which could then be used to understand disturbances and control methods to minimize them. This paper used computational gust data to develop basic disturbance models to understand the response of a fixed wing and thrusting disk. In both instances, the effect of a gust around a cuboid building is significant and may cause significant flight perturbations that cannot be ignored. Furthermore, for larger UAV, the magnitude of corrective control required must be acknowledged and considered in the design phase when such vehicles are developed.

Correction in Acknowledgments

A correction has been made to Acknowledgments as follows:

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We added below new refs and delete one ref [76]. With these corrections, the order of some references have been adjusted accordingly.

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The authors state that the scientific conclusions are unaffected. This correction was approved by the Academic Editor. The original publication has also been updated.

Reference

1. Mohamed, A.; Marino, M.; Watkins, S.; Jaworski, J.; Jones, A. Gusts Encountered by Flying Vehicles in Proximity to Buildings. *Drones* **2023**, *7*, 22. [CrossRef]