Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 131 **2026**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2026.131.7

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Marcisz, M., Sokołowski, S. Influence of surrounding terrain morphology at Gliwice-Trynek aerodrome on flight operations based on a 3D model of aerodrome approach areas. *Scientific Journal of Silesian University of Technology. Series Transport*. 2026, **131**, 121-136. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2026.131.7

Marek MARCISZ[1], Szymon SOKOŁOWSKI[2]

INFLUENCE OF SURROUNDING TERRAIN MORPHOLOGY AT GLIWICE-TRYNEK AERODROME ON FLIGHT OPERATIONS BASED ON A 3D MODEL OF AERODROME APPROACH AREAS

Summary. In this paper, the potential applications of 3D modeling of aerodrome approach areas and their significance for the precise representation of the aerodrome environment are presented. The findings indicate that UAV photogrammetry constitutes an efficient method for monitoring adjacent areas, enabling the analysis of topography's impact on the safety and efficiency of flight operations. Integrating 3D terrain models with navigation systems enhances the situational awareness of operational personnel. Specifically, the study identified critical terrain hazards: tree stands near thresholds 08 and 10 necessitating steeper climbs and posing bird-strike risks; a Venturi effect between the southern waste-disposal site and warehouses causing wind acceleration; and a nearby water reservoir contributing to fog and solar glare. Implementing these 3D models into digital airspace management addresses these immediate threats and supports the development of autonomous UAV systems, increasing operational safety in regions with complex topography.

Keywords: UAVs, drones, photogrammetry, 3D models

[1] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Zygmunta Krasińskiego Str. 8, 40-019 Katowice, Poland. Email: marek.marcisz@polsl.pl. ORCID: https://orcid.org/0000-0002-8178-880X
[2] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Zygmunta Krasińskiego Str. 8, 40-019 Katowice, Poland. Email: szsokolowski99@gmail.com. ORCID: https://orcid.org/0009-0003-6869-7932

1. INTRODUCTION

Contemporary history demonstrates an exceptionally dynamic development of unmanned aerial vehicle (UAV) technologies, classified as emerging technologies that have significantly revolutionized numerous socio-economic sectors. Initially employed almost exclusively in military applications, UAVs are now widely used in many civilian fields, including air transport, environmental monitoring, precision agriculture, and geoinformatics.

Unmanned aerial vehicles, equipped with advanced global navigation satellite system (GNSS) navigation receivers, multispectral sensors, and high-resolution optoelectronic cameras, play a key role in modern methods of spatial data acquisition. Particular importance is attached to contemporary photogrammetry, which – by leveraging data acquired from UAVs – enables the generation of orthophotomaps and three-dimensional terrain models of high accuracy.

Modern drone-based photogrammetry, supported by the rapid development of artificial intelligence (AI) algorithms and machine learning (ML) techniques, offers the capability for near-real-time processing and analysis of imagery, resulting in a substantial acceleration and cost reduction of topographic surveys compared to traditional methods [3]. The application of these technological solutions allows for the creation of precise three-dimensional models of the geographic environment, which in turn significantly enhances the efficiency and safety of operations conducted in airspace.

The implementation of unmanned aerial vehicles in the production of maps and digital terrain models has revolutionized contemporary geoinformation techniques, offering a new standard of quality and precision in the acquisition and analysis of topographic data. In this context, the use of UAVs in aerodrome photogrammetry assumes particular significance for ensuring the safety of flight operations, as it enables the precise assessment of terrain morphology and the location of obstacles in the vicinity of aerodrome infrastructure.

The aim of the present study was to analyze the potential of unmanned aerial vehicle technology in photogrammetry, with a particular focus on terrain modeling processes and the identification of hazards to flight operation safety. The subject of the research was Gliwice-Trynek aerodrome (ICAO code: EPGL), for which a detailed photogrammetric three-dimensional model was developed. Based on this model, an analysis was conducted of the influence exerted by existing built structures and terrain relief characteristics on flight operations carried out in its vicinity. This defined scope of research made it possible to formulate answers to two principal research questions: (1) in what ways do built-environment elements and terrain morphology affect the conduct of flight operations around Gliwice-Trynek aerodrome, and (2) what potential hazards – arising from the distribution of objects and terrain configuration – may impact the safety level of these operations.

2. OUTLINE OF THE CURRENT STATE OF DRONE PHOTOGRAMMETRY AND 3D MODELING

Contemporary spatial data play a critical role across numerous economic sectors and research domains, finding application in cartography, civil and structural engineering, geoinformatics, environmental protection, and strategic spatial planning. The dynamic evolution of UAV technology has driven the adoption of innovative spatial data-acquisition methods – most notably photogrammetry and LiDAR systems – which facilitate the creation of high-resolution, three-dimensional models of terrain and built environments [1].

Photogrammetry, defined as the measurement technique that employs photographic analysis to determine the precise spatial coordinates of ground points, enables the generation of dense point clouds and detailed surface models, and – through deployment on UAV platforms – permits remote monitoring of extensive, often logistically challenging or inaccessible areas [8].

Execution of photogrammetric surveys necessitates specialized imaging hardware, including metric-grade cameras and multispectral or LiDAR sensors, together with advanced processing software and a variety of aerial platforms such as satellites, manned aircraft, and UAVs. Imagery captured at multiple flight altitudes and under varying sensor-to-surface angles undergoes rigorous digital photogrammetric workflows – comprising image matching, spatial triangulation, and bundle adjustment – to produce highly accurate three-dimensional representations of natural terrain features and anthropogenic structures. Advances in sensor miniaturization, onboard data processing, and high-performance numerical algorithms have automated much of this workflow, substantially increasing processing throughput, reducing manual intervention, and enhancing both positional accuracy and geometric fidelity of the final models.

The growing importance of UAVs in contemporary photogrammetry stems from clear operational and economic advantages over traditional aerial survey methods. By classical definition, photogrammetry involves collection of spatial information via aerial photographs – historically acquired from manned platforms – which are then processed into digital elevation models and three-dimensional object reconstructions [2]. Modern UAVs, equipped with professional-grade optical and navigation systems, enable rapid, precise, and remotely conducted data acquisition campaigns. Such capabilities not only accelerate project timelines and reduce field deployment costs but also permit surveys in hazardous or otherwise inaccessible environments. Moreover, the flexible definition of flight parameters and real-time mission adjustments allow optimization of point-cloud density and coverage, supporting production of orthophotomaps and textured 3D models for design and spatial-planning applications [9].

Advanced photogrammetric software incorporates robust triangulation algorithms, automated image-matching routines, and optimized bundle-adjustment techniques to identify and align common reference points across sequential images. The output of these integrated processes is a dense, georeferenced point cloud from which mesh models and fully textured three-dimensional representations are derived. Further automation – through normalized cross-correlation, outlier-detection routines, and machine-learning-based error-reduction methods – minimizes interpretive inaccuracies and ensures sub-pixel-level precision in reproducing fine terrain details, thereby elevating the overall quality and reliability of spatial datasets.

Selection of appropriate photogrammetric software depends on project-specific requirements such as desired accuracy thresholds, budget constraints, data-format compatibility, and interoperability with existing GIS or CAD systems. Commercially available packages offer comprehensive functionality – orthophotomap generation, point-cloud classification, mesh reconstruction, 3D visualization, and advanced spatial analysis. Modern toolsets leverage state-of-the-art photogrammetric reconstruction algorithms to convert raw imagery into fully georeferenced spatial data, applicable in environmental assessments, urban development planning, and civil infrastructure engineering. As one of the most precise modeling methodologies, photogrammetry applies rigorous principles of projective geometry and computational reconstruction to faithfully reproduce real-world object geometries from overlapping digital photographs [5].

The application of photogrammetric 3D modeling spans multiple industry domains – including engineering, architectural heritage documentation, environmental conservation, archaeology, and aviation. In the aviation sector, three-dimensional terrain and obstacle models are indispensable for detailed analysis of potential hazards surrounding aerodromes and along flight corridors. These models enable precise assessment of obstacle heights, slope gradients, and clearance envelopes – critical inputs for infrastructure design and optimization of flight paths. Furthermore, such three-dimensional reconstructions underpin high-fidelity flight simulators and pilot-training platforms, providing realistic virtual reproductions of actual terrain conditions in controlled environments, thereby significantly enhancing overall flight-operation safety [11].

3. METHOD

Gliwice-Trynek aerodrome, which is the subject of this study, operates as a public civilian aerodrome that is not subject to a formal certification procedure. The facility is situated within the Aerodrome Traffic Zone (ATZ) of Gliwice. The aerodrome operator is Upper Silesian Accelerator for Commercial Enterprises Ltd. (GAPR), while the principal infrastructure user remains the Gliwice Aero Club. Additionally, the aerodrome serves private operators and training institutions, including the Academic Training Centre for Aviation (ATO) of the Silesian University [10].

The aerodrome infrastructure is configured to accommodate small- and medium-sized general-aviation aircraft. Within its layout there are three runways: one paved concrete strip designated 08R/26L, and two grass runways corresponding to directions 08L/26R and 10/28. The aerodrome also features runway lighting, thereby enabling round-the-clock operations under appropriate procedures. Ancillary aerodrome elements include, inter alia, an aircraft apron, taxiways, hangars, administrative buildings, and aviation-fuel refueling points.

Operation intensity at EPGL is notably high, directly influencing the safety level of the flight procedures conducted. The variety of operation types and the number of aircraft present in the aerodrome's airspace demand precise coordination among air traffic controllers, flight crews, and infrastructure managers [10]. Critical phases of flight operations – such as take-offs and landings – require particular vigilance, especially when executed under conditions of elevated traffic density.

An additional risk factor comprises terrain-related obstacles located in the immediate vicinity of the aerodrome, encompassing tall buildings, overhead power lines, and other infrastructural elements. This issue is of particular importance for glider and helicopter operations, which by their nature are conducted at lower altitudes and thus are more sensitive to nearby obstructions [10].

In light of the foregoing considerations, continuous monitoring and real-time coordination of all flight operations at Gliwice-Trynek are imperative. Effective safety management relies on close collaboration between pilots, air traffic controllers, and aerodrome infrastructure administrators. These operational characteristics justify the selection of this aerodrome as the study site, for which a detailed three-dimensional spatial model was developed and a hazard analysis – arising from terrain morphology and built-environment configuration – was performed.

To fulfill the research objectives, low-altitude photogrammetry was employed using a UAV platform. The photographic data obtained constituted the basis for the generation of a digital 3D model of the surveyed area. The choice of photogrammetric software followed a market analysis of available tools, ultimately resulting in the selection of Agisoft Metashape due to its sophisticated algorithms and capabilities for generating dense point clouds, mesh models, and orthophotomaps [7].

The initial stage of the spatial-modeling procedure involved the preparation of geospatial data files delineating the boundaries of the planned UAV flight mission. For this purpose, Google Earth Pro was utilized to precisely define the photogrammetric survey area (Fig. 1).

Fig. 1. Photogrammetric flight area over Gliwice-Trynek aerodrome

In the next phase of the study, a detailed photogrammetric flight plan over the Gliwice-Trynek aerodrome area was developed. Mission preparation and execution were carried out using the dedicated DJI Pilot 2 software installed on the ground control unit of the DJI Mavic 3 Enterprise UAV. The choice of the DJI Mavic 3 Enterprise was dictated by its superior technical parameters, optimal mobility, and compact size (weighing only 915 g), which are crucial operational advantages in the highly dynamic and restricted environment of an active aerodrome. While higher-end alternatives like the DJI Matrice 300 RTK were considered, the Mavic 3 Enterprise was ultimately selected due to its immediate operational availability, circumventing the lengthy administrative procedures associated with institutional equipment and allowing for flexible scheduling aligned with the aerodrome's operational windows. Theoretically, compared to standard consumer drones, the Mavic 3 Enterprise offers a significant advantage through its 4/3 CMOS sensor and mechanical shutter, which effectively eliminate the rolling shutter effect – a critical requirement for high-resolution, distortion-free photogrammetric imaging and flight stability. The DJI Pilot 2 software was selected to ensure seamless, native compatibility with the hardware, guaranteeing reliable execution of the programmed flight grid without the integration issues occasionally encountered with third-party applications.

The survey was performed using the default settings recommended by DJI Pilot 2, which the application automatically tailored to the specifics of the planned mission, thereby guaranteeing adherence to the predetermined accuracy thresholds and spatial-imaging parameters (Fig. 2). The photogrammetric flight covered an area of 6.24 km^2 and was conducted at an altitude of 120 m AGL (Above Ground Level), achieving an optimal balance between terrain-detail fidelity and operational efficiency. The applied flight altitude of 120 m was strictly dictated by the legal constraints of the European Union Aviation Safety Agency (EASA) and national regulations, which restrict UAV operations in this category to a maximum of 120 m AGL. Operationally, this altitude provided the optimal compromise, allowing for the efficient coverage of a large area within a reasonable timeframe while maintaining a high Ground Sample Distance (GSD) sufficient for accurate 3D modeling. Regarding the built-in wide-angle camera (84° FOV), such lenses inherently introduce radial and tangential distortions that could theoretically vary with altitude. Since empirical testing at different heights was precluded by the aforementioned legal altitude limit, these optical distortions were successfully mitigated during the post-processing phase. The photogrammetric software utilizes an auto-calibration algorithm during the image alignment process (based on Brown's distortion model) to mathematically calculate and compensate for lens distortions across the dataset, ensuring high geometric accuracy regardless of the wide field of view.

The total duration of the flight campaign, including necessary technical breaks for UAV battery replacements and adjustments to comply with the current operational requirements and safety procedures in force at EPGL, amounted to approximately four hours. Throughout the operation, complete oversight of the mission and continuous assessment of air-traffic conditions in the vicinity of the aerodrome were maintained, which was essential given the dynamic nature of the operating environment and the possibility of unforeseen changes in airspace organization.

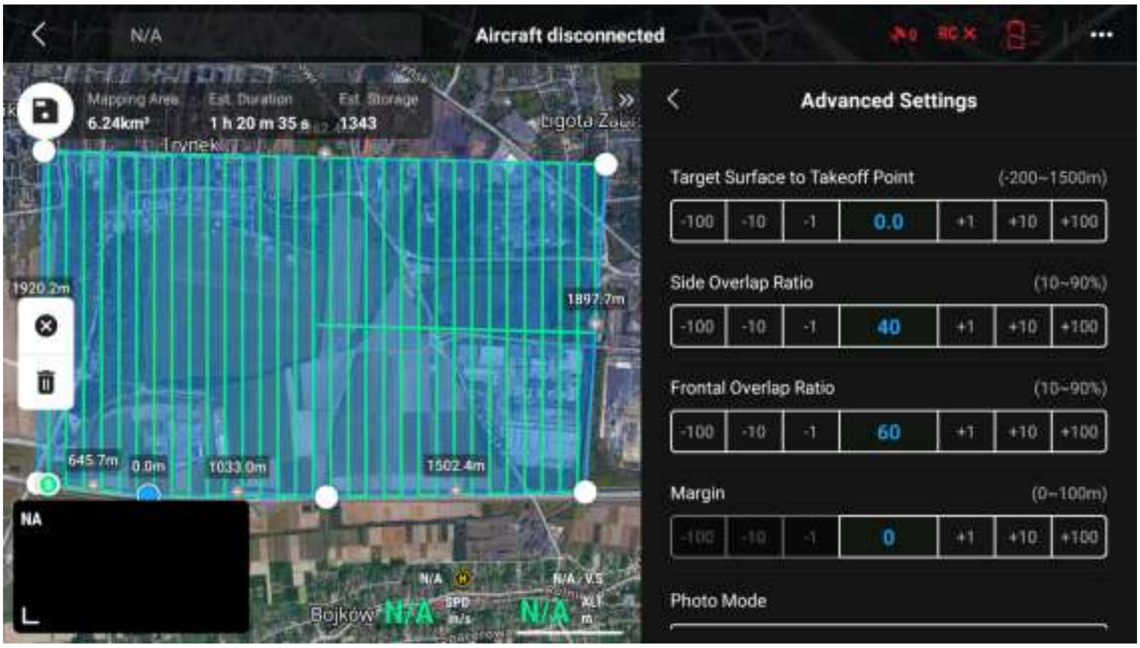

Fig. 2. Photogrammetric flight plan over Gliwice-Trynek aerodrome

The acquisition of photogrammetric data was carried out using the onboard wide-angle camera integrated into the DJI Mavic 3 Enterprise UAV (Fig. 3). During the flight campaign, a total of 1 398 high-resolution digital photographs were captured. The cumulative size of the collected imagery exceeded 10 GB.

In the next phase of the study, all photogrammetric data acquired during the UAV flight campaign were subjected to processing in Agisoft Metashape. Upon importing the entire set of high-resolution images into the software environment, a thorough initial quality assessment was conducted, during which any photographs exhibiting suboptimal exposure levels or insufficient resolution – factors that could potentially compromise the integrity of the final 3D model – were systematically excluded.

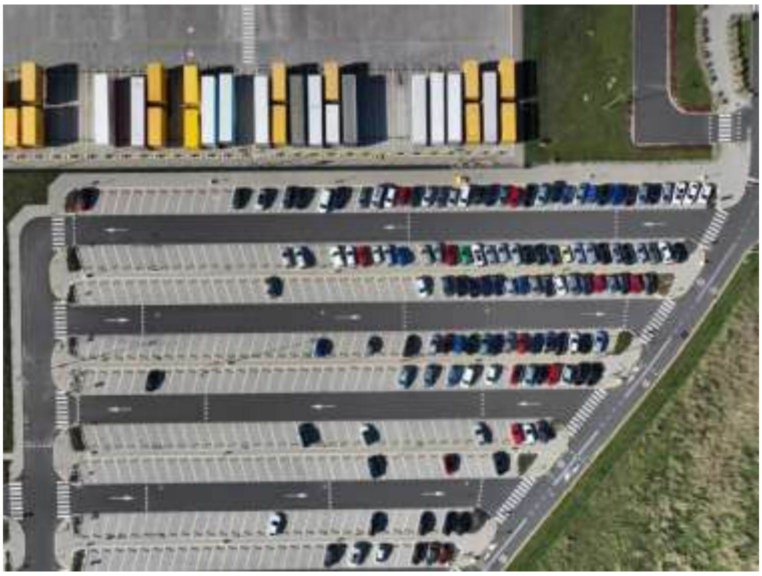

Fig. 3. Sample photograph captured during the photogrammetric flight

The first major operation within the reconstruction workflow involved the image-alignment procedure. This step successfully identified and matched 1 449 664 tie points across overlapping photographs, resulting in the creation of the so-called sparse point cloud. This preliminary point cloud serves as the foundational approximation of the spatial structure of the surveyed area.

Subsequently, the workflow progressed to the generation of a dense point cloud. Advanced photogrammetric algorithms were applied, taking into account both the internal (intrinsic) and external (extrinsic) orientation parameters of the camera. By performing precise pixel-level matching across the aligned images, these algorithms produced a highly detailed spatial representation of all visible features. The dense-cloud generation yielded a total of 424 348 298 points, thereby enabling an exceptionally accurate reconstruction of the terrain's topographic variations.

The conversion of the dense point cloud into a fully triangulated three-dimensional mesh entailed several sequential operations. First, all point clouds were co-registered and optimally aligned. Next, surface-reconstruction algorithms were applied to interpolate between points and construct the geometric framework of both natural landforms and man-made infrastructure. The resulting mesh comprises 37 million polygons, which provides a rich geometric detail suitable for both visual examination and quantitative spatial analysis of Gliwice-Trynek aerodrome and its immediate surroundings.

An evaluation of the stitching quality of the 1 398 separate images confirmed a highly successful reconstruction of the expansive aerodrome surface. The application of the 'Aggressive' depth filtering parameter effectively eliminated most outliers and noise, resulting in a cohesive and continuous mesh for the vast majority of the mapped area without significant artifacts. A notable exception, however, was the water reservoir located east of the aerodrome. Water surfaces inherently lack static tie points due to their homogeneity, reflectivity, and continuous motion. Consequently, while the visual 3D model (mesh texture) exhibited only minor visual artifacts in this area, the Digital Elevation Model (DEM) encountered processing difficulties, resulting in local topological inaccuracies over the water's surface. Despite this isolated issue, the overall geometric fidelity of the terrain and critical aerodrome infrastructure remained highly accurate and fully suitable for subsequent spatial hazard analysis.

Finally, a 2.5D Digital Elevation Model was generated from the dense point cloud. This step involved rasterizing the three-dimensional information onto a regular grid, assigning to each grid cell a specific elevation value that accurately reflects the underlying surface morphology. The completed DEM met all predefined quality and accuracy criteria, thus forming a robust basis for subsequent analyses of how local terrain characteristics may influence the safety and performance of flight operations at the study site (Fig. 4).

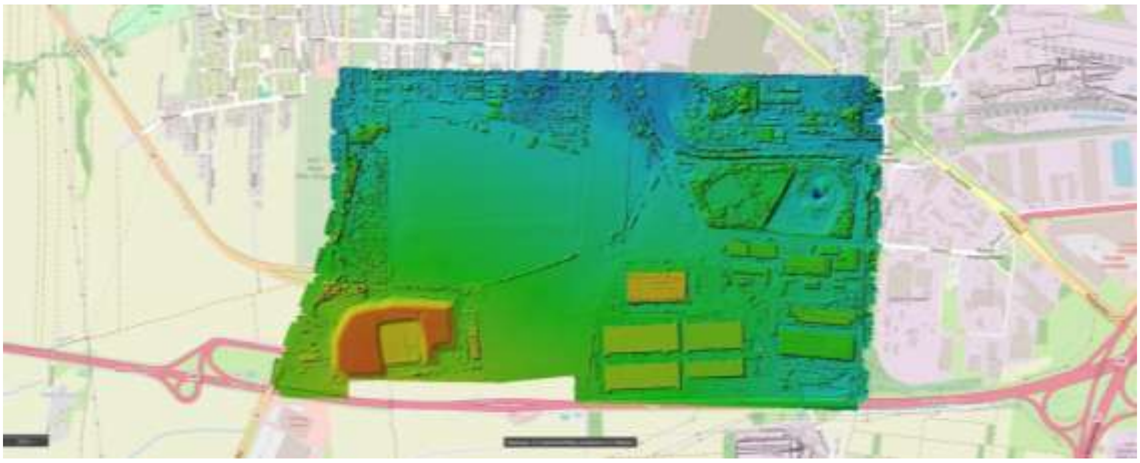

Fig. 4. Digital Elevation Model of Gliwice-Trynek aerodrome

4. RESULTS

The developed three-dimensional model of Gliwice-Trynek aerodrome and its immediate surroundings (Fig. 5) constitutes a substantial source of information on terrain obstacles and infrastructure components, all of which directly affect the safety and systematic organization of flight operations conducted at this facility.

Fig. 5. 3D model of Gliwice-Trynek aerodrome and its approach areas

The analysis of the model revealed that the aerodrome terrain is characterized by a relatively flat relief, lacking any significant natural elevations or ground-based obstacles in the immediate vicinity of the aerodrome's operational infrastructure. This morphological uniformity has important operational implications, as it enables the establishment of stable and predictable approach and departure paths, as well as the correct delineation of the aerodrome traffic circuit.

Within the surveyed area, several notable anthropogenic features were identified – residential and industrial buildings, warehouse facilities, forested zones, a waste-disposal site, and a water reservoir – all of which exert a direct or indirect influence on the planning and execution of flight operations. In the immediate surroundings of the aerodrome, structures such as buildings and masts reach heights ranging from 12.5 m to over 20 m above ground level, necessitating their inclusion in the design of approach, take-off, and missed-approach procedures. In particular, these obstacles affect minimum overflight altitudes and the permissible flight-path parameters during each phase of flight operations.

Forested areas located in close proximity to the runway complex represent an additional factor impacting flight activity. Their presence along the approach axis or runway alignment can induce localized meteorological variations – such as modifications in wind patterns, air temperature stratification, and humidity levels – which bear directly on the safety of take-off and landing operations, especially for glider and helicopter flights conducted at lower altitudes.

The waste-disposal site, situated in the southern sector of the study area, constitutes a terrain obstacle of variable height. Its exact position and elevation profile must be mandatorily accounted for when planning low-altitude flight trajectories and in the formulation of emergency procedures.

Another element affecting local operating conditions is the water reservoir located to the east of the aerodrome zone. This body of water may give rise to micro-meteorological phenomena – such as elevated air humidity and the formation of radiation fog – which can substantially reduce visibility and atmospheric stability, particularly during morning and evening hours.

Accounting for all the aforementioned environmental and infrastructural elements is essential to the correct planning and safe execution of flight operations in the Gliwice-Trynek aerodrome area. An integrated spatial analysis – based on data derived from the three-dimensional model – enables precise delineation of height-restriction zones and the adjustment of operational procedures to current terrain and environmental conditions [10].

5. DISCUSSION

Gliwice-Trynek aerodrome is situated within an area characterized by favorable terrain morphology, alongside environmental and anthropogenic features that may pose potential hazards to flight operations. Both the underlying terrain relief and the distribution of natural and man-made obstacles in the immediate vicinity of the aerodrome infrastructure are of critical importance for operational safety.

The analysis demonstrated that the aerodrome occupies predominantly flat terrain, which facilitates aerial operations by eliminating risks associated with elevation differentials. However, residential and industrial buildings, as well as technical-infrastructure elements, are located in close proximity to the runways (Fig. 6). Their elevation characteristics and spatial arrangement relative to the take-off and approach paths must therefore be duly considered within flight-operation procedures.

The spatial arrangement and distribution of built structures in the immediate proximity of critical operational zones – including runway strips, aircraft aprons, taxiways, and final approach corridors – necessitates a comprehensive spatial analysis and meticulous planning of all associated flight procedures. These edifices, by virtue of their vertical dimensions and precise siting, can restrict the usable volume of airspace, influence the establishment of minimum overflight altitudes, and alter available aerial corridors, thereby constraining the maneuverability of aircraft in the aerodrome's vicinity.

Fig. 6. Three-dimensional model of buildings on the Gliwice-Trynek aerodrome grounds

Moreover, the presence of tall buildings and other constructions generates complex aerodynamic phenomena, such as localized vortices and irregular wind currents, which exert a direct impact on flight operations during both the approach and landing phases as well as during initial climb. Such phenomena have the potential to compromise the stability of the flight path and demand heightened corrective inputs from flight crews when navigating these critical zones.

An additional operational consideration is the reduction of visual cues and overall visibility caused by the proximity of built structures. These sight-line obstructions affect not only airborne crews but also ground personnel – particularly under conditions of poor meteorological visibility, including fog, precipitation, or the onset of dusk.

Furthermore, groups of trees and contiguous forest complexes – especially those situated along the approach axes to runways 08 and 10 (Fig. 7) – pose further limitations. These natural obstacles, owing to their height and alignment relative to the runway centerlines, can impact both climb-out and approach trajectories, while also influencing local micro-meteorological conditions. In particular, they may increase the incidence of mechanical turbulence and lead to variable wind directions within the near-ground layer, thereby presenting an additional factor to be mitigated during flight-operation planning.

Fig. 7. Groups of trees on the approach to runways 08 and 10

Natural forest stands, as significant terrain obstacles, substantially restrict the available airspace immediately surrounding the aerodrome, thereby compelling flight crews to meticulously adjust both take-off and approach procedures. In particular, departures from runways 08 and 10 are affected by the presence of tall trees located just before the runway thresholds; aircraft must execute a steeper climb gradient to ensure sufficient obstacle clearance. This requirement imposes a considerable challenge for platforms with limited climb performance, as the greater the height of vegetation directly aligned with the runway centerline, the more constrained becomes the minimum safe overflight altitude, and the less latitude there is in planning both arrival and departure flight paths.

Similarly, during landing operations, these trees within the glide path force pilots to maintain a higher threshold-crossing height. This adjustment effectively reduces the available landing distance, thereby increasing the probability of runway overruns – particularly under adverse meteorological conditions such as heavy precipitation, gusting winds, or low visibility. Additionally, forest stands generate localized vortices and mechanical turbulence, most pronounced in strong wind scenarios, which can induce unexpected deviations in the flight path during the critical final approach phase. These aerodynamic disturbances are inherently difficult to forecast accurately, and their intensity depends closely on prevailing wind direction and speed.

Moreover, the presence of extensive wooded areas in proximity to the aerodrome attracts bird populations, which in turn present a serious hazard to flight safety. Bird strikes occurring at low altitudes during take-off and landing phases significantly elevate the risk of ingestion events that may damage engines or impair other vital onboard systems. To mitigate these avian hazards, it is recommended that aerodrome management implement systematic vegetation control measures – such as strategic tree trimming – and deploy dedicated bird-monitoring and deterrence systems throughout the aerodrome perimeter [6].

Finally, particular attention must be paid to the waste-disposal site and adjacent warehouse complexes located to the south of Gliwice-Trynek aerodrome. These man-made structures, by virtue of their considerable height and specific spatial arrangement, alter local aerodynamic conditions by inducing a Venturi-type effect. The constriction of airflow between closely spaced obstacles causes an increase in wind velocity alongside a corresponding drop in dynamic pressure within the resulting airflow corridor. Such localized wind acceleration can destabilize flight operations during periods of southerly winds (Fig. 8), with direct implications for both climb-out and approach trajectories. Consequently, these effects necessitate heightened procedural caution in flight-path planning and demand increased situational awareness and vigilance from flight crews when conducting operations in this sector.

The elevation model developed for the Gliwice-Trynek aerodrome (Fig. 4) clearly highlights significant elevation differences between the waste-disposal site and warehouse complexes – depicted in orange – and the level of the surrounding terrain, shown in shades of green and blue. Field measurements revealed that the height of these man-made structures is approximately 25 m above ground level.

The observed Venturi effect, manifesting as a localized acceleration of wind between tall obstacles, directly impacts flight operations – especially during the critical phases of take-off and landing. Elevated wind-stream velocities in the near-ground layer can destabilize aircraft flight paths precisely when aerodynamic susceptibility is greatest. Sudden wind-speed increases due to the Venturi effect may force flight crews to make rapid, dynamic corrections to their course and approach parameters. In practice, this can lead to runway overshoots beyond the intended touchdown zone, thereby reducing the effective runway distance available for aircraft deceleration and safe rollout [4].

Fig. 8. 3D model of Gliwice-Trynek aerodrome with marked waste-disposal site (in red) and warehouses (in blue)

At Gliwice-Trynek, where these obstacles lie to the south of the primary runway, wind acceleration in this operational sector poses a heightened hazard for departing aircraft. Airframes with limited tolerance for abrupt wind-speed changes may experience difficulty maintaining stable climb performance immediately after lift-off. An unexpected surge in airflow during this phase can lead to loss of control, requiring crews to execute swift and precise flight-parameter adjustments to preserve safety.

It is important to note that the Venturi effect is not exclusively associated with southerly winds. Depending on prevailing wind direction and intensity, similar accelerative phenomena can occur in different areas of the aerodrome's airspace; however, their magnitude and spatial distribution will vary accordingly. Narrow passages between large structures act as aerodynamic channels, intensifying local airflow and obliging flight crews and air-traffic controllers to continuously adapt flight parameters and control procedures – thereby imposing an additional cognitive and operational workload on all personnel.

Thus, the combination of the waste-disposal site, warehouse complexes, and the resultant Venturi effect creates unique aerodynamic conditions within the Gliwice-Trynek aerodrome operating area that influence every phase of flight operations. Increased wind speeds, associated turbulence, and rapidly changing aerodynamic conditions demand heightened vigilance and exacting procedural compliance from both flight crews and ground personnel to ensure the highest possible level of safety.

An additional factor shaping local meteorological conditions is the water reservoir situated to the east of Gliwice-Trynek aerodrome (Fig. 9). Its presence affects atmospheric parameters around the aerodrome, with direct implications for the safety and efficiency of ongoing flight operations.

The thermal and hygrometric properties of water reservoirs give rise to distinct and often complex meteorological phenomena that can markedly affect flight operations – particularly during take-off, landing, and low-altitude maneuvering phases. A primary hazard associated with the proximity of such bodies of water to aerodromes is the increased likelihood of radiation fog formation during clear, cool nights and advection fog under warm, moist airflow – conditions most prevalent in the early morning and late evening hours. These fog events frequently result in severe visibility reductions within the designated approach corridors, thereby complicating the precise execution of approach and landing procedures and substantially elevating the probability of an improper runway touchdown or, alternatively, the necessity to execute a missed-approach and go-around maneuver.

Fig. 9. Water reservoir in the vicinity of Gliwice-Trynek aerodrome

Moreover, temperature contrasts between the cooler water surface and the warmer adjacent land generate localized shifts in both wind direction and speed. Such micro-meteorological effects manifest as turbulent zones and small-scale vertical air currents – both updrafts and downdrafts – that can severely destabilize an aircraft precisely as it enters the most critical stages of its flight profile. Flight crews must therefore remain on high alert and prepared to implement immediate trajectory corrections in order to maintain a stabilized glide path and ensure adherence to the flight plan. Additionally, elevated levels of water vapor emanating from the reservoir foster the development of low-level stratiform clouds, contributing further to changes in moisture content and directly influencing aerodynamic efficiency – particularly affecting wing lift and drag characteristics, thereby altering climb rates, descent paths, and overall performance profiles.

Another significant operational threat inherent to nearby water bodies is solar glare – intense sunlight reflecting off the water's surface directly into the eyes of flight crews. This glare is especially acute when the sun sits low on the horizon, during both sunrise and sunset periods. Such reflections can momentarily impair external visual references as well as the readability of cockpit instruments, making it difficult for pilots to accurately gauge distances to the runway or determine their height above ground. In extreme cases, glare-induced visual impairment may precipitate temporary disorientation or erroneous assessments of critical flight parameters, thus necessitating an immediate go-around or missed-approach decision. This seasonal phenomenon intensifies during spring and summer months, when daylight hours are extended and the incidence of strong solar radiation is at its peak.

Surface heterogeneity at and around Gliwice-Trynek aerodrome – comprising both hard pavements such as asphalt and concrete alongside natural grass areas – also exerts a profound influence on the local microclimate and thermal regime. Differences in specific heat capacity and thermal conductivity between these materials lead to uneven surface heating throughout the day. Pavement surfaces absorb and re-radiate heat more rapidly and to a greater extent than grass fields, creating thermal plumes, localized turbulence zones, and micro-eddy formations near runway thresholds. These thermal currents may intermittently disrupt both approach trajectories during landing phases and initial climb gradients during take-off, thereby requiring pilots to execute dynamic, in-flight adjustments to their flight-control inputs and to maintain a continuous awareness of changing aerodynamic conditions.

Uneven ground heating can further precipitate the formation of thermal inversion layers, which disrupt the normal vertical airflow above the aerodrome. On warm, sunny days, asphalt and concrete surfaces emit considerable amounts of stored heat into the immediate atmosphere, generating localized low-pressure pockets that draw in cooler air from the surrounding natural terrains. This inflow produces irregular horizontal and vertical air currents, enhanced turbulence, and mixing layers in close proximity to the runway environment – collectively elevating the operational risks associated with both departure and arrival phases, where precise attitude and speed control are paramount.

Importantly, these thermal effects persist well into nighttime hours, as artificial surfaces gradually release the heat they have accumulated during daylight, maintaining local temperatures above those of the adjacent fields, forests, and meadows. These nocturnal thermal emissions influence air-density gradients, thereby modifying lift coefficients, affecting engine performance, and altering aircraft handling characteristics at low altitudes.

The juxtaposition of industrial hard-scapes, urbanized zones, and natural landscapes – such as forests, meadows, and water bodies – further intensifies micro-meteorological phenomena around the Gliwice-Trynek aerodrome. Differentially heated surfaces create alternating pressure zones, rising thermal columns, and updraft corridors, each contributing to a highly dynamic airflow environment. Flight crews must therefore continuously monitor ambient conditions via onboard instruments and visual cues, executing real-time flight-parameter adjustments to anticipate and counteract sudden encounters with updrafts or downdrafts. Maintaining aerodynamic stability under these variable conditions demands both precise stick-and-throttle coordination and heightened situational awareness.

Overall, the variable thermal conditions and attendant localized wind-shear events – characterized by abrupt shifts in wind direction, speed, and density – constitute additional hazards during the most critical phases of flight. These phenomena can induce momentary lift loss, unintended roll or pitch excursions, or unexpected deviations from the planned flight path, thereby requiring prompt and decisive corrective action by flight crews. Ensuring the highest levels of safety for all operations within the Gliwice-Trynek aerodrome vicinity thus depends on rigorous procedural compliance, continuous meteorological monitoring, and the capacity of crews and ground personnel to adapt swiftly to changing aerodynamic and environmental circumstances.

6. CONCLUSION

The development of a three-dimensional spatial model of Gliwice-Trynek aerodrome proved to be a highly effective tool for assessing the influence of terrain morphology and existing infrastructure on the safety and efficiency of flight operations. The results of the conducted analyses demonstrated that the use of low-altitude photogrammetry with unmanned aerial vehicles (UAVs) constitutes one of the most precise and efficient methods for acquiring spatial data. This approach enables faithful reproduction of real-world topography in a three-dimensional environment, as well as the identification of landscape features and infrastructural elements that may pose hazards to flight safety – particularly in areas characterized by complex terrain relief.

For the study area in question, it was shown that the presence of buildings and natural landformations within specific sectors immediately adjacent to the aerodrome affects the safety of ongoing operations, especially during approach and landing phases as well as take-off procedures. These findings underline the necessity for systematic monitoring and periodic updating of spatial models covering areas contiguous to aerodrome infrastructure, with the aim of ensuring their conformity to the current state of the operational environment.

The analysis also highlighted significant benefits arising from the application of UAVs in aerodrome photogrammetric surveying. The integration of this technology with aerospace engineering systems and airspace-management platforms points the way toward future standards in the oversight of aerodrome operational environments. The photogrammetric data collected – when integrated into digital airspace-management systems – facilitate the prediction of potential hazards and the identification of aerial obstacles, thereby supporting the development of autonomous UAV systems and enhancing overall operational safety in the long term.

Moreover, precise and up-to-date photogrammetric representations make it possible to forecast the impact of surrounding infrastructure and topographic conditions on approach paths and departure trajectories. This capability is especially critical at aerodromes with intricate spatial configurations. The results obtained confirm that the rapid advancement of drone technologies enables the generation of high-resolution spatial models, which, in turn, assist aerodrome managers in continuously monitoring zones adjacent to operational areas.

In conclusion, the findings of this study affirm that the implementation of UAV-based monitoring of aerodrome operational environments represents a significant frontier in modern aerospace engineering. They also underscore the considerable potential of this technology to streamline spatial-planning processes and improve airspace management around aerodrome perimeters.

References

1. Brassel Hannes, Alexander Zouhar, Hartmut Fricke. 2020. „3D Modeling of the aerodrome environment for fast and accurate LiDAR semantic segmentation of apron operations". In: *AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*: 1-10. San Antonio, USA. 11-15 October 2020. San Antonio, USA. DOI: 10.1109/DASC50938.2020.9256495.
2. Cisło-Lesicka Urszula. 2010. „Generation of 3D buildings for three-dimensiona lmultiresolution topographic database". *Archiwum Fotogrametrii, Kartografii i Teledetekcji* 21: 63-73. ISBN: 978-83-61576-13-6.
3. Jarząbek-Rychard Małgorzata. 2015. „3D building modeling based on laser scanning data". PhD thesis, Wroclaw, Poland: Wrocław University of Environmental and Life Sciences.
4. Leung Dennis Y.C., W.Y. Lo, W.Y. Chow, P.W. Chan. 2012. „Effect of terrain and building structures on the airflow in an aerodrome". *Journal of Z hejiang University Science A* 13(6): 461-468. DOI: 10.1631/jzus.A1100293.
5. Michałowska Krystyna (ed.). 2015. *Modelowanie i wizualizacja danych 3D na podstawie pomiarów fotogrametrycznych i skaningu laserowego*. Rzeszów: Wyższa Szkoła Inżynieryjno-Ekonomiczna z siedzibą w Rzeszowie. [In Polish: *3D data modeling and visualization based on photogrammetric measurements and laser scanning*. Rzeszów: University of Engineering and Economics in Rzeszów]. ISBN: 978-83-60507-29-2.

6. Mitsevich Liudmila, Natalia Zhukovskaya. 2021. „3D modeling and GIS analysis for aerodrome forest obstacle monitoring". *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLIII-B2-2021: 753-757. DOI: 10.5194/isprs-archives-XLIII-B2-2021-753-2021.
7. Oszczak Bartłomiej, Dariusz Tanajewski, Adam Harmaciński, Mateusz Klimczuk. 2011. „3D modeling of buildings at the aerodrome Dajtki-Olsztyn in applications AutoCAD Civil 3D and Google SketchUp". *Annals of Geomatics* 4(48): 129-137. ISSN: 1731-5522.
8. Quan Xiuhao, Reiner Doluschitz. 2021. „Unmanned aerial vehicle (UAV) technical applications, standard workflow, and future developments in maize production – water stress detection, weed mapping, nutritional status monitoring and yield prediction". *Landtechnik* 76(1): 36-51. DOI:10.15150/lt.2021.3263.
9. Rábago Jordi, May Portuguez-Castro. 2023. „Use of drone photogrammetry as an innovative, competency-based architecture teaching process special issue". *Drones* 7(7): 1-19. DOI: 10.3390/drones7030187.
10. Zawisza Tomasz. 2023. „Traffic safety management on the apron using a heuristic algorithm". PhD thesis, Warsaw, Poland: Warsaw University of Technology.
11. Zhang Ziya,Weijun Pan, Junjie Zhou, Qiyang Zhang. 2021. „Research on rapid 3D modeling of aerodrome navigation facilities based on oblique photography technology". *IOP Conf. Series: Earth and Environmental Science* 693: 1-6. DOI:10.1088/1755-1315/693/1/012095.

Received 04.12.2025; accepted in revised form 30.04.2026