

UAV Airspace Surveillance and Security Management

Mihai NEACSU^{*,1}, Gabriela-Liliana STROE^{1,2}, Larisa-Anda STROE¹,
Alina DRAGOMIRESCU², Valentin SOARE²

*Corresponding author

¹Faculty of Aerospace Engineering,
National University of Science and Technology POLITEHNICA Bucharest,
Splaiul Independenței 313, 060042, Bucharest, Romania,
micky969@ymail.com*, stroe.gabriela@incas.ro, larisa_anda.stroe@upb.ro

²INCAS – National Institute for Aerospace Research “Elie Carafoli”,
B-dul Iuliu Maniu 220, Bucharest 061126, Romania,
dragomirescu.alina@incas.ro, soare.valentin@incas.ro

DOI: 10.13111/2066-8201.2026.18.3.17

Received: 23 July 2026/ Accepted: 13 August 2026/ Published: September 2026

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Abstract: *This paper reviews current developments in UAV airspace surveillance and security management, emphasizing the role of multi-sensor surveillance, Remote Identification, geographic information systems, and weather-aware monitoring. The study also discusses current research challenges and future directions in intelligent airspace management, highlighting the importance of integrated surveillance architectures to improve aviation safety and operational efficiency. The rapid growth of Unmanned Aerial Vehicle (UAV) operations has significantly transformed modern airspace, creating new challenges for surveillance, safety, and security. The increasing number of civilian and commercial UAV applications requires efficient airspace management systems that ensure safe integration with conventional aviation while maintaining situational awareness and regulatory compliance. Recent advances in sensor technologies, artificial intelligence, and Unmanned Aircraft System Traffic Management (UTM) have improved the capability to detect, identify, and monitor UAV operations in real time.*

Key Words: *Airspace Management, MATLAB simulation, security management, surveillance, UAV*

1. INTRODUCTION

The rapid expansion of Unmanned Aerial Vehicles (UAVs) in civilian, industrial, and governmental applications has created new challenges for modern airspace management and security. The increasing number of UAV operations requires advanced surveillance, monitoring, and management solutions that can maintain safe integration with existing air traffic systems while addressing potential unauthorized or unsafe activities.

This research focuses on developing and analyzing UAV airspace surveillance and security management concepts by integrating geographic information systems, environmental modeling, flight monitoring techniques, and risk assessment approaches. The proposed framework considers UAV trajectory observation, altitude monitoring, environmental influences, and airspace awareness to improve the understanding of UAV behavior within complex operational environments.

Modern surveillance technologies, including radar systems, satellite navigation, remote identification, and sensor fusion approaches, are examined as key components for achieving reliable UAV detection and tracking. The study also highlights the importance of regulatory frameworks, automated monitoring systems, and intelligent decision-support tools for improving airspace safety and resilience. The objective of this research is to provide an integrated perspective on UAV airspace surveillance and security management, supporting future developments in safe UAV integration, air traffic management, and protection of critical airspace environments.

Radar systems remain an important technology for detecting and tracking airborne objects. They provide information about position, movement, and altitude. However, small UAVs can present challenges because of their reduced size and limited radar signature. Global Navigation Satellite Systems (GNSS), including GPS and Galileo, are widely used for UAV navigation. These systems provide accurate positioning information but may be affected by environmental conditions and signal limitations. Remote Identification (Remote ID) has become an important element in UAV security management. It allows authorized systems to obtain information about UAV identification and operational status, improving transparency and accountability in airspace operations. Artificial intelligence and machine learning techniques are increasingly applied to UAV monitoring. Applications include: automatic object recognition, trajectory analysis, anomaly detection, and predictive monitoring. AI-based systems can support operators by analyzing large quantities of surveillance data and identifying unusual behavior patterns.

Current research directions include: autonomous airspace management, artificial intelligence-based surveillance, integration of UAVs into smart cities, 3D airspace modeling, digital twins for aviation systems, and real-time risk assessment. Future UAV security systems are expected to combine advanced sensing technologies, automated decision support, and regulatory frameworks to ensure safe and efficient airspace operations.

2. STATE OF THE ART

Artificial intelligence and machine learning methods are increasingly being incorporated into UAV surveillance systems to improve automated analysis capabilities. These technologies support applications such as trajectory prediction, anomaly identification, object recognition, and decision assistance. Intelligent monitoring systems can process large volumes of information from multiple sensors and provide improved situational awareness for airspace managers. Recent developments in autonomous systems demonstrate that artificial intelligence will play an increasingly important role in future UAV monitoring and management architecture.

The future of UAV airspace surveillance is expected to integrate advanced sensing technologies, artificial intelligence, digital communication infrastructures, and regulatory frameworks. Research directions include three-dimensional airspace modeling, digital twin environments, autonomous traffic management, and real-time risk assessment. These developments aim to create safer and more efficient aviation ecosystems that support the continuous growth of UAV operations.

Artificial intelligence has emerged as one of the most influential technologies supporting next-generation airspace surveillance. Modern machine learning algorithms can process large volumes of heterogeneous sensor information in real time, enabling automatic trajectory classification, abnormal flight detection, predictive movement analysis, and operational risk estimation. Instead of relying exclusively on predefined operational rules, intelligent

surveillance systems continuously learn from historical and real-time observations, improving their capability to identify unexpected UAV behavior while reducing false alarms. This evolution transforms surveillance systems from passive monitoring platforms into intelligent decision-support environments capable of assisting aviation authorities during increasingly complex operational scenarios [1]. Another significant research direction concerns the implementation of Remote Identification (Remote ID), which has become a fundamental requirement within several international regulatory frameworks. Remote ID enables authorized entities to obtain identification and positional information from UAVs operating within shared airspace, thereby improving operational transparency and accountability. Nevertheless, the widespread adoption of Remote ID has also generated new research challenges associated with privacy protection, authentication mechanisms, data integrity, and cybersecurity. Recent studies emphasize that future surveillance systems must balance operational transparency with secure information exchange to prevent unauthorized access or manipulation of identification data [2].

Cybersecurity has consequently become an inseparable component of UAV airspace security management. The digitalization of surveillance infrastructures, increasing reliance on wireless communications, and growing autonomy of UAV platforms have expanded the potential attack surface of unmanned aviation ecosystems. Current research increasingly treats UAV surveillance as a cyber-physical system in which operational safety depends equally on physical monitoring and digital resilience. Accordingly, advanced security architectures incorporate intrusion detection, cryptographic authentication, anomaly detection algorithms, and resilient network designs that maintain reliable operation even under adverse cyber conditions [3]. Environmental conditions constitute another essential factor influencing UAV surveillance and operational safety. Atmospheric turbulence, wind fields, precipitation, visibility, and terrain morphology directly affect flight stability, navigation accuracy, sensor performance, and mission reliability. Consequently, modern surveillance frameworks increasingly incorporate Geographic Information Systems (GIS), Digital Elevation Models (DEM), and numerical weather prediction data into real-time monitoring platforms. The integration of environmental information allows surveillance systems to evaluate operational conditions dynamically and to support more informed decision-making during flight planning and airspace monitoring [4].

The convergence of artificial intelligence, multi-sensor surveillance, digital mapping, and advanced regulatory frameworks is gradually transforming UAV airspace management into an intelligent and adaptive system. Rather than functioning solely as a mechanism for aircraft observation, future surveillance architectures are expected to provide continuous situational awareness, automated risk assessment, predictive trajectory analysis, and integrated support for both civil aviation safety and airspace security. Despite substantial technological progress, several challenges remain unresolved, particularly regarding interoperability between surveillance platforms, harmonization of international regulations, cybersecurity, and the integration of autonomous UAV operations within increasingly congested airspace. These challenges continue to motivate intensive scientific research and provide the foundation for developing next-generation UAV surveillance and security management systems. The continuous increase in UAV operations has accelerated research into advanced airspace surveillance systems capable of supporting safe and efficient integration of unmanned aircraft into shared airspace. Conventional air traffic management systems were developed primarily for manned aviation and are not fully adapted to the growing number of autonomous and remotely piloted aircraft. Consequently, the concept of Unmanned Aircraft System Traffic

Management (UTM) has emerged as a complementary framework for coordinating UAV operations through digital services, real-time monitoring, and automated decision support [5]. Modern UAV surveillance increasingly relies on multi-sensor systems that combine radar, electro-optical cameras, satellite navigation, and Remote Identification technologies. These integrated approaches improve detection reliability and tracking accuracy while reducing the limitations associated with individual sensing technologies [6]. Artificial intelligence has further enhanced surveillance capabilities by enabling automated trajectory prediction, anomaly detection, and risk assessment based on real-time operational data [7].

Environmental conditions also play an important role in UAV operations. Recent studies show that integrating geographic information systems, digital elevation models, and meteorological data into surveillance platforms improves flight monitoring and supports safer operational planning [8]. At the same time, cybersecurity has become an essential component of UAV airspace management because digital surveillance systems must protect both operational information and communication infrastructures from potential cyber threats [9]. Overall, current research indicates that future UAV surveillance systems will combine intelligent data processing, environmental awareness, and automated traffic management to provide secure, efficient, and scalable airspace operations. This study examined the current challenges and emerging solutions associated with UAV airspace surveillance and security management in the context of increasingly complex aviation environments. The analysis demonstrates that UAV integration requires a shift from conventional monitoring approaches toward more adaptive management concepts that combine operational awareness, intelligent data interpretation, and continuous assessment of airspace conditions. The research highlights that effective UAV surveillance is not determined by a single technology but by the overall management framework's ability to transform heterogeneous information into reliable operational knowledge. The integration of numerical simulation, geographic representation, environmental parameters, and intelligent processing provides a valuable methodology for investigating UAV behavior and evaluating the performance of future airspace management concepts [10]. The development of simulation-based approaches represents an important contribution because it enables researchers to investigate complex UAV scenarios under controlled conditions, identify system limitations, and evaluate potential improvements before implementation in real operational environments. Such approaches are particularly valuable for studying dynamic airspace conditions where direct experimentation may be difficult, costly, or restricted. Although significant progress has been achieved in UAV surveillance technologies, several scientific challenges remain regarding model validation, interoperability between systems, and the representation of highly dynamic operational environments. Addressing these challenges will require closer integration between aerospace engineering, artificial intelligence, cybersecurity, and air traffic management research [11-12].

3. INTEGRATED UAV AIRSPACE SURVEILLANCE AND SECURITY MANAGEMENT

This study is therefore timely because it addresses the growing need for integrated UAV airspace surveillance and security management. By examining recent developments in surveillance technologies, geographic information systems, environmental data integration, and intelligent monitoring approaches, the research contributes to a better understanding of how modern airspace can be managed in increasingly complex operational environments. The study also reflects the ongoing transition from conventional surveillance methods toward intelligent, data-driven systems that support continuous monitoring and improve situational

awareness [13]. The findings of this research are relevant to several stakeholder groups, including civil aviation authorities, air navigation service providers, airport operators, emergency management organizations, researchers, and policymakers. Improved surveillance and security management can enhance aviation safety, strengthen regulatory compliance, support the secure integration of UAVs into shared airspace, and contribute to the resilience of critical aviation infrastructure.

From a scientific perspective, this study contributes to the continuing development of UAV airspace management by synthesizing recent advances in surveillance technologies, artificial intelligence, environmental awareness, and digital traffic management. It also identifies current research challenges and emerging trends, providing a foundation for future investigations into intelligent, interoperable, and resilient airspace management systems that can adapt to the evolving demands of both civil aviation and broader airspace security. In recent years, international conflicts have demonstrated that UAVs can also be employed in ways that affect aviation safety and airspace security. The presence of UAVs in or near conflict zones, as well as the possibility of unauthorized or unidentified UAV operations in adjacent regions, has highlighted the need for robust surveillance and airspace management systems. These developments have reinforced the importance of continuous monitoring, timely detection, accurate tracking, and effective coordination between civil aviation authorities and other responsible institutions to reduce risks to legitimate airspace users [14].

Beyond conflict-related concerns, the rapid expansion of commercial drone operations has increased the complexity of low-altitude airspace. The coexistence of manned aircraft, commercial UAVs, emergency services, and recreational drones requires modern surveillance systems capable of maintaining comprehensive situational awareness while supporting safe and efficient traffic management. Consequently, airspace surveillance has become a critical component of aviation safety, enabling authorities to monitor airspace activity, identify irregular operations, and support informed operational decision-making. Advances in autonomous navigation, miniaturized sensors, artificial intelligence, and commercial drone technology have enabled UAVs to perform a wide range of legitimate missions, including environmental monitoring, infrastructure inspection, disaster response, agriculture, logistics, and scientific research. At the same time, the increased number of UAV operations has introduced new challenges for aviation authorities responsible for ensuring the safety, security, and efficient management of shared airspace [15].

The rapid development of Unmanned Aerial Vehicle (UAV) technologies has introduced significant transformations in modern airspace management, creating new requirements for advanced surveillance, security, and operational coordination systems. The increasing diversity and complexity of UAV applications demonstrate that traditional airspace monitoring approaches are no longer sufficient to address the challenges associated with large-scale unmanned aircraft integration. Consequently, intelligent and adaptive surveillance frameworks have become essential for maintaining situational awareness, improving operational safety, and supporting efficient airspace utilization [16].

This study highlights that effective UAV airspace surveillance and security management require integrating multiple technological components, including geographic information systems, environmental modeling, sensor fusion, artificial intelligence, and digital traffic management concepts. This combination enables a more comprehensive understanding of UAV behavior through continuous monitoring, improved trajectory analysis, and enhanced decision-support capabilities. Modern surveillance systems are progressively evolving from simple detection mechanisms toward intelligent platforms capable of interpreting complex operational situations and supporting proactive management strategies [17-18].

The analysis of current research demonstrates that multi-sensor surveillance architectures represent a fundamental direction for improving UAV monitoring performance. The integration of radar, optical systems, satellite navigation, remote identification technologies, and advanced data-processing methods provides increased reliability compared with individual sensing approaches. At the same time, incorporating artificial intelligence offers new opportunities for automated trajectory prediction, anomaly detection, and risk assessment, allowing future systems to manage increasingly complex airspace environments more effectively.

The study also emphasizes the importance of considering environmental and operational factors within UAV surveillance models. Weather conditions, terrain characteristics, and atmospheric disturbances can significantly influence UAV performance and monitoring accuracy. Therefore, future airspace management systems should incorporate real-time environmental information and realistic geographic representations to improve the reliability of numerical simulations and operational assessments [19].

The development of MATLAB-based numerical simulation frameworks represents an important contribution to the research and evaluation of UAV airspace management concepts. Such simulations provide a flexible environment for analyzing UAV trajectories, testing surveillance strategies, evaluating sensor performance, and investigating future airspace scenarios before practical implementation. However, increasing the scientific value of these models requires continuous improvement through realistic data integration, validation processes, and interoperability with advanced simulation and digital twin platforms.

With the increasing global use of UAVs and the growing complexity of airspace operations, security management has become an essential element of aviation research. Ensuring safe UAV integration requires a balanced approach that combines technological innovation, regulatory development, cybersecurity measures, and international cooperation. Future airspace systems will depend on intelligent, resilient, and adaptive architectures capable of supporting both the expansion of UAV applications and the protection of aviation safety.

Overall, UAV Airspace Surveillance and Security Management represents a multidisciplinary research field that combines aerospace engineering, information technologies, artificial intelligence, cybersecurity, and environmental modeling. Continued scientific development in this area will contribute to the creation of safer, more efficient, and more resilient airspace management systems capable of responding to the evolving challenges of future aviation environments [19].

4. NUMERICAL SIMULATIONS AND OBTAINED RESULTS

This program creates a three-dimensional model of a UAV moving through the air. It assumes that the UAV starts from a specific location and then moves at a fixed speed and in a fixed direction. The simulation records the UAV's position at every step and displays the complete flight path in a 3D graph.

The model represents three types of movement:

- movement in one horizontal direction,
- movement in another horizontal direction,
- changes in altitude.

The altitude is also modified using a mathematical wave function, which represents the UAV climbing and descending during flight. The final result is a visual representation of a UAV trajectory in three-dimensional space.

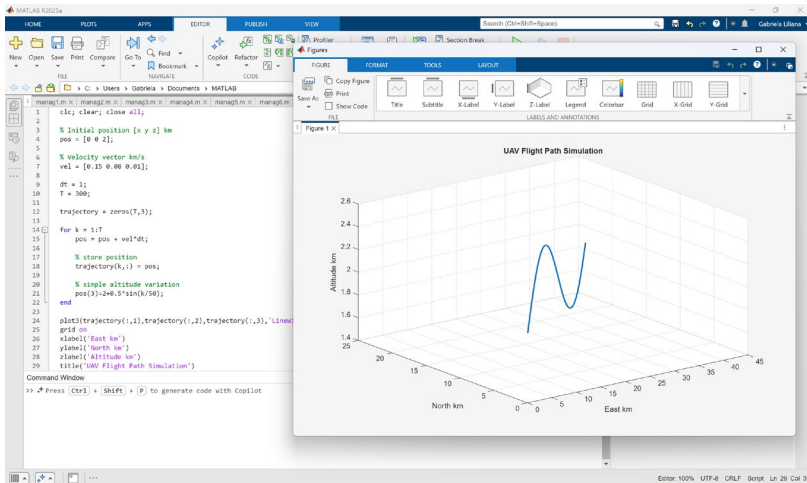


Fig. 1 UAV 3D Trajectory simulation over terrain

This program simulates UAV flying while being affected by unpredictable environmental conditions, such as wind. Instead of following a perfectly straight path, the UAV position changes randomly because external forces disturb its movement.

The simulation generates random wind effects and adds them to the UAV's movement. This creates a more realistic flight path because real aircraft are affected by atmospheric conditions. The output shows how a UAV trajectory can become irregular due to environmental disturbances. This type of model is useful for studying navigation accuracy and flight-control performance.

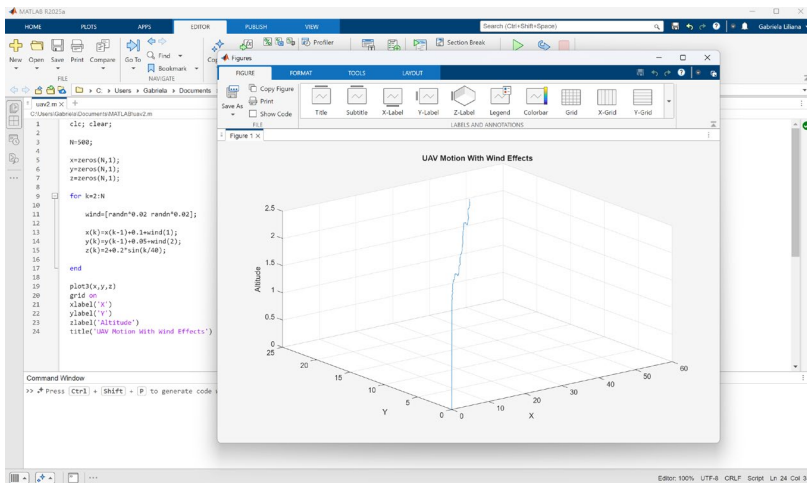


Fig. 2 UAV Random Flight Path with Wind Disturbance

This program models the relationship between distance and a radar system's ability to detect a UAV. The main idea is that detection capability decreases as the distance between the radar and the UAV increases. When the UAV is close to the sensor, the probability of detection is high. As the UAV moves farther away, the detection probability decreases.

The simulation creates a graph showing how detection performance changes with distance. It represents a simplified sensor model and does not include the complexity of real radar systems.

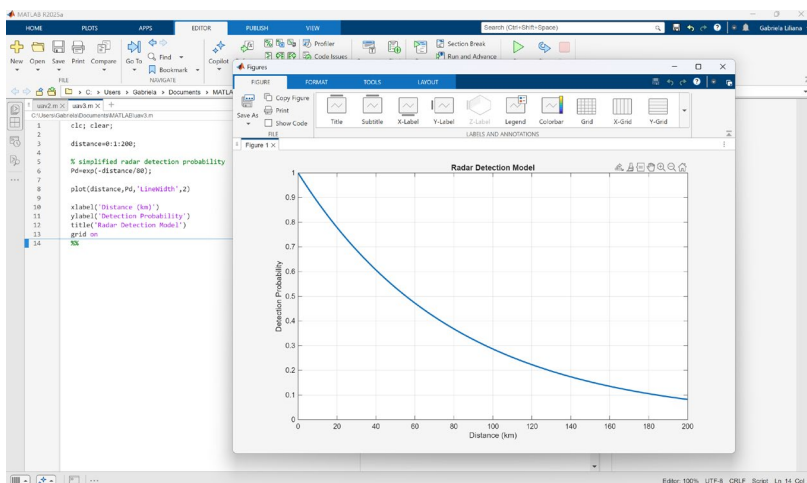


Fig. 3 Radar Detection Probability Simulation

This program simulates an airspace monitoring system that checks whether a UAV enters a defined restricted area. First, a virtual protected zone is created. Then, random UAV positions are generated. The program compares each UAV position with the boundaries of the protected zone. If the UAV position falls inside the defined area, the system identifies it as an entry into the restricted region.

This type of simulation represents the basic principle behind digital geofencing, where software monitors whether an aircraft remains within authorized areas.

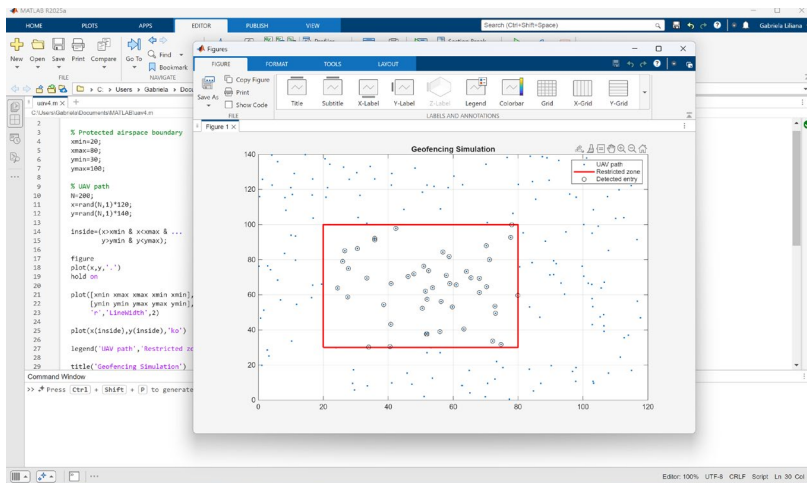


Fig. 4 Airspace Geofence Violation Detector

This program demonstrates how a tracking system can estimate the position of a moving UAV when measurements contain errors. In real situations, sensors such as GPS or radar do not provide perfect information. They contain noise and inaccuracies. The Kalman filter solves this problem by combining previous predictions with new measurements. The program first simulates UAV movement. Then it adds artificial measurement errors. Finally, the Kalman filter processes the noisy data and produces a smoother and more accurate estimate of the UAV position. This method is widely used in navigation, robotics, aviation, and autonomous systems.

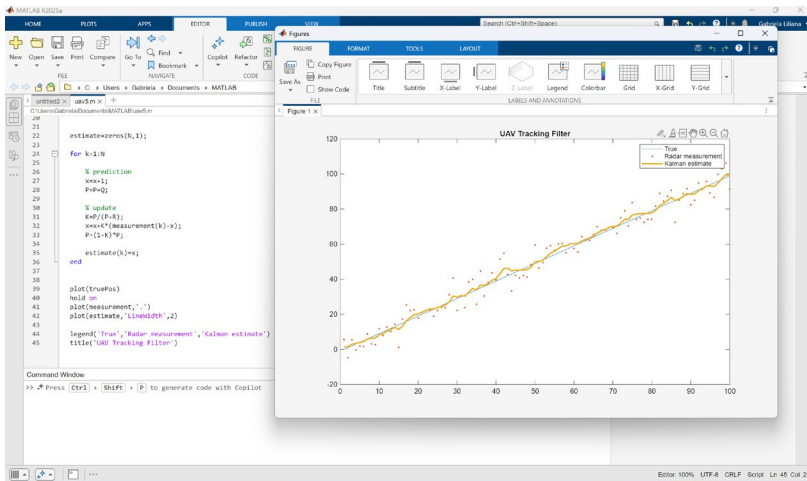


Fig. 5 Kalman Filter UAV Tracking

This program simulates several UAVs moving in the same airspace at the same time. Each UAV is assigned a different flight path generated by random movement. The program displays all UAV trajectories together in a three-dimensional environment. The purpose is to study how multiple aircraft can occupy the same airspace and how their movements can be represented mathematically. Such models are useful for research on air traffic management, drone operations, and collision-avoidance concepts.

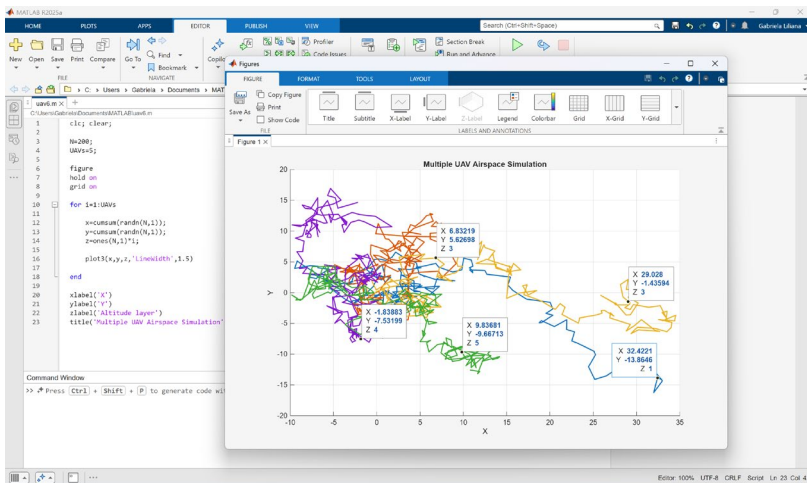


Fig. 6 Multi-UAV Airspace Simulation

This program demonstrates the difference between the actual UAV position and the position reported by a GPS system.

The UAV is assumed to follow a known path. Random errors are then added to simulate GPS inaccuracies caused by measurement limitations, atmospheric effects, or signal disturbances. The simulation compares:

- the true UAV position,
- the GPS-reported position.

The result shows that GPS measurements usually follow the real path but contain small deviations. This helps researchers understand positioning uncertainty.

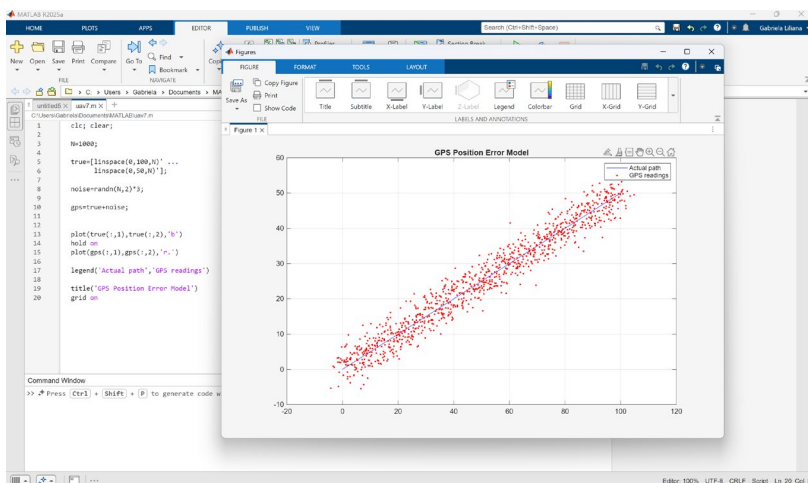


Fig. 7 GPS Error Simulation

This program studies how communication quality changes as the distance between a UAV and a communication station increases. As distance increases, the received signal becomes weaker. The simulation calculates how this affects communication performance.

The program uses concepts such as:

- signal strength,
- noise,
- communication errors.

The result demonstrates that longer distances generally produce less reliable communication. This type of model is important for studying the reliability of UAV communication networks.

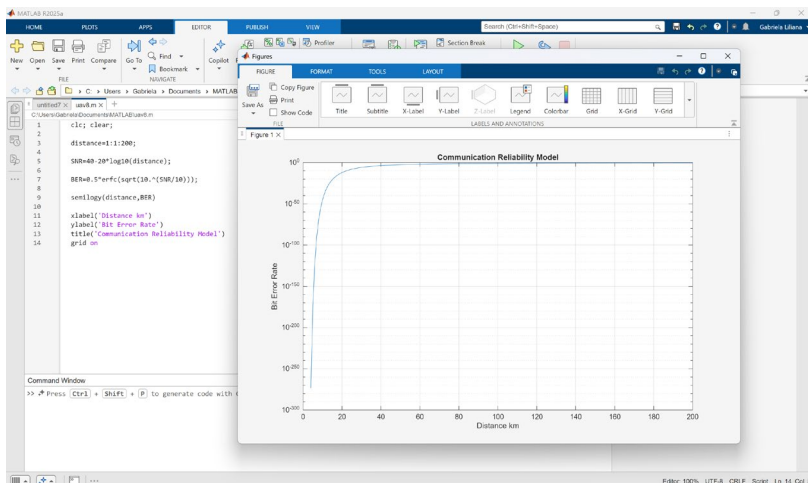


Fig. 8 UAV Communication Link Reliability

This program uses a statistical method called Monte Carlo simulation to estimate the probability of a UAV reaching a destination within a certain time. Instead of performing the calculation once, the program repeats the simulation thousands of times with different random conditions. Each simulation uses slightly different values for UAV speed. After many repetitions, the program calculates how often the UAV meets the selected condition. This approach is useful when systems involve uncertainty and cannot be predicted exactly. This

program creates a simple real-time visualization of UAV movement. The UAV follows a curved path while changing altitude. The position is updated continuously, creating an animation similar to a monitoring display. The purpose is to demonstrate how a tracking interface can show an aircraft's movement over time. Such visualization tools are useful for training, research, and studying airspace-management concepts. These ten MATLAB programs and 9 graphs represent different parts of a UAV monitoring and simulation system:

- Trajectory simulation shows how a UAV moves.
- Environmental models show how conditions affect flight.
- Detection models represent sensor observation.
- Geofencing models represent airspace monitoring.
- Tracking algorithms improve position estimates.
- Communication models study connectivity.
- Statistical simulations analyze uncertainty.
- Visualization tools display UAV behavior.

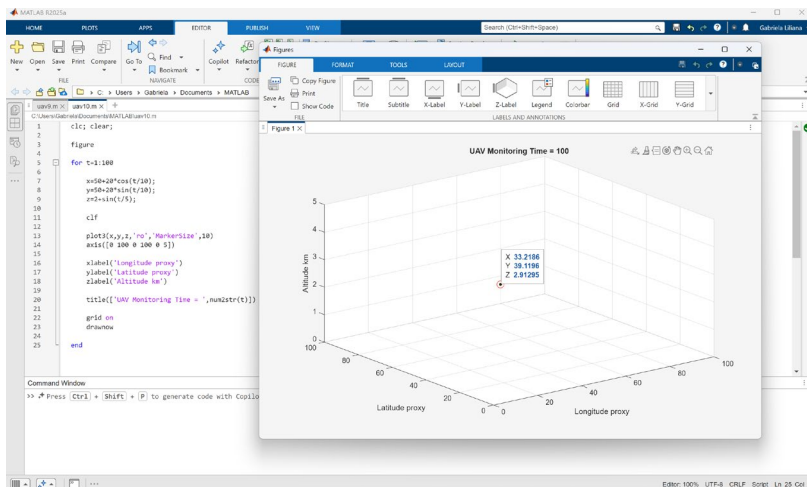


Fig. 9 Airspace Monitoring Dashboard

The graph (fig. 9) represents a conceptual UAV airspace monitoring scenario over a European geographic region. It illustrates how a UAV trajectory can be displayed and analyzed using a two-dimensional map-based visualization. The purpose of the graph is to demonstrate the principles of airspace observation, position tracking, and movement analysis. The visualization contains a simplified representation of European airspace and a simulated UAV flight path. It is designed for academic study of aerospace systems, air traffic monitoring, and surveillance technologies.

The graph (fig. 10) uses a geographic coordinate system to represent the UAV's location. The horizontal axis represents the east–west position, while the vertical axis represents the north–south position. This allows the UAV's movement to be displayed on a map-like surface. The European region shown in the graph provides a reference area for observing the simulated UAV movement. In professional systems, this type of representation would normally use detailed geographic information, including national boundaries, aviation zones, and terrain information.

The red line represents the UAV's simulated flight path.

The trajectory shows how the UAV changes position over time. Each point along the line represents a recorded location during the observation period.

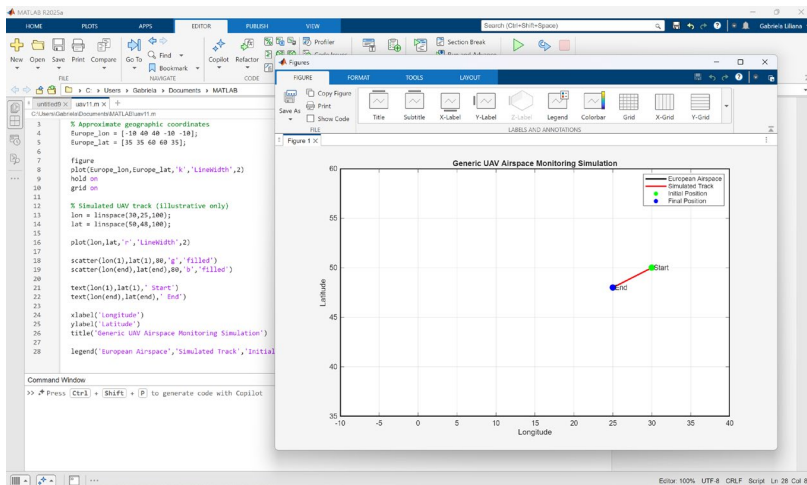


Fig. 10 Explanation of the UAV Airspace Monitoring

The trajectory allows researchers to examine:

- the direction of movement,
- changes in flight path,
- the overall travel pattern,
- the behavior of the aircraft during the simulation.

A straight trajectory indicates stable movement, while changes in the path may represent variations in direction, environmental influences, or changes in flight conditions.

The green marker indicates the initial position where the UAV is first detected in the simulation.

This point represents the beginning of the monitoring process. In an airspace surveillance system, the first detection provides the starting information needed for continuous observation.

The initial observation is important because the quality of early position information affects how accurately the UAV can be followed during the rest of the flight. The blue marker represents the last recorded position of the UAV during the simulation. This point shows the final location after the monitoring period. Comparing the initial and final positions allows researchers to understand the UAV's general movement pattern.

The final position provides information about the overall direction of travel and the area covered during observation. The graph demonstrates the basic operation of a UAV tracking system.

A monitoring system continuously receives information about an aircraft's position and displays it visually. Operators or researchers can use this information to understand aircraft movement and maintain awareness of activity within a defined airspace.

The visualization supports analysis of:

- aircraft movement patterns,
- airspace usage,
- tracking performance,
- monitoring capability.

This type of graph is commonly used in aerospace and aviation studies because it provides an easy method to understand aircraft behavior.

Researchers can use similar visualizations for:

- unmanned aircraft traffic studies,
- airspace management research,

- autonomous vehicle development,
- aviation safety analysis.

The objective is not only to display movement but also to evaluate how effectively a monitoring system can observe and represent aircraft activity. This simplified graph does not represent a real UAV event or operational situation. It is only a conceptual model.

The graph does not include:

- real-time aircraft information,
- detailed geographic features,
- weather conditions,
- communication limitations,
- sensor imperfections,
- altitude variations.

A more advanced academic simulation would add three-dimensional flight information, environmental effects, sensor uncertainty, and realistic airspace conditions. The UAV airspace monitoring graph provides a visual representation of aircraft movement within a simulated European environment. It demonstrates how trajectory visualization can support the understanding of UAV behavior, airspace observation, and aviation monitoring systems. Such models are valuable tools in aerospace engineering and air traffic research because they help researchers study how aircraft movements can be represented, monitored, and analyzed in complex airspace environments. This model creates a three-dimensional environment. The surface represents terrain elevation. The UAV is displayed as a moving point above the terrain. The simulation continuously updates the UAV position, creating a simple real-time monitoring display.

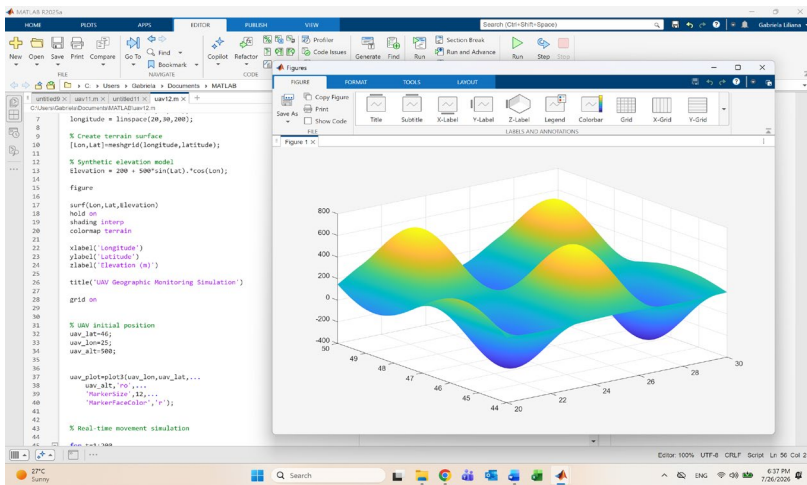


Fig. 11 UAV airspace monitoring graph

This simulation introduces environmental conditions affecting UAV movement:

- wind disturbance
- temperature variation
- turbulence.

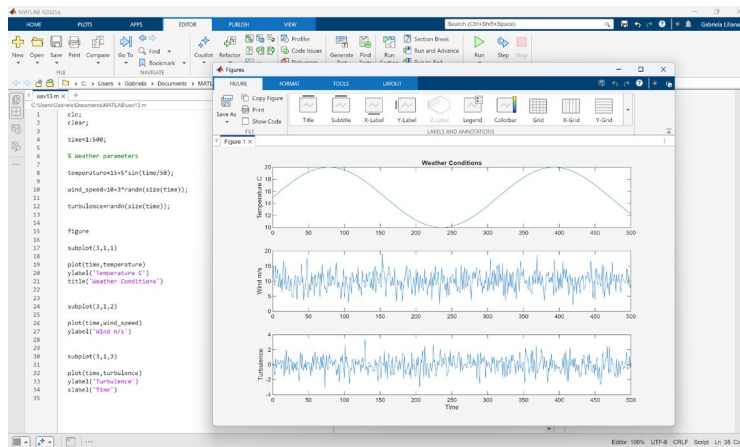


Fig. 12 Weather Influence Model

The graph represents changing atmospheric conditions. Temperature graph - Shows variation of air temperature during the flight period. Temperature effects:

- battery performance,
- sensors,
- aerodynamic efficiency.

Wind graph - Shows changing wind speed. Wind may influence:

- UAV stability,
- energy consumption,
- navigation accuracy.

Turbulence graph - Represents random atmospheric disturbances. Higher turbulence means a more unstable flight environment. UAV Altitude Monitoring Model - Purpose - Shows UAV altitude variation during flight. For civilian UAV operations, maximum allowed altitude depends on:

- country regulations,
- UAV category,
- operational authorization.

Many European civilian drone operations use a common reference limit of approximately 120 m above ground level (AGL) for open-category operations, although exceptions and national rules may apply.

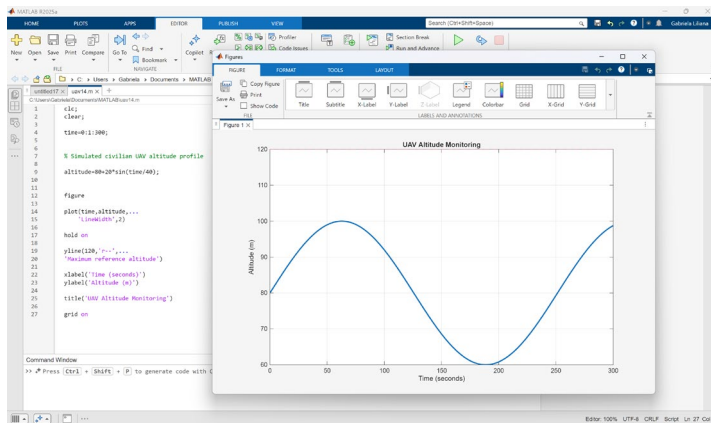


Fig. 13 UAV Altitude Monitoring Model

The graph shows UAV height changes during operation. The blue line represents a regulatory reference altitude.

The UAV altitude curve allows researchers to observe: climb behavior, altitude stability, possible altitude exceedance.

This type of graph is used in UAV safety studies.

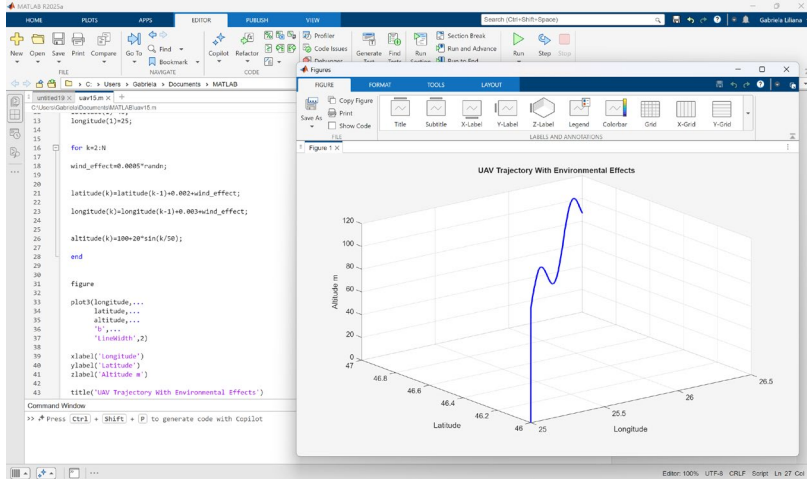


Fig. 14 3D Flight Path with Weather Disturbance

3D Flight Path with Weather Disturbance – Purpose – for combines: geographic movement, altitude, environmental disturbance. This simulation represents a UAV moving through a three-dimensional environment. The model includes: horizontal movement, altitude changes, random environmental influence. The trajectory is not perfectly straight because environmental conditions introduce variation. **Real-Time Airspace Monitoring Dashboard Concept** - A more advanced MATLAB project could integrate geographic data; possible sources include digital elevation models (DEM), OpenStreetMap, geographic layers, and GIS shapefiles. **Weather Data** - Possible inputs: wind speed, wind direction, temperature, precipitation, visibility, UAV Parameters, examples: altitude, speed, battery status, and position accuracy. **Visualization** - Dashboard components: 2D map, 3D terrain view, altitude graph, weather panel, Trajectory History.

5. CONCLUSIONS

These simulations could assist researchers in evaluating the performance of intelligent airspace management concepts under a wide range of operating conditions while supporting aviation safety and regulatory compliance. Another research opportunity is implementing intelligent surveillance algorithms within MATLAB. Artificial intelligence techniques, including machine learning and deep learning, could be incorporated to classify flight behavior, identify anomalous trajectories, predict future aircraft positions, and support automated risk assessment. These capabilities would allow surveillance systems to transition from passive observation toward intelligent decision-support platforms. Future research should focus on improving interoperability between UTM platforms, integrating artificial intelligence for autonomous decision support, and enhancing multi-sensor data fusion for more accurate UAV detection and tracking. Additional work is needed to strengthen cybersecurity, improve the integration of real-time weather information into surveillance systems, and develop digital

twin technologies for predictive airspace management. Harmonizing international regulations and standards will also be essential to support the safe expansion of UAV operations in increasingly complex airspace environments.

Future research should focus on developing increasingly realistic MATLAB-based numerical simulation models capable of supporting the analysis of UAV airspace surveillance and security management under complex operational conditions. While current simulations primarily represent simplified flight trajectories and basic surveillance scenarios, next-generation numerical models should incorporate greater realism by integrating environmental, operational, and regulatory constraints into a unified simulation framework.

One important research direction is integrating high-resolution geographic information into MATLAB simulation environments. Future models should employ Digital Elevation Models (DEM), Geographic Information Systems (GIS), and realistic terrain databases to represent the influence of mountains, valleys, urban areas, and critical infrastructure on UAV operations and surveillance performance. Such simulations would provide more representative operational scenarios for evaluating airspace monitoring strategies.

Another promising area involves incorporating dynamic meteorological conditions into numerical simulations. Environmental parameters such as wind speed and direction, atmospheric turbulence, precipitation, temperature, humidity, and visibility could be introduced as time-varying variables affecting UAV trajectory, flight stability, and sensor performance. These models would improve the realism of airspace surveillance studies by considering environmental uncertainty during UAV operations.

Future MATLAB simulations should also include multiple cooperative and non-cooperative UAVs operating simultaneously within the same airspace. Multi-UAV scenarios would enable the investigation of traffic density, trajectory interactions, conflict detection, airspace congestion, and surveillance system performance under increasingly complex operating conditions. Such simulations are particularly relevant as the number of UAV operations continues to increase.

Future numerical models should also investigate multi-sensor surveillance architectures that integrate data from simulated radar, electro-optical sensors, infrared cameras, satellite navigation systems, and Remote Identification (Remote ID). Sensor fusion algorithms could be evaluated to assess their effectiveness in improving tracking accuracy, reducing uncertainty, and maintaining situational awareness across varying environmental conditions.

An additional research direction involves developing real-time visualization and digital twin environments using MATLAB. Digital twins could continuously update virtual airspace representations using simulated or recorded flight data, allowing researchers to evaluate surveillance strategies, monitor traffic evolution, and analyze operational scenarios within a realistic virtual environment.

Finally, future studies should investigate automated airspace management algorithms capable of supporting flight monitoring, geofencing, altitude compliance verification, conflict detection, and operational risk visualization.

Overall, the continued development of MATLAB-based numerical simulations will provide increasingly sophisticated research tools for studying UAV airspace surveillance and security management. By integrating realistic environmental models, geographic information, intelligent data processing, and advanced visualization techniques, future simulation frameworks can improve the understanding of UAV operations and support the design of safer and more efficient airspace management systems.

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