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Automatic Aircraft Landing System: A Review

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ABSTRACT

The aircraft landing phase, marking the finishing of a flight plane, is a critical yet dangerous aerial maneuver. Even though it might seem simple, predicting the complexities of performance during landing presents a big challenge due to the dynamic characteristics of the phase, interaction with piloting methods, as well as inherent uncertainties in aerodynamics. Landing is executed in close proximity to the ground at reduced airspeed, the landing phase entails an escalated safety risk. Notably, incidents and accidents, particularly overruns where aircraft fail to slow sufficiently on the runway before landing, underscore the imperative for advanced landing technologies. This paper presents a comprehensive review of research spanning from 2000 to the present exploring smart techniques like fuzzy logic and machine learning, an array of control strategies ranging from classic PID control to sophisticated hybrid control approaches, and optimization procedures utilizing diverse optimization algorithms. The primary objective is to provide a comprehensive evaluation of the existing research landscape, offering insights that can propel the evolution of strategies for safer and more efficient landings and making sure the plane touches down safely.

Keywords: Automatic landing, Flight control, Turbulence.

1. INTRODUCTION

The landing phase, which constitutes just 4% of an aircraft's total flight time, Within the aviation sector, has a contradictory relevance **(Yadav et al., 2022)**. Despite its concise length, as shown in **Fig. 1,** it is responsible for approximately fifty percent of all detrimental incidents **(Airplanes, 1959)**. Achieving a successful landing requires an extraordinary degree of precision as pilots navigate a multitude of variables, including runway conditions, weather, air traffic, and visibility **(Suharev et al., 2019)**. Proficiency and skill are prerequisites for ensuring a safe and seamless touchdown.

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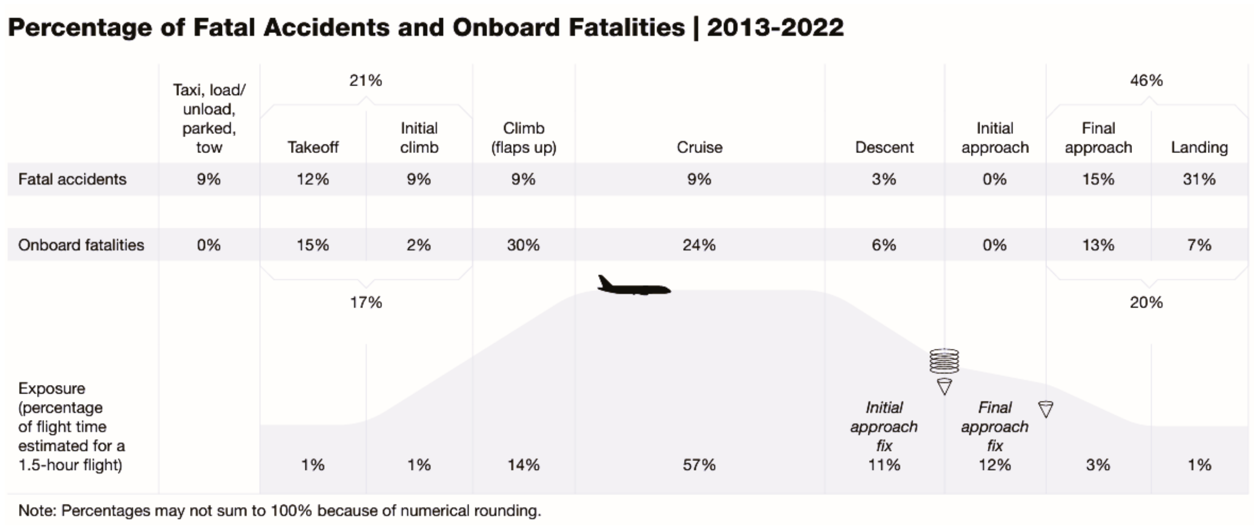

Figure 1. Statistical result of aircraft accident fetal **(Airplanes, 1959)**.

The sequential stages that the plane takes during landing, as shown in **Fig. 2**, are categorized into five distinct phases, namely the base leg, glide slope, flare-out, touchdown, and post-landing roll. Among these phases, the glide slope and flare-out stages are particularly pivotal. In the glide slope stage, the airplane descends along a predetermined course at a steady pitch angle. In the flare stage, the airplane's nose is raised slowly to ensure a smooth landing. **(Gudeta and Karimoddini, 2019)**. During these two stages of landing, the plane is exposed to risks caused by wind shear, which is a sudden change in wind speed and direction at a distance close to the runway, which leads to difficulty controlling the plane and deviating from the correct path **(Wang and Lu, 2018).** The unpredictable fluctuations in wind speed and direction, especially at low altitudes or reduced speeds compound the difficulties. Wind changes produce turbulence, which both increases the aircraft's dynamic stresses and also damages its structural integrity. The result affects maneuvering ability as well as passenger comfort **(Khattak et al., 2023)**. Therefore, it is important to increase the control power of the aircraft during the landing phase against turbulence and maintain the accuracy of the aircraft approach to maintain the safety of passengers and reduce aviation accidents **(Yadav et al., 2022)**.

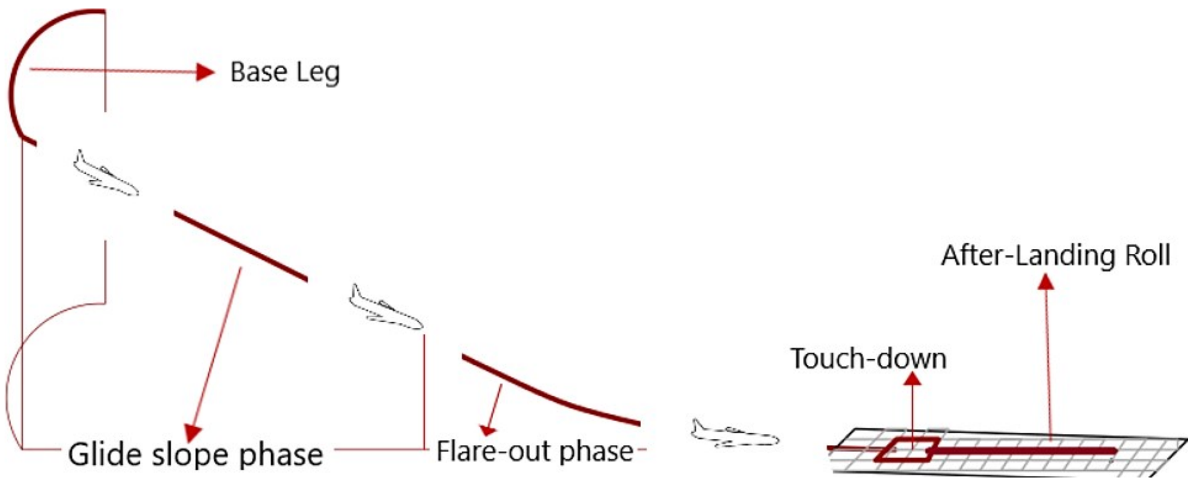

Figure 2. Aircraft phases **(Gudeta and Karimoddini, 2019)**.

Table 1. Common factors linked to flight incidents during the approach and landing phases **(Suharev et al., 2019)**.

Factor	Flight accidents %
Pilots' incorrect decisions	74
Skipping or improperly performing actions	72
Ineffective crew interaction, mutual assistance, and mutual control	63
Not adequate crew understanding of the flight situation in the horizontal and/or vertical plane	52
Invalid (incomplete or inaccurate) assessment of flight conditions	48
Slow or late crew action	45
Difficulty of manual piloting	45
Wrong or incomplete mutual understanding between the pilot and the controll	33
Improper use of automated control systems	20

Table 1. demonstrates the impact of factors, on compromising the safety of the final phase of a flight where the human factor plays a big role **(Suharev et al., 2019)**. To address these challenges and minimize risks it is crucial to develop landing controllers for aircraft that can accurately track trajectories and ensure a touchdown within the desired timeframe. Additionally, these controllers should be resilient in dealing with factors such as wind turbulence, measurement inaccuracies, and possible malfunctions in actuators **(Gudeta and Karimoddini, 2021)**.

Recognizing the importance of landings and considering the influence of factors many researchers have dedicated their efforts to creating automatic aircraft landing systems using various techniques and methodologies. There are a lot of literature surveys on the landing control of unnamed aerial vehicles (UAV). **(Noor et al.,2017)** discusses the different control techniques used to have an accurate and autonomous landing in UAV (visual processing landing, satellite navigation landing, ground station navigation landing, arrestor recovery landing) and shows the strengths and weaknesses between these techniques. **(Gautam et al., 2014)** discusses the integration of control techniques with the GPS (Global positioning system) and INS (inertial navigation sensors) to increase their accuracy and reliability such as (PID control, nonlinear control, Intelligent control, Hybrid control. and Robust control). It also addresses the vision approach, which is combined with traditional ways to ensure a secure landing and is utilized when the landing pad is unfamiliar or unstable. They also explore the Guidance-Based Landing and Recovery Landing Techniques. Guidance-based landing uses clever algorithms to guide UAVs from their current location to a target. Proportional guidance maintains a constant line-of-sight angle, whereas pursuit guidance leads the UAV toward a moving target, utilizing pure or pseudo-pursuit rules for precise control. UAVs may land in narrow spaces using recovery landing techniques such as vision-based net recovery and arrested landing. They use ground vision systems, sophisticated guidance laws, and novel solutions such as airbags and tail hooks to ensure safe and accurate landings. **(Zhang, 2017)** provides a detailed look at the features, trends, and control systems of vertical take-off and landing (VTOL) aircraft, which combine the range and speed of fixed-wing planes with the ability to take off and land in small spaces. It investigates technologies including jet thrust vectoring and tilting rotors, which are used in aircraft such as the Harrier, F-35B, and V-22 Osprey. The study also looks at the technological challenges and power systems involved. VTOL aircraft have significant potential for military and civilian applications, notably in urban mobility and fighting, but constant innovation is required to meet current technical challenges. **(Xin et al., 2022)** investigate several vision-based strategies enabling UAVs to land autonomously. It categorizes landing circumstances as static (permanent landing locations), dynamic (moving platforms such as trucks or ships), and complicated (unpredictable settings). The paper addresses the problems and technologies utilized in each category, including target recognition, feature-based approaches, and machine learning, as well as how many sensors can be integrated to increase landing accuracy.

There are also review papers discussing the techniques used to solve the problem of the aircraft landing problem (ALP). ALP is a method that sequences and schedules arriving aircraft to solve the problem of aircraft congestion when landing at the airport. **(Zipeng and Yanyang, 2018)** divides the ALP into single and multiple-runway situations, emphasizing the growing importance of multi-runway airports. The study investigates various optimization goals and constraints while accounting for stakeholder interests. It also looks into several algorithmic methodologies for addressing computing challenges that face ALP, focusing attention on the trend that goes in the direction of dynamic, multi-airport configurations for air traffic control. **(Zulkifli et al., 2018)** concludes that advanced computational techniques may be applied for solving the complex ALP, which is aggravated with factors like the number of planes, runway availability being different, and the existence of various types of aircraft with minimum separation requirement and all weather conditions. The review included papers for solving ALP using intelligent techniques based on genetic algorithms, particle swarm optimization, ant colony optimization, and dynamic programming. The goal is that through the use of such intelligent methods, the development of more effective and flexible solutions for managing aircraft landings should be achievable, similar to the challenges faced by air traffic controllers daily.

This paper takes a close look at the different strategies used to control commercial aircraft during landing. Landing is a crucial part of flying, demanding accurate and dependable control systems to ensure safety. We'll dive into the various methods and advancements in this field, pointing out important discoveries and innovations. By reviewing current approaches and their strengths and weaknesses, we'll highlight future research opportunities. Our goal is to provide a clear and comprehensive overview that helps improve landing control strategies for commercial planes.

2. AIRPLANE LANDING SYSTEM TECHNIQUES

Automated landing procedures in challenging environments involve a range of techniques, which can be broadly classified into three categories based on their association with intelligent systems, control methodologies, and optimization approaches. To facilitate implementation, the researchers used a simplified model of a commercial aircraft in the simulations that moves only in the longitudinal and vertical planes. The motion equations for the airplane are as follows **(Miller et al., 1995)**:

$$\Delta\dot{u} = X_u(\Delta u - u_g) + X_w(\Delta w - w_g) + X_q\Delta q - g(\tfrac{\pi}{180})\cos(\gamma_0)\Delta\theta + X_E\delta_E + X_T\delta_T, \quad (1)$$

$$\Delta\dot{w} = Z_u(\Delta u - u_g) + Z_w(\Delta w - w_g) + (Z_q - \tfrac{\pi}{180}U_0)\Delta q - g(\tfrac{\pi}{180})\sin(\gamma_0)\Delta\theta + Z_E\delta_E + Z_T\delta_T, \quad (2)$$

$$\Delta\dot{q} = M_u(\Delta u - u_g) + M_w(\Delta w - w_g) + M_q\Delta q + M_E\delta_E + M_T\delta_T, \quad (3)$$

$$\Delta\dot{\theta} = \Delta q, \quad (4)$$

$$\Delta\dot{h} = -\Delta w + \frac{\pi}{180} U_0 \Delta\theta, \quad (5)$$

Where u is the aircraft longitudinal velocity (ft/s), w is the aircraft vertical velocity (ft/s), q is the pitch rate (°/s), θ is the pitch angle (°), h is the aircraft altitude (ft), δE is the incremental elevator angle (°), δT is the throttle setting (ft/s), γo is the flight path angle (−3°), and g is the acceleration due to gravity (32.2 ft/s^2). The parameters Xi, Zi, and Mi represent the stability and control derivatives.

2.1 Landing System Techniques Based on Intelligent Schemes

Intelligent schemes: Many papers have employed artificial intelligence computing methodologies including fuzzy logic and machine learning to tackle problems during landing.

2.1.1 Fuzzy Logic

Fuzzy logic is a mathematical framework commonly utilized for addressing situations marked by uncertain and imprecise information. It distinguishes itself from binary logic, which relies on precise true or false values. Fuzzy logic, in contrast to binary logic, allows statements to show different levels of truth or untruth, enabling strong and adaptable decision-making and reasoning processes in uncertain and complicated engineering systems. In the fuzzy logic method, every input and output are classified into separate fuzzy sets. Each set is assigned membership values ranging from 0 to 1, which quantify the degree of relationship with a certain set **(Gautam et al., 2014)**. The five stages in the fuzzy inference procedure: fuzzification of input variables, applying the fuzzy operator (AND or OR) in the antecedent, fuzzy inference from the antecedent to the consequent, aggregating the consequents across rules, and defuzzification **(Sabri et al., 2013; Afaneen, 2013).**
(Nho and Agarwal, 2000) creates a fuzzy logic control (FLC)system for both linear and nonlinear aircraft models to land automatically. The research focuses on a linear longitudinal airplane model with deployed landing gear and flaps at sea level. The fuzzy controller presents temporal responses for different parameters and supports the flare maneuver and glide-path capture. Experiments carried out on a nonlinear aircraft model with six degrees of freedom (6DOF) prove that this type of controller for instance can be used in practice to control both elevator and engine thrust at the same time when landing an aircraft. According to the results, the nonlinear airplane model has strong performance and stability with low steady-state error.
(Juang and Chio, 2005) proposed a model for aircraft landing control using fuzzy modeling networks. In this method, a fuzzy controller is combined with the linearized inverse aircraft model. The controller, which follows a multilayered fuzzy neural network structure, is responsible for issuing control commands at different stages of the aircraft's landing procedure. It trains the network by applying the Backpropagation Through Time algorithm. At each stage of landing, the linearized inverse aircraft model produces error signals which are transmitted to re-circulate back through the controller. These simulation results show the tracking performance and stability of the system. The fuzzy controller does its job, making it to be used in severe applications such as really bad turbulence.
(Raj and Tattikota, 2013) implement a fuzzy logic controller into Matlab's Personnel

Launching System (PLS) to track a predetermined travel trajectory for a smooth landing. In the study, as illustrated in **Fig.3** below, the fuzzy controller compares the classical controller's error during landing to the pre-setup program and corrects the errors to ensure a safe landing.

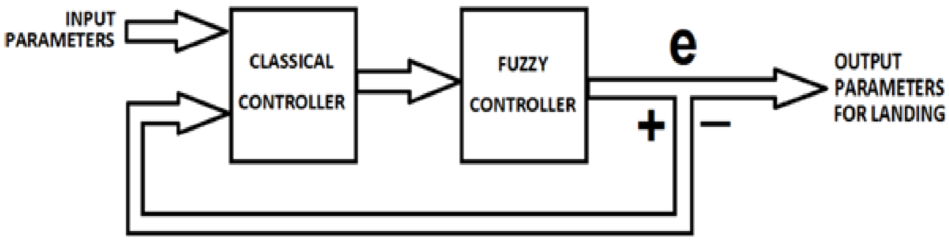

Figure 3. Basic idea **(Raj and Tattikota, 2013)**.

(Nowak et al., 2022) explores the innovative concept of integrating a vision system into an aircraft's automatic flight control system, specifically to manage longitudinal motion from the final approach to touchdown during automatic landing. This system consists of two vital components: a vision system and an automatic landing system. The vision system employs specialized image-processing algorithms to detect red and white PAPI lights (A Precision Approach Path Indicator is an arrangement of lights located adjacent to the threshold of an airport runway, serving to offer visual guidance regarding the descent path during the final phase of the approach) through onboard cameras, providing crucial positional information for the automatic landing system. The automatic landing system utilizes control algorithms based on a fuzzy logic expert system to replicate pilot actions during the landing process. The study involved testing these components as both software and hardware modules in a laboratory setup to control an aircraft model within a simulated environment. The results from these experiments demonstrate that this vision-based approach holds promise as an alternative to automated landing support systems. It is essential, however, to note that the innovative system is sensitive to variations in lighting conditions. The study acknowledges this shortfall, suggests some remedies, and calls for further research.
There is much research on using the fuzzy technique for making aircraft landing decisions under different weather conditions to enhance the pilot's decision-making and support the LCOs. In the study by **(Zadeh, 2011)**, an adaptive Neuro-Fuzzy Inference System is used to determine a successful touchdown using input variables such as visibility, pilot experience, and airspeed. Simulation results have shown that the system can forecast the success probabilities of landing. **(Ramli et al., 2014)** present a weather forecasting model for practical use in air traffic control systems using fuzzy hierarchical methods. The application provides forecasts of airport weather by fusing variables and combinations of meteorological parameters from web data sources with structured knowledge into a Mamdani model. The fuzzy weather forecasting model considers visibility, wind speed, and air turbulences in the context of supporting defuzzification to generate informed results. Because the forecasting approach here is based on current data, air traffic controllers can generate relevant forecasts.
(Wu et al., 2016) proposed a decision-making method for the secure landing of aircraft-on-aircraft carriers. As imprecision might characterize information about the environment and human decisions may not represent that which is optimal to do, the paper introduces a method that makes decision-making more accessible for the LCOs and pilots of landing consoles. That method will be named Fuzzy Multi-attribute Group Decision Making

(FMAGDM) and will consider factors that are caused by the given environment: weather and visibility, the state of air traffic, the height of clouds, and the aircraft's performance. Since the technique incorporates the views of various decision-takers, it pools the experience to help find the best landing approach in terms of diverse considerations. Using simulations, the technique works in different situations, proving the method can be used to find the safest landing approaches.

In a paper authored by **(Wijaya et al., 2016)**, the authors used fuzzy logic to see if an aircraft is fit to land or take off. This method considers visibility, wind speed, and wind direction and allows rainfall. The study highlights the application of fuzzy logic in air traffic during inclement weather. While in the study of **(Pratiwi et al., 2021)**, utilized the Mamdani fuzzy simulation method for decision-making purposes in aircraft landing. Variables such as the direction of the wind, speed, visibility, and experience were accounted for in the making of judgments about landing. The results from the fuzzy logic system were fine-tuned with the represented decisions obtained from AirNav Ahmad Yani Airport Semarang and indicated that the intelligent system based on fuzzy logic could be used to determine when to land an airplane.

Another study introduced by **(Seitbattalov et al., 2021)**, improved the landing performance of Boeing 747-100 and enhanced the decision-making process for pilots. To make landings safer and to help pilots figure out the right speed, different data from radar, GPS, and sensors are taken into account. The fuzzy logic system, based on the Mamdani Fuzzy Inference System, gives pilots information about the right braking force and distance to stop safely during landings. Overall, the paper is important for improving how planes land making it safer for Boeing 747-100 pilots.

2.1.2 Machine Learning

Machine learning (ML) is a field, within intelligence that involves creating algorithms based on data subsets. These algorithms can utilize combinations of features and weights derived from principles. In ML there are four employed methods, for tasks; supervised, unsupervised, semi-supervised, and reinforcement learning **(Choi et al., 2020)**.

ML helps make decisions better, especially during airplane landings. By looking at data, environment and real-time sensor inputs these algorithms can find patterns and make accurate predictions. This move to use data more is different from the old ways of using rules. Using ML, airplane landing systems now have a smart learning part. This lets them get better by collecting information and adjusting how they work in different situations.

Artificial neural network (ANN) is a machine learning algorithm that draws inspiration from the mechanisms of the human brain. ANNs are highly adaptive, and they can change their parameters by training on data. This adaptive process allows ANNs to better comprehend and solve complex control problems. This adaptability of ANNs allows them to effectively handle complex systems by making decisions based on a range of complex datasets. **Fig. 4** illustrates the basic structure of ANN. Imagine we feed input, usually as a bunch of numbers, into the first part called the input layer. Then, this input is sent to some middle parts called hidden layers. In these hidden layers, the network makes decisions based on what it learned before and figures out how small random changes affect the final result. This whole learning process happens over and over. When you have lots of these hidden layers, then it is called deep learning **(O'Shea and Nash, 2015)**.

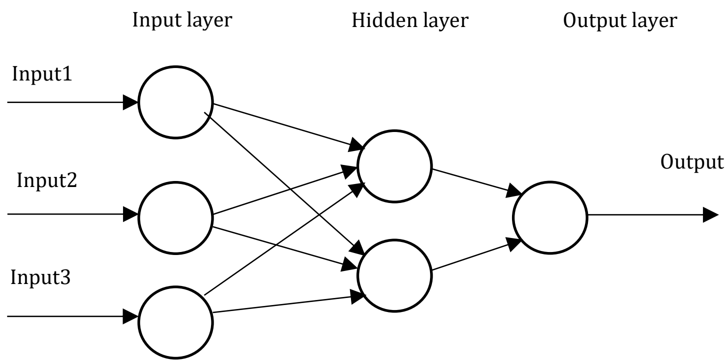

Figure 4. Simple structure of three-layered feedforward neural network (FNN).

(Juang et al., 2002) explored the application of neural networks within the domain of aircraft automatic landing (ALS) control, particularly in conjunction with the linearized inverse aircraft model and analyzed the limitations of traditional automatic landing systems and underlines the need for improved control mechanisms capable of dealing with difficult environmental conditions and presents five neural network controllers, encompassing a multilayer functional-link network, an adapted back-propagation network, a counter-propagation network, a radial basis function network, and a basic back-propagation network. These controllers are structured with three layers and undergo training through an adapted learning-through-time process. The paper's comprehensive simulation analysis demonstrates that the neural network controllers effectively expand the safety margin of automatic landing systems, resulting in improved tracking performance and enhanced robustness, particularly in scenarios involving severe turbulence. In comparison to the conventional autolander with fixed parameters, the intelligent controller based on the linearized inverse aircraft model exhibits superior performance.

(Juang et al., 2003) introduced that neural network controller can effectively lead aircraft to safe landings in stormy conditions, removing the need for gain scheduling, according to the results of this study, which applies a learning-through-time technique for training the landing controller. While conventional controllers limit safe landings to 30 feet per second of wind speed turbulence, a well-trained neural network controller increases this to 65 ft/sec. Furthermore, the neural network controller can tolerate wind shear up to 55 ft/sec, surpassing the conventional controller's limit of 40 ft/sec.

(Juang and Cheng, 2006) used neural networks to develop an intelligent ALS capable of guiding the aircraft to a safe landing in adverse wind circumstances. Five distinct neural network controllers are presented: the traditional back-propagation network (BPN), counter-propagation network (CPN), improved BPN (IBPN), radial basis function network (RBFN), and multilayer functional-link network (MFLN). The main findings show that certain neural network controllers, particularly well-trained BPN and MFLN controllers, can significantly resist turbulence up to 65 ft/s, allowing for safe landings in difficult conditions without the need for gain scheduling.

(Juang et al., 2011) used the adaptive resource allocating network (ARAN) controller to enhance aircraft landing control. It uses convergence theorems, particularly the Lyapunov theory, to assure system stability and successful learning convergence. The ARAN controller, built on a DSP architecture, performs significantly better when adaptive learning rates are used instead of fixed rates, particularly in scenarios with wind disturbances.

(Lungu and Lungu, 2017) described a new system named the Adaptive Landing System (ALS); it guides an aircraft throughout the landing and comprises two controllers for the glide phase and flare phase. An adaptive control system using a neural network supports it in making adaptations based on the dynamics of a plane. By breaking the plane's movements down into simpler components and using complex algorithms, the ALS could increase landing precision and decrease errors over older methods. Simulations prove that ALS is better with smoother landings and fewer errors.

In another study, **(Eroglu et al., 2020)** proposed a method that mixes computer learning with nonlinear flight control to deal quickly and effectively with broken actuators. They developed a model that uses ANN layers to predict the characteristics of actuator failures through sequences of flight path changes. These predicted failure factors are then used by an autoland controller. It uses nonlinear dynamic inversion to aid in quick and smooth recovery from different kinds of actuator failures. The researchers emphasized that this suggested system could also enhance the safety and reliability of an aircraft, particularly regarding weather conditions or mechanical problems.

This study of **(Tang and Lai, 2020)** focuses on using Deep Deterministic Policy Gradient (DDPG), a sort of Deep Reinforcement Learning (DRL), to improve airline landings. They experimented with several methods of teaching the computer how to land and discovered that it could learn rather well even in severe winds. The amazing part is that this strategy not only helps planes land safely but also teaches us more about how planes fly during landing. This could help pilots make better decisions or create better landing systems.

The study conducted by **(Luong et al., 2020)**, examines the limitations of oleo-pneumatic shock-absorbing struts, in aircraft landing gear. They propose Magnetorheological (MR) dampers as an alternative. MR dampers are considered active suspension systems that can adjust damping forces using magnetic fields allowing them to adapt to different landing scenarios. The research introduces a network controller that is trained using two methods; genetic algorithms and policy gradient estimation. This controller is specifically designed for aircraft landing gear equipped with MR dampers showcasing its ability to learn autonomously without knowledge of the system. The performance of the network controller is evaluated through simulations comparing it to passive dampers and an adaptive hybrid controller across various aircraft masses and descent speeds. The results indicate that both neural network controllers trained with genetic algorithms and policy gradient estimation perform similarly to the hybrid controller. This suggests that real-time landing condition estimation or, in-depth system expertise is not necessary thus increasing the versatility of aircraft landing gear.

(Puranik et al., 2020) presents a system that utilizes supervised machine learning to analyze aviation flight data with a focus, on predicting airspeed and ground speed during aircraft landings in time. The framework uses data, from airline operations to train a prediction model that works globally. It employs forest regression offline. Then tests its online prediction abilities using new data. The paper introduces several innovations, such as automated feature selection, dataset balancing, and sensitivity analysis for optimal prediction windows. The resulting model displays efficient computational performance for potential online use, delivering predictions within a second for all tested flights. Acknowledging limitations, especially outliers with prediction errors slightly exceeding 10 knots, the framework provides valuable information for pilots, operators, or air traffic control to improve decision-making during landings.

The study by **(Gil et al., 2022)** discusses methods to assist pilots make safer decisions during aircraft landings. It claims that many accidents may have been prevented if pilots had chosen to go around rather than land when things didn't look right. The authors suggest a new computer system that can be utilized in the aircraft to assist pilots in determining whether to go around based on predicted hard landings. They evaluated their method using a large amount of flight data and discovered that it worked fairly well, with 85% of the time being correct on when to go around. This means it might be a very useful tool for pilots to avoid accidents during landings.

2.2 Landing System Techniques Based on Controlling Methods

As part of a comprehensive evaluation, this section includes a systematic separation of research publications that used control approaches such as PID control, nonlinear control, robust control, and hybrid control to address issues encountered during airplane landing.

2.2.1 PID Control

A PID controller can be likened to a system that helps maintain stability. Its objective is to ensure that a system's output matches our desired outcome by verifying and changing it as needed **(Salih and Saleh, 2022)**. The reason it is widely used is due to its robustness; moreover, it is easier to tune and applicable in different applications. A PID controller is made up of three components: Proportional (P), Integral (I), and Derivative (D). Each component plays a role in the control and stabilization of the system by varying the amount of power it exerts to correct the error between the set point and actual practice **(Bansal et al., 2012; Abbas and Sami, 2018)**. The PID controller's combination of proportional, integral, and derivative actions allows it to handle control issues in a variety of industries and applications **(Szabolcsi, 2018)**.

(Sudha and Deepa, 2016) improved the stability and performance of aircraft pitch control dynamics. Its purpose was to figure out how to modify the PID controller parameters to optimize system characteristics and dynamic performance in a variety of flying conditions The study identified the Zeigler Nichols tuning method as the approach for achieving stability and performance enhancements.

In another research conducted by **(Rehman et al., 2021)**, the researchers explored ways to enhance the stability of a Boeing aircraft by incorporating a PID controller into its control system. The researchers developed a model for the aircraft's control system. Implemented a PID controller using MATLAB (R2021a) to improve stability. They opted for closed-loop strategies due to their ability to produce responses. The findings of their study revealed that disturbances, within the system could be effectively managed through the application of a PID controller. The evaluation of the control system design considers time domain requirements especially emphasizing the goal of achieving seamless stabilization. The findings, from analyzing the state space model both with and without the PID controller are extensively deliberated upon. The investigation primarily focuses on state variables, like aircraft angle, pitch angle, and pitch rate. Initially, the system response time was 35.0977 seconds, but with the integration of the PID controller, the system settled in 0.0741 seconds This integration is identified as the optimal solution for enhancing stability in the control system of a commercial Boeing aircraft.

2.2.2 Robust Control

Robust control, within the domain of control engineering, centers on creating control systems that possess the ability to uphold stability and performance robustness despite uncertainties and dynamic alterations within the controlled system. This viewpoint is critical, particularly in cases where traditional control approaches are subject to external disturbances, parameter variations, or inherent modeling flaws. The major purpose of robust control is to maintain the system's behavior within set bounds that are predefined, ensuring a reliable guarantee of safety, dependability, and the preservation of an optimally operating condition. **(Dorato, 1987; Sariyildiz et al., 2018; Matušů et al., 2019; Ali et al., 2023)**

There are notable examples of applied robust control, particularly in the domains of aerospace and aviation. The main purpose here is to carefully select control mechanisms that provide constant stability and regulated oversight of aerial vehicles, even when subjected to the unpredictable and chaotic manifestations of varied weather events and perturbations. **(Postlethwaite et al., 2007; Sariyildiz et al., 2019)**.

(Belcastro et al., 1992) presents a method for determining how planes stay on the correct path when tracking in extreme wind conditions. The major goal is to create a strong control system based on μ-synthesis to reduce errors in altitude, airspeed, and pitch angle while adhering to specific constraints. They employed mathematical models for wind shear based on previous accidents at Kennedy International Airport in 1975. It also takes into account wind gusts as disturbance inputs, utilizing the Dryden turbulence model. This study contributes to better airplane control under difficult situations, hence helping the goal of enhancing control in high-wind and turbulent environments.

(Lungu and Lungu, 2015) focused on the implementation of advanced control techniques, particularly H2/H∞ and dynamic inversion. Driven by the lack of significant advancement in the development of longitudinal plane landing control systems with these methods, the authors present an improved automatic landing system with new parts, including dynamic inversion-based subsystems, an optimal observer, mixed H2/H optimization, and reference models. They use an optimum component to handle sensor errors and disturbances and a guidance component to compute trajectories as part of their control technique. The research proves its theoretical results with exhaustive numerical simulations centered on landing a Boeing 747 while adhering to stringent Federal Aviation Administration (FAA) accuracy standards. In addition, it verifies the accuracy of the results by closely examining the temporal features throughout the glide slope and flare phases and investigates how parameter changes affect glide slope duration and height. Although it does not directly evaluate performance it provides insights and improvements, to the field of aircraft landing control by exploring and validating approaches, through simulations.

Both publications **(Lungu et al., 2016)** focus on the improvement of Automatic Landing Systems (ALS) to ensure robustness against disturbances, sensor errors, and wind shears while meeting the accuracy standards set by the FAA. The ALS used the H-inf control to offer strong stability, and dynamic inversion to enable accurate tracking. The presented ALS is designed specifically for longitudinal plane landings but is also adaptable to various flight paths. This system incorporates an optimal observer, two reference models for altitude and velocity, and a dynamic compensator. The ALS demonstrates resilience under circumstances such, as wind shears and sensor faults especially when it comes to rejecting measurement noise and low-intensity wind shears.

The study of **(Razzazan et al., 2016)** revolves around using a Model Predictive Controller to manage the motion of a Boeing 747. The modeling process relies on equations that consider variables in a state space. The study extensively examines the effectiveness and efficiency of this method through adjustments of controller parameters. The simulation results strongly support the idea that this control method is proficient in following desired trajectories and mitigating the impact of interactions within control loops. This highlights the suitability of Model Predictive Control as a method, for managing the motion of a Boeing 747.

The study of **(Voicu and Buţu, 2017)** presented a problem related to tracking the glideslope of an aircraft during challenging wind conditions specifically focusing on the incident that occurred at Kennedy International Airport in 1975. Their research utilized H∞ control, for a Boeing 737 aircraft aiming to ensure system stability and robust performance by minimizing the norm of the closed loop transfer function. The study successfully demonstrated the effectiveness of this approach in handling wind shear situations during landing. Although specific numerical results were not provided the paper offers a structured methodology that can be applied to aircraft models.

Another research paper **(Lungu, 2017)** discusses a landing system for aircraft in the longitudinal plane using a combination of H2 and H∞ control approaches to create a reliable H2/H∞ controller. This controller ensures trajectory tracking during landing including glide slope and flare phases. The theoretical findings were validated through simulations involving a Boeing 747 confirming the stability of the system when disruptions are present. The paper also delves into components of the system such as modeling landing geometry implementing an observer for state estimation and utilizing a dynamic compensator, for the mixed H2/H control law. However, there is no data provided regarding simulations or precise performance results.

(Tamkaya et al., 2019) This research paper introduces a method, for enhancing the landing control systems of airplanes moving away from traditional approaches. By combining the model following technique the P K layout, H∞ synthesis, and LMI solution methods while also accounting for wind shear disturbances, the study presents a complete framework. A set reference model guides the flare phase with the model following technique ensuring alignment with desired altitude levels. By formulating a P matrix for control setup the issue is transformed into an H∞-optimal control challenge. The simulation results confirm the effectiveness of the proposed approach demonstrating its superiority over LQR methods. Further, including wind shear effects highlights the robustness of this method to challenging weather conditions.

(Wang et al., 2020) employed a robust controller to land an airplane in windy conditions. The first part involves designing with airplane dynamics and wind shear in mind, followed by introducing a SIRAC system. It includes a stable inversion (SI) and a robust auto-landing controller (RAC) created using H-synthesis techniques. This is done to improve the predictability of the landing path under diverse scenarios. The SI aims to improve landing precision, while the H∞ stabilizes in strong gusts. Even in difficult conditions, an integrated system allowed aircraft to land smoothly. It has demonstrated its ability to track the landing path while still performing well in high-wind situations.

2.2.3 Nonlinear Control

Nonlinear control is a very important technique due to its robustness and strength to the external effect, making it suitable for nonlinear systems. It plays an important part in the aircraft control system. Aerospace systems possess nonlinear dynamics, which are effectively addressed through the use of control techniques. Engineers and researchers utilize these techniques to regulate systems, such as employing backstepping regulation and sliding mode control **(Iqbal et al., 2017; Saud and Hasan, 2018)** .

(Yoon et al., 2012) introduced a backstepping controller specifically designed for the landing of a fixed-wing aircraft. Their focus was, on managing the dynamics of the aircraft while incorporating adaptability to estimate modeling errors and external disturbances. The control law's effectiveness is confirmed through numerical simulations, particularly in scenarios involving gusts and actuator failures. Conducting a comparative analysis entails the assessment of the limited adaptive backstepping controller against the gain-scheduled classical controller, non-adaptive backstepping controller, and unconstrained adaptive backstepping controller. While the controllers performed similarly in the presence of wind turbulence, the gain-scheduled PI controller experienced elevated tracking errors during a 55m/s wind gust. Among the backstepping controllers, the constrained adaptive backstepping controller consistently displayed the lowest tracking error, demonstrating its superior performance due to its adaptability and constraint handling, as confirmed by performance indices.

(Rao and Go, 2014) investigates the sliding mode control technique to create a nonlinear aircraft controller for autonomous landing maneuvers. The suggested sliding mode controller demonstrates superior performance compared to the traditional PID controller in terms of quick alignment with the reference glide path, accurate tracking, and smooth flare maneuver execution. The paper also explores the use of Lyapunov stability criteria for formulating a control law designed to guide the sliding functions toward a solution, ultimately leading the aircraft's trajectory to converge with the reference path. Thorough validation of the controller ensues, utilizing simulations with a nonlinear aircraft model initially situated at a considerable offset from the nominal landing trajectory. It highlights how well the sliding mode controller works.

(Rigatos, 2021) introduces a method for the control of vertical take-off and landing (VTOL) aircraft where this method uses wing tip forces with small pitch degrees and directed thrust as control inputs. To address the intricate nonlinear dynamics of VTOL aircraft, the paper employs an iterative technique for approximate linearization using Taylor series expansion centered around a temporary operating point. Subsequently, an H-infinity feedback controller is devised for the approximately linearized model, while considering model uncertainties and external disturbances. The feedback gains of the controller are computed through the solution of an algebraic Riccati equation at each time step. The paper asserts that this innovative approach ensures rapid and precise tracking of VTOL aircraft's state variables, even when encountering moderate variations in control inputs, and indicates that the stability of the control scheme is rigorously demonstrated through Lyapunov analysis.

2.2.4 Hybrid Control

Hybrid control systems play a role, in enhancing the auto landing capabilities of aviation. By combining continuous and discrete dynamics, these systems enhance the precision and reliability of autoland systems ensuring landings in various conditions. This integration is vital for managing variables and challenges ultimately leading to safer and more efficient air travel **(Antsaklis and Nerode, 1998)**.

(Lungu et al., 2013) conducted a study on aircraft control during the landing phase introducing an automatic landing system (ALS). The ALS utilizes both PID controllers and their fuzzy variations through dynamic inversion. The theoretical findings were validated through simulations conducted under scenarios, including situations with or, without wind shears and sensor errors. Based on simulation data it was observed that the new ALS performs well in tracking the desired flight path angle during glide slope and flare phases. Wind shears were identified as the factor affecting system variables while sensor errors had minimal impact. This research contributes to advancements in landing geometry understanding PID controller design, and control law synthesis by investigating wind shear and gyro errors thus enhancing our knowledge of aircraft landing control, particularly in challenging conditions.

(Juang and Yu, 2015) enhanced the performance of ALS by integrating two control techniques; the Cerebellar Model Articulation Controller (CMAC) and Sliding Mode Control (SMC). These techniques are specifically used to lessen the effects of wind during landings. The researchers further optimized the SMC parameters using Evolutionary Computational techniques named chaotic practical swarm optimization (CPSO). The resulting intelligent control system excels, at resisting wind disturbances assisting pilots in challenging landing situations. Additionally, they made advancements in aircraft landing control through the utilization of Lyapunov theory for deriving learning rules and implementing TI C6713 DSP controllers for real-time control.

(Lungu and Lungu, 2016) introduced an architecture designed for managing lateral directional aircraft motion during landings. This innovative system addresses aspects such as angular deviations and lateral velocities concerning the runway. It integrates PID control, a radio navigation system, a system that measured the distance between plane and runway radio markers, and an adaptive controller. The adaptive controller employs dynamic inversion principles along, with a compensator, a neural network trained using error vectors estimated by the system, and a Pseudo Control Hedging block. Extensive numerical simulations have been conducted to verify the stability of this software-based implementation while also confirming the occurrence of overshoots. The final analysis emphasizes the control of aircraft's directional movements, during the landing phase. This achievement can primarily be attributed to the integration of elements resulting in advancements compared to previous research studies.

To make sure planes land safely, especially when there are big problems with the controls, **(Yu and Zhang, 2016)** used fault tolerant control to create a safety system for Boeing 747-100/200 aircraft and made a smart control approach using Laguerre functions (LF-MPC) to improve how quickly the controller reacts when there is a problem, where this functions method efficiently reallocates control efforts among the remaining functional actuators during fault scenarios while optimizing critical parameters for increased fault tolerance. The study also addresses the incorporation of time-delayed fault detection and diagnosis (FDD) information within the feedback control loop. Simulations validate the efficacy of the FTC and LF-MPC techniques, particularly in scenarios involving stuck elevators during the landing process. The research utilizes a comprehensive benchmark model encompassing various aircraft dynamics and environmental factors, demonstrating the robustness and reliability of the fault-tolerant control system in challenging landing conditions.

(Brukarczyk et al., 2021) introduced a system designed to automate aircraft control during the landing phase. Specifically focused on the longitudinal phase of the landing process. Propose a vision system that interprets ground markers to establish a precise glide path, for the aircraft. To mimic human pilot decision-making during landings the automatic landing system employs control algorithms based on logic expert systems. The researchers conducted laboratory testing using the hardware in the loop approach, which yielded results for this integrated system. The fuzzy rule base of the expert system comprises fourteen principles that intricately define how the aircraft should be controlled at stages of landing. By using sets the vision system effectively links deviation observed in relation to a yellow marker with the aircraft height above the runway thereby significantly improving precision and control efficiency throughout the landing process. Overall this study represents progress in developing and implementing a landing system, in real-world scenarios.

2.3 Landing System Techniques Based on Optimization Algorithms

Optimization algorithms play a pivotal role as a collection of essential instruments employed to identify the optimal solutions that are most favorable, whether it is aimed at minimizing or maximizing the objective functions, while simultaneously adhering to specific constraints. This class of algorithms includes Integer Programming, Linear Programming, and Metaheuristic techniques, all of which are designed to find high-quality optimal solutions. There has been a rise in aviation engineering research targeted at addressing the numerous issues associated with aircraft landing procedures. Particle swarm optimization and genetic algorithms are two instances of metaheuristic methodologies that have big attention in these fields owing to their efficacy in uncovering optimal solutions within practical timeframes. Optimization algorithms are widely classified into three types: Local Search Methods, Global Search Methods, and Hybrid Methods that expertly integrate local and global search results and global search strategies. **(Blum, 2003; Desale et al., 2015; Maier et al., 2018).**

By integrating a hybrid fuzzy-neural controller with a Particle Swarm Optimization (PSO) algorithm, **(Juang et al., 2005)** increases the intelligence of the automatic landing system. The research utilizes the existing flight control law, which is responsible for maintaining stability, controlling the aircraft's attitude and trajectory, and ensuring safe and efficient operation, in developing the intelligent controller, illustrating its tracking performance and adaptive capabilities through software simulations. In contrast to the 30 ft/sec wind speed limit of turbulence for safe landings with a conventional controller(PID controller), the hybrid controller, incorporating the PSO algorithm, achieves a superior limit of 90 ft/sec.

(Yu et al.,2013) used a DSP chip to develop an embedded (cerebellar model articulation controller) CMAC intelligent controller with optimization algorithms for an aircraft landing system to design an intelligent ALS controller. The researchers employed four optimization algorithms to fine-tune the pitch autopilot controller parameters. PSO, BFO, CPSO, and BSO are the names for practical swarm optimization, bacterial foraging optimization, chaos particle swarm optimization, and bacterial swarm optimization. The use of CMAC with optimization improves real-time flight control, works more efficiently, and consumes less computer memory. Simulations revealed that the DSP controller can manage a larger spectrum of turbulence than previously thought. The new way of controlling, well-trained adaptive CMAC-PID, works better than the older method (PID), letting airplanes safely land even in tough wind conditions but now it's increased to 57 feet per second. This means airplanes can land more safely in strong winds.

(Luo and Duan, 2014) introduced ALS that incorporates a Chaotic Artificial Bee Colony (CABC) optimization algorithm. The research examines the details of aircraft angling landing procedures, including factors such as wind disturbances and trying to achieve perfectly balanced coordination between thrust control and elevator controls. A Vertical Rate Referenced Guidance System and an Angle of Attack Referenced Approach Power Compensation System (APCS) are integrated into the system to further its capabilities. In the closed-loop system, the CABC optimization algorithm is used to calculate optimal filter parameters and control gains. One interesting aspect of this study is that it points out the increased efficiency in designing complex aircraft control systems made possible by using a new fitness function during design, thus lowering overall complexity.

(Qian et al., 2017) developed a neural network model to predict landing distance and improve safety procedures in order to solve the problem of aircraft runway overruns when planes land on their tails. The Extreme Learning Machine (ELM) Principle is used to carry

out the following research. Input parameters include pitch angle, vertical velocity, engine revolutions per minute, atmospheric elevation, ground speed, and wind speed. A comparison of different activation functions such as Sigmoidal, Sine, Hardlim, and Radial basis functions indicates that the latter is always better at making predictions on airplane landing distance. Also, the work integrates PSO and ELM to provide a prediction model based on PSO-ELM. This selects optimum parameters for maximum accuracy of results. The results show that the PSO-ELM model achieved a high level of accuracy, with inaccuracies less than 6 %.
In **(Bian et al., 2019)** the problems in optimizing airborne ALS are highlighted. In designing ALS, a combination of the modified particle swarm algorithm and the damped Broyden Fletcher Goldfarb Shanno method is used to make sure that accurate trajectory tracking will be maintained as well as maintaining a constant sink rate. This could thus be called it hybrid optimization approach. For tuning the parameters, then, authors use a quasi-random sequence based particle initialization and the damped BFGS method for searching. Three-point searching is used as an alternative if the case results in failure. The modified niching method is used to lead each particle toward a calculated local minimum point. The results of this study indicate that using the HPSO-BFGS algorithm to optimize ALS parameters enhances flight path tracking accuracy. In the conclusion, it points out that, with simulations verified on an F/A-18 model aircraft (the simulated data are in good agreement), this optimized ALS proved to be very effective and robust under all kinds of turbulent conditions. In addition, statistical data on control gains are provided as supplementary information which will help in the design of ALS.
Using a multi-objective algorithm, **(Zarchi and Attaran, 2019)** also provide ideas for improving the efficiency of landing gear systems on aircraft such that vibration absorption is better in varying conditions during landings. It uses a bee-intelligent algorithm to optimize controller coefficients, hydraulic actuator parameters, and the vibration absorber all at once. In particular, this study includes sensitivity and robustness analyses for various landing scenarios. The results testify to how flexible the algorithm is in adapting to different situations. The analysis of an Airbus 320-200 model via numerical modeling shows that the performance exceeds passive methods, so passenger comfort will increase and structural fatigue life may be extended.
(Dai et al., 2021) came up with new aircraft automatic landing systems in which sliding mode control (SMC) and fuzzy system are combined to have (FSMC). The study used various forms of particle swarm optimization to optimize controller parameters using adaptive weight PSO (AWPSO) and grey-based PSO (GPSO). This intelligent control system is capable of ensuring safe landings in even the worst wind shear conditions, up to 58 ft/s. It also shows real-time control using an embedded digital signal processor (DSP). Although the hardware implementation depends on a DSP, its efficiency and reliability are confirmed. Much more advanced than previous models it features superior wind shear resistance as well. This study examines DSP-based embedded FSMC with optimization algorithms to improve ALS control in all possible situations. Another study by **(Dai and Juang, 2019)** used the same controlled system of FSMC but applied more wind shear turbulence strength, from 138 ft/s up to 145ft/s. The result shows the excellence of the control system (FSMC) with GPSO than AWPSO in facing turbulence strength and guiding the plane to a successful landing.
(Abdulla and Mohammed, 2023) focuses on designing a pitch angle control system for aircraft using the Linear Quadratic Gaussian (LQG) optimal controller method with a numerical tuning algorithm. This approach also requires trying and error to solve for weighting matrices, an unavoidable shortcoming that may compromise the controller performance. In response, the paper suggests using a genetic algorithm (GA) to optimize

state and control weighting matrices. That is trying all possible combinations of their elements in search of an optimal solution. First, MATLAB simulations are used to evaluate the transient and steady-state performance of both traditional and optimized LQG pitch controller schemes in great detail. The simulation results also indicate that the newly developed optimized GA_LQG controller can compensate for noises in aircraft system dynamics, and achieves more robustly stable tracking performance than even a traditional LQG pitch control system. Additionally, the paper gives readers a mathematical model of system dynamics and describes LQG controller technology. The genetic algorithm tuning method is explained in great detail.

(Chen et al., 2023) suggest a new way to improve the operation of a civil airplane's automatic landing system. They use a special method, the non-dominated sorting genetic algorithm II (NSGA-II), and also include flying quality measures in their plan. These kinds of measurements--such as how well the plane stays on course, how quickly it responds, and How smoothly it lands--are all important in assessing whether or not a given Autoland system functions properly. Not only does it make design easier, but the method also reduces work setting controls to just this right. Of course, the paper doesn't give all the details about these flying quality measures. However, computer simulations in this article show that using a new method can make it easier for automatic landing systems to perform properly. In sum, the paper provides a method to improve the settings of civil airplanes' automatic landing systems.

3. ANALYSIS AND DISCUSSION

The reviewed literature on the autonomous landing of commercial airplanes shows a plethora of control systems, right, from conventional PID control to fuzzy logic, machine learning, and hybrid methods. A comparison of the control techniques under different turbulence conditions is given in Table 2. PID Control is commonly done as it is simple and easy, but there are drawbacks in maintaining high dynamic unforeseen conditions like turbulence at the time of landing. Fuzzy logic controllers have shown to be robust in dealing with uncertainties and imprecise information; hence, they are suitable for landing scenarios with fluctuating turbulence levels. It has been demonstrated in the research works of **(Nho and Agarwal, 2000; Juang and Chio, 2005)** that fuzzy logic can be applied to the glide-slope and flare-out stages of landing, so that touchdowns will be performed gently and smoothly, even under stormy conditions. Machine learning approaches, mainly based on neural networks and reinforcement learning, are those that are highly adaptive and predictive and can enhance landing performance. Hybrid methods, therefore, which combine fragments of classical, fuzzy, and machine learning controls, should be a promising approach for attaining peak performance. These methods exploit the strong points of either control in addressing their weaknesses. While these advances have been accomplished, there still exist some technical bottlenecks in the development of efficient automatic landing systems. One of the main challenges is the turbulence that impacts the stability and accuracy of the landing trajectories. The big deal for improving the responsiveness and accuracy of a system lies in integrating advanced sensor technologies and real-time data processing.

Table 2. Comparison between the control strategies used in ALS.

Control type	Turbulence strength (ft/sec)
PID	30
Neural Network	40
CMAC+PID+PSO	57
FSMC+ PSO	58
BPN, MFLN	65
Fuzzy+ NN+ PSO	90
SMC+ CMAC+ CPSO	133
FSMC + AWPSO	138
FSMC + GPSO	145

4. CONCLUSIONS

This literature survey focuses on the existing research on the control of landing and the design of the controller for commercial aircraft. Therein, the prime emphasis is on increasing the accuracy and safety of landing aircraft, maintaining control of the landings, and raising adaptability to bring down the occurrence of mishaps during this critical phase of flight. Fuzzy logic has proved to be effective in automating landings and, hence, in increasing the accuracy and the probability of the event. In contrast, control by neural net controllers has proved reliable and stable, thus reducing any chance of error by a pilot. Robust control methods are necessary to maintain performance under adverse conditions, ensuring accuracy and safety. Implementing robust control laws must consider most of the environmental factors and aerodynamic constraints present. The application of nonlinear control techniques is quite adept under turbulent conditions. Hybrid control schemes, in combination with multiple control schemes, increase the levels of safety and accuracy over a wide range of scenarios. Optimization methods play an integral role in making the whole system quite adaptive, especially under challenging weather conditions. However, the implementation is very complex; it needs large amounts of training data, and there are some issues related to hardware and cost. Moreover, it has to be carefully integrated into the existing aircraft systems. Nevertheless, their potential to enhance aircraft landing performance under numerous conditions cannot be overlooked. In particular, incorporating fuzzy logic, neural networks, robust control, and hybrid schemes represents a landmark in landing control technologies. Research and development in this direction need to continue for safe and accurate aircraft landing.

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Afrah A. Ali: Writing – review & editing, Writing – original draft, Methodology. Nizar H. Abbas: Proofreading, Result verification, Writing – review & editing. Ahmed Hameed Kaleel: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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نظام الهبوط الآلي للطائرات: استطلاع الأدبيات

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الخلاصة

تعتبر مرحلة هبوط الطائرة، التي تشير إلى انتهاء رحلة الطائرة، مناورة جوية حاسمة وخطيرة. على الرغم من أن الأمر قد يبدو بسيطًا، إلا أن التنبؤ بتعقيدات الأداء أثناء الهبوط يمثل تحديًا كبيرًا بسبب الخصائص الديناميكية للمرحلة، والتفاعل مع أساليب القيادة، فضلاً عن الشكوك المتأصلة في الديناميكا الهوائية. يتم تنفيذ الهبوط على مقربة من الأرض بسرعة جوية منخفضة، وتنطوي مرحلة الهبوط على مخاطر متزايدة على السلامة. ومن الجدير بالذكر أن الحالات والحوادث، وخاصة التجاوزات التي تفشل فيها الطائرات في التباطؤ بدرجة كافية على المدرج قبل الهبوط، تؤكد ضرورة استخدام تقنيات الهبوط المتقدمة. تقدم هذه الورقة مراجعة شاملة للأبحاث الممتدة من عام 1999 إلى الوقت الحاضر لاستطلاع التقنيات الذكية مثل المنطق الغامض والتعلم الآلي، ومجموعة من استراتيجيات التحكم التي تتراوح من التحكم PID الكلاسيكي إلى أساليب التحكم الهجينة المتطورة، وإجراءات التحسين باستخدام خوارزميات التحسين المتنوعة. الهدف الأساسي هو تقديم تقييم شامل للمشهد البحثي الحالي، وتقديم رؤى يمكن أن تدفع تطور الاستراتيجيات من أجل هبوط أكثر أمانًا وكفاءة، وتوفير رؤى لتحسين الاستراتيجيات من أجل هبوط أكثر أمانًا وسلاسة، والتأكد من هبوط الطائرة بأمان.

الكلمات المفتاحية: الهبوط التلقائي، التحكم في الطيران ، الاضطرابات.