Proceedings of CONF-SEML 2026 Symposium: Computational Analysis and Modeling in Complex Intelligent Systems
DOI: 10.54254/2755-2721/2026.GU32739

Research on Intelligent Human-AI Collaboration Mode for Single Pilot Operation

David Hu

Shanghai Jiao Tong University, Shanghai, China
609845392@qq.com

Abstract. The current mainstream dual-crew pilot mode faces challenges, including high pilot training costs, extended training cycles, and suboptimal crew coordination efficiency. To reduce pilot workload, improve flight efficiency, and address pilot shortages, NASA has proposed single-pilot operation (SPO). Given the potential workload overload and safety risks a single pilot may face, introducing artificial intelligence (AI) for collaborative assistance is a necessary approach to ensure flight safety. To this end, it is necessary to solve the collaboration problem between AI and human pilots during flight. This paper reviews research progress on human-AI collaboration for SPO. It combines research on AI for intelligent driving of civil aircraft to analyze the applicability and limitations of AI in SPO mode. Propose a hypothetical collaborative framework HAMA-GABA-AABA (Human-Pilot Are Better At, Ground-Operators Are Better At, AI Are Better At) for the collaborative work of human pilots, AI, and ground operators in the SPO mode. By comparing the advantages of the three in dimensions such as speed, consistency, reasoning computation, and perception, dynamic task allocation during flight is achieved, giving full play to the advantages of human-AI-ground collaborative work, and providing theoretical references for the intelligent and unmanned development of commercial aircraft in the future.

Keywords: Single pilot operation, Human-AI collaboration, Task allocation, Artificial intelligence

1. Introduction

With the continued growth of global civil aviation passenger traffic, the aviation industry is facing dual pressures: a pilot shortage and rising operating costs. The crew configuration of civil airliners has evolved from the five-person system (captain, first pilot, flight engineer, navigator, and radio operator) in the 1950s to the current two-person pilot mode [1,2], which has been in use for several decades. However, it still faces problems such as high pilot training costs, long training cycles, low crew coordination efficiency, and the risks of decision-making conflicts [2]. To enhance flight efficiency and address the pilot shortage, NASA [1] has proposed a three-step strategy from two-person piloting to unmanned piloting, and has identified the single pilot operation (SPO) mode as the current development direction for the new generation of commercial aircraft. But due to limitations in the aircraft cockpit's intelligence and public concerns about the safety of the single-pilot mode [3], research on SPO remains at the stage of theoretical study and simulation verification.

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.GU32739

Nowadays, the rapid development of artificial intelligence (AI) technology has provided opportunities for further research on the SPO mode. The academic community has begun to study the application of AI in aircraft cockpits [4,5], but research on AI in the SPO mode remains relatively limited. To ensure flight safety, reduce the burden on pilots, and improve operational efficiency, achieving efficient collaboration between artificial intelligence and human pilots in the SPO mode has become a key to advancing research.

This study will begin with a review of current research on human-AI collaboration in SPO, introduce the application of AI in the intelligent driving of civil aircraft, and analyze the applicability and limitations of AI in SPO. And based on the HABA-MABA-AABA (Human Are Better At, Machine Are Better At, AI Are Better At) [4,5], theoretical framework for expansion, combined with the human-AI-ground collaborative working environment under the SPO mode, propose a hypothetical model HAMA-GABA-AABA (Human-Pilot Are Better At, Ground-Operators Are Better At, AI Are Better At) for the collaborative work of human pilots, AI, and ground operators. Taking the typical flight-stage tasks of commercial aircraft as an example, this paper analyzes the collaboration mechanism among human pilots, AI, and ground operators at each flight stage under the SPO mode, providing theoretical references for the future intelligent and unmanned development of commercial aircraft.

2. Literature review

2.1. SPO mode system architecture

The Single Pilot Operation (SPO) mode is a commercial aviation driving mode in which only one pilot is assigned. With the support of upgraded onboard equipment and remote ground station operators, a single person can safely and effectively complete the flight of the route. The core of it is the tripartite collaborative architecture of "pilot, onboard intelligent system, and ground operator" [2]. The operation mode is dynamically divided into four scenarios based on the pilot's capability status (healthy/incapacitated) and operational standardization (normal/off-normal), and the transfer logic of control rights is defined accordingly [2], which reflects the dynamic nature and situational dependence of collaboration [2].

In recent years, research on intelligent assisted driving and unmanned driving modes in civil aviation has gradually increased both at home and abroad. NASA of the United States proposed two overall design schemes for SPO research [1]: advanced automation substitution and ground control assistance. At the same time, it was mentioned that the core concept of SPO lies in disability response and human-machine collaboration. Wang et al. [2] systematically described the organizational structure of the SPO mode for its establishment, proposed a collaborative mode of "pilot + cockpit automation system + ground airline operator" under the SPO, and built a remote-control demonstration and verification system for SPO. The feasibility of the SPO mode was verified through pilot operation evaluation. Yue et al. [6] proposed a complete organizational structure and components of a commercial remotely piloted aircraft (CRPA) system, established a tripartite collaboration including on-board automatic/autonomous systems, remote ground crews, and air traffic control (ATC), and verified the feasibility and advantages of the remotely piloted operation (RPO) mode through the modeling of airport surface operation processes. Li et al. [7] studied the impact of single-pilot operation (SPO) and dual-pilot operation (DPO) in abnormal and emergencies. They demonstrated that, under current technical conditions, SPO requires additional systems (such as ground support personnel or intelligent systems) to ensure flight safety.

DOI: 10.54254/2755-2721/2026.GU32739

2.2. Task allocation of Human-AI collaboration

Human-AI collaboration has gradually come to the fore amid the rapid development of AI. Based on research in cognitive science and human factors engineering, it is proposed that AI should avoid harming or replacing humans, but should enhance humans and form a complementary relationship with them. The collaboration between humans and AI should follow the concept of "Human-Centered AI" (HCAI) [8]. In the SPO mode, the human-AI collaboration relationship becomes key, involving multiple dimensions such as defined roles, interdependence, trust [4].

There has been considerable research on task allocation in human-AI collaboration in aircraft cockpits. Xu et al. [8–11] proposed the concept of "Human-Centered AI" (HCAI) in response to the current state of artificial intelligence development and conducted a series of interdisciplinary research on this concept. Based on the human factors engineering design guidelines for single-pilot operation (SPO) of large commercial aircraft, a preliminary research plan for human factors engineering in intelligent aircraft cockpits was proposed, grounded in the concept of "Human-Centered AI". Korentsides et al. [4,5], expanded from Fitts's classic "HABA-MABA" (Human Are Better At, Machine Are Better At) concept. The concept framework of "HABA-MABA-AABA" (Human Are Better At, Machine Are Better At, AI Are Better At) was proposed. Compare the capabilities of humans, machines, and AI from the dimensions of speed, consistency, information capacity, memory, reasoning computation, sensing, perceiving, etc. [5] Based on the existing aviation team science, propose collaboration principles applicable to AI as a potential team member to achieve balanced and effective human-AI collaboration. Ziakkas et al. [12] combined AI with the Competency-Based Training and Assessment (CBTA) framework, proposed an AI-CBTA fusion framework, and applied it to SPO, verifying that AI can provide decision support as a "virtual co-pilot" to make up for the lack of a second pilot in single-pilot operations.

2.3. Safety analysis

While promoting research on the SPO mode, some scholars have also discussed its security. Wang et al. [13] conducted a simulation flight test to study the influence of general cognitive ability and special ability of pilots on psychological load in SPO mode, verifying that there is a significant correlation between flight ability and the characterization indicators of pilots' psychological load, providing theoretical support for the future intelligent SPO cockpit human-machine function allocation design. Puca and Guglieri [14] systematically reviewed 128 studies, analyzed SPO-related research from three fields: operation, automation, and digital and cognitive flight assistants, and deeply explored key issues such as psychological workload assessment and pilot disability management, emphasizing the crucial role of human factors engineering and regulatory frameworks in the implementation of SPO. Gao et al. [3] conducted a survey and analysis of public trust and acceptance of the SPO mode and AI pilots, identifying public fear and anxiety regarding the SPO mode and the application of AI systems. They emphasized that when introducing AI technology into the aviation industry, the public's emotions and trust mechanisms must be taken into account.

To sum up, at present, scholars at home and abroad have conducted rich discussions, research, and system architecture on the SPO mode, and have achieved phased results in the application of AI in aircraft cockpits. However, research on human-AI collaboration between aircraft pilots and AI within the SPO mode remains incomplete. The main debates revolve around the feasibility of the SPO mode, the role positioning of AI, and the establishment of human-AI trust. At present, the theoretical circle has not yet formed a unified framework, which is an important direction for future research.

DOI: 10.54254/2755-2721/2026.GU32739

3. Discussion & synthesis

3.1. Theoretical combination

To better adapt to the core characteristics of the SPO mode, namely "the flight driving mode achieved by the collaboration of a single pilot, cockpit intelligent automatic system and ground airline operators" [2], this study attempts to introduce the HABA-MABA-AABA theoretical framework [4,5] into the SPO research and conduct targeted expansion and optimization. The "human" role is clearly defined as "pilot", the "AI" role as "airborne intelligent system", and the "ground operator" role under the SPO mode is incorporated to adapt to the human-AI-ground collaborative working environment [2]. Based on this, the hypothetical model framework "HAMA-GABA-AABA" (Human-Pilot Are Better At, Ground-Operator Are Better At, AI Are Better At) is proposed.

The HAMA-GABA-AABA framework compares the capabilities of human pilots, AI, and ground operators based on key attributes such as speed, consistency, memory, reasoning, computation, sensing, and perception [4,5]. As shown in Table 1, specifically.

Table 1. Application of SPO based on the HAMA-GABA-AABA framework

Attribute	Human Pilot	AI System	Ground Operator
Speed	Dynamically varies with external factors; with physiological latency.	Rapid, real-time processing of massive data; low latency.	Subject to communication latency; supports parallel processing.
Consistency	Susceptible to fatigue, emotional states, and experience disparities.	Highly consistent and fatigue-resistant; susceptible to recurring systematic errors.	Subject to fatigue, but maintains high intermediary consistency through rotation.
Information Capacity	Struggles to process multiple data streams simultaneously.	High-capacity parallel processing; deficient in priority judgment.	Extensive ground database access; network bandwidth-dependent.
Memory	Limited working memory; strong experiential memory and intuition.	Large storage capacity with accurate recall; no understanding.	Ground knowledge bases for rapid retrieval.
Reasoning Computation	Strong inductive reasoning; fuzzy situational judgment.	Strong in defined-scope computation, logic, and pattern recognition.	Global-perspective logical reasoning.
Sensing	Constrained by vision, attention, and physiological perception.	Continuous onboard sensor monitoring; hardware-dependent.	No direct physical environment perception.
Perceiving	Strong subtle cue perception and intention understanding in complex environments.	Data-based risk detection; no human intention understanding.	Macro perception capable; understands pilot intentions and provides psychological support.

3.2. Analysis of typical flight phase tasks

The flight process of commercial aircraft can be divided into key stages, such as takeoff, climb, cruise, descent, approach, and landing [2]. There are significant differences in task characteristics and cognitive load across stages, which directly affect the collaboration mode between AI and human pilots. This section presents a task analysis of the takeoff and climb stage of commercial flight, grounded in the HABA-GABA-AABA framework.

DOI: 10.54254/2755-2721/2026.GU32739

3.2.1. Takeoff stage

The takeoff stage, as a crucial starting point for flight safety, is characterized by high complexity and high cognitive load. Typical tasks at this stage include engine start-up and inspection, taxiing and guidance, takeoff inspection, and takeoff decision-making. The task types include routine, procedural, and decision-making, and it is necessary to monitor the status of multiple systems and environmental changes simultaneously.

Based on the analysis of the HABA-GABA-AABA framework, the task division during the takeoff stage is shown in Table 2.

Table 2. Analysis of the takeoff stage based on the HABA-GABA-AABA framework

Task	Collaboration Mode	Reasons
Engine start-up and inspection	Pilots take the lead; AI alerts on critical parameters; ground operators retrieve and cross-verify data.	Pilot: better adaptability; AI: speed & consistency; Ground: database trend analysis for anomaly detection.
Taxiing and guidance	AI automatically plans routes; pilots monitor throughout; ground operators push airport surface information.	AI: superior info capacity & consistency; Pilot: attention-limited; Ground: compensates for onboard perception gaps.
Takeoff inspection	AI executes standardized checklists; pilots perform final confirmation; ground operators cross-verify critical system statuses.	AI: information capacity advantage; Pilot: tacit knowledge & intuitive judgment; Tripartite verification enhances safety.
Decision-making	Pilots lead decision-making; AI provides weather and system data support; ground operators provide runway conditions and airspace traffic flow analysis.	Pilot: superior reasoning & situational judgment; AI: decision support basis; Ground: macroscopic analysis to avoid blind spots.

3.2.2. Climbing stage

During the climbing stage, the tasks are mainly procedural and information processing, with a medium to high cognitive load, and continuous monitoring of the status of multiple systems is required. Typical tasks include altitude control, heading adjustment, performance monitoring, and system status checking.

Based on the analysis of the HABA-GABA-AABA framework, the task division in the climbing stage is shown in Table 3.

DOI: 10.54254/2755-2721/2026.GU32739

Table 3. Analysis of the climbing stage based on the HABA-GABA-AABA

Task	Collaboration Mode	Reasons
Altitude control	AI executes altitude control; pilots perform dynamic monitoring and intervention; ground operators provide optimization suggestions.	AI: consistency & speed advantage; Pilot: context-based intervention timing; Ground: global airspace optimization.
Heading adjustment	AI adjusts heading; pilots confirm rationality and handle anomalies; ground operators provide route congestion warnings.	AI: information processing & consistency; Ground: global traffic access & proactive warnings.
Performance monitoring	AI monitors engine performance and fuel consumption; pilots receive system alerts and handle anomalies; ground operators analyze long-term performance trends.	AI: capacity & memory; Pilot: experience-based judgment; Ground: database & computing access.
System status checking	AI executes continuous status checks; pilots handle abnormal situations; ground operators remotely verify critical system health status.	AI: multi-source integration advantage; Ground: external perspective & independent verification.

3.3. The principle of human-AI-ground collaborative task allocation

Based on the task decomposition of typical flight phases and the HABA-GABA-AABA framework analysis, this paper proposes principles for human-AI-ground collaborative task allocation in SPO mode, providing a reference for the design of intelligent flight systems.

• AI Integration of Structured Tasks: Repetitive, procedural, and information-processing tasks (e.g., route monitoring, fuel management) are delegated to AI systems for execution.

• Human-AI Collaborative Decision-Making: Decision-critical tasks (e.g., handling anomalies, weather avoidance) are led by human pilots, with AI systems providing data-driven support and recommendations.

• Human-AI Complementary Monitoring: Human pilots oversee the operational status of AI systems, while AI systems continuously monitor the flight environment and aircraft conditions.

• Ground Support for Off-Normal Operations: When pilots encounter off-nominal flight states, ground operators act as "remote co-pilots" to provide assistance and ensure flight safety.

3.4. The limitations of the research

The limitations of this study lie in the following: Firstly, most existing research on SPO is based on simulated environments or theoretical models, lacking large-scale empirical data. Puca and Guglieri [14] noted that one key challenge in implementing the SPO mode is the lack of sufficient empirical research to verify the effectiveness of human factors engineering and regulatory frameworks. Secondly, the interpretability and reliability of AI systems still need improvement. The investigation by Gao et al. [3] shows significant differences in public trust in AI pilots, indicating that the transparency and reliability of AI systems are crucial for promoting the SPO mode. Third, there is

DOI: 10.54254/2755-2721/2026.GU32739

insufficient research on the differentiated implementation strategies of the SPO mode across various aircraft types, routes, and airlines, which limits its universality. Finally, although the HAMA-GABA-AABA framework proposed in this study has some theoretical innovations, it lacks practical application verification. Future research requires large-scale empirical studies to verify its effectiveness and provide a more solid foundation for the promotion of the SPO mode.

4. Conclusion

This study reviews the progress in research on collaboration between AI and human pilots in the SPO mode. It provides the first comprehensive framework for human-AI-ground collaboration in SPO, addressing a critical gap in current research. The HAMA-GABA-AABA framework enables dynamic task allocation based on comparative capabilities across key dimensions, offering a practical approach to implementing SPO safely and efficiently. Research shows that the SPO mode is technically feasible, but key issues such as human-AI collaboration mechanisms, task allocation optimization, and security risk assessment need to be addressed. AI systems should serve as auxiliary tools rather than decision-making entities, adopting a collaborative model of "human-led and AI-assisted". For task allocation, a dynamic strategy should be adopted, adjusted in real time based on the flight stages and contexts. Safety is the primary consideration for the SPO mode and a key factor in public acceptance. It is necessary to establish comprehensive safety assessment standards and an emergency response mechanism to enhance the transparency and reliability of the AI system.

Future related research can focus on the following directions: Further refine the interaction mechanisms between AI and human pilots to improve collaborative efficiency and trust, particularly the quality of interaction in complex decision-making scenarios. Strengthen AI's decision-making and robustness in abnormal situations, develop more reliable algorithms for anomaly detection and handling, and reduce the system failure rate. Systematically collect real flight data on SPO mode to construct multi-dimensional analysis models, and provide a solid empirical foundation for the optimization and verification of SPO. Based on differences in route characteristics, aircraft types, and airlines' operational requirements, customize and develop the implementation path and standards for the SPO mode to enhance its universality and adaptability.

With technological advancements and in-depth research, the SPO mode is expected to become an important development direction for the future civil aviation industry, providing an effective approach to addressing pilot shortages and enhancing aviation operational efficiency.

References

[1] D. Comerford et al., "NASA's single-pilot operations technical interchange meeting: proceedings and findings", pp. 1–300.

[2] WANG M, XIAO G, WANG G Q. Single pilot operation mode technology [J]. Acta Aeronautica et Astronautica Sinica, 2020, 41(4): 323541 (in Chinese). doi: 10.7527/S1000-6893.2019.23541.

[3] S. Gao, Z. Lu, H. Luan, M. Yin, and L. Wang, "AI pilot in the cockpit: an investigation of public acceptance", Int. J. Hum.-Comput. Interact., Jan. 2024, doi: 10.1080/10447318.2024.2301856.

[4] J. Korentsides, J. R. Keebler, C. M. Fausett, S. M. Patel, and E. H. Lazzara, "Human-AI teams in aviation: considerations from human factors and team science", J. Aviat./Aerosp. Educ. Res., vol. 33, no. 4, pp. 1–12, Jan. 2024, doi: 10.58940/2329-258X.2046.

[5] J. Korentsides et al., "The use of artificial intelligence (AI) in the flight deck: enhancing human-AI teamwork in aviation", J. Air Transp. Res. Soc., vol. 6, p. 100099, June 2026, doi: 10.1016/j.jatrs.2025.100099.

[6] L. Yue, W. Miao, X. Gang, and W. Guoqing, "Conceptual architecture for remotely piloted operation mode in commercial aircraft", vol. 37, no. 2, pp. 1–14.

DOI: 10.54254/2755-2721/2026.GU32739

[7] Q. Li, C.-H. Chen, K. K. H. Ng, X. Yuan, and C. Y. Yiu, "Single-pilot operations in commercial flight: effects on neural activity and visual behaviour under abnormalities and emergencies", Chin. J. Aeronaut., vol. 37, no. 8, pp. 277–292, Aug. 2024, doi: 10.1016/j.cja.2024.04.007.
[8] XU Wei, "User - Centered Design (IV): Human - Centered Artificial Intelligence, " Chinese Journal of Applied Psychology, vol. 25, no. 4, pp. 291 - 305, 2019.
[9] XU Wei, CHEN Yong, DONG Wenjun, et al. Human factors engineering research on single pilot operations for large commercial aircraft: progress and prospect [J]. Advances in Aeronautical Science and Engineering, 2022, 13(1): 1-18(in Chinese), doi: 10.16615/j.cnki.1674-8190.2022.01.01.
[10] XU Wei, GE Liezhong, GAO Zaifeng. Human-AI interaction: An emerging interdisciplinary domain for enabling human-centered AI [J]. CAAI transactions on intelligent systems, 2021, 16(4): 605–621.
[11] W. Xu, "User Centered Design (VII): From Automated to Intelligent Flight Deck, " Chinese Journal of Applied Psychology, vol. 28, no. 4, pp. 291-313, 2022.
[12] D. Ziakkas, K. Pechlivanis, and A. Plioutsias, "Enhancing aviation risk assessment through artificial intelligence: the single pilot operations case study", Transp. Res. Procedia, vol. 88, pp. 305–314, Jan. 2025, doi: 10.1016/j.trpro.2025.05.037.
[13] WANG L, YANG Z C, HONG R Y, et al. Analyzing the correlation between pilot ability and mental load in simulated SPO scenarios [J]. Journal of Safety and Environment, 2025, 25(10) : 3872 3881, doi: 10.13637/j.issn.1009-6094.2024.2253.
[14] N. Puca and G. Guglieri, "Enabling civil single-pilot operations: a state-of-the-art review", Aerotec. Missili Spazio, vol. 104, no. 3, pp. 187–212, June 2025, doi: 10.1007/s42496-024-00223-7.