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Human Factors and Safety Considerations for Automatic Takeoff Capabilities and Operations in General Aviation Aircraft: A Review of the Literature

Kelene A. Fercho, PhD[1]
David C. Newton, PhD[2]

[1]Flight Technologies and Procedures Division
Federal Aviation Administration
Oklahoma City, OK 73169

[2]Civil Aerospace Medical Institute (CAMI)
Federal Aviation Administration
Oklahoma City, OK 73169

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12. Abstract

Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this report identified and synthesized 14 studies (1999–2023) on automatic takeoff systems and human factors issues for fixed-wing General Aviation (GA) aircraft and Optionally Piloted Vehicles (OPVs). Across the reviewed literature, automatic takeoff followed a four-stage operational sequence—pilot engagement of system, automatic centerline tracking and energy management, rotation, and climb to 500 ft above ground level (AGL)—where authority transitions to a conventional autopilot. Pilot involvement across this sequence depended on system architecture: full-authority Fly-by-Wire designs automated all flight controls paired with pilot supervision, whereas limited-authority retrofits required pilots to retain manual control of certain inputs, such as ground steering, throttle management, and mechanical clutch disengagement. This shift from active flying to supervisory monitoring introduces human performance risks, including vigilance decrements, mode confusion, and delayed response to off-nominal events. This safety risk during the takeoff phase of flight is highest during high-speed Rejected Takeoffs (RTO), where current GA prototypes rely on manual pilot intervention—such as retarding throttles or pressing stick disconnects—rather than automated RTO execution. To mitigate this hazard, simulator and flight test data demonstrate that directive warnings ("CONTINUE/REJECT") messages shorten pilot decision latency compared to non-directive warnings (“Engine Failure”), provided the display communicates the real-time rationale for the alert. Future research should evaluate automatic takeoff capabilities under a wider variety of operational conditions to better characterize pilot workload, monitoring vigilance, mode awareness, display interpretability, and flight safety during non-normal operations.

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List of Abbreviations

Acronym	Abbreviation Explained
AC	Advisory Circular
AFGS	Auto flight guidance system
AFM	Aircraft Flight Manual
AGL	Above ground level
AIAA	American Institute of Aeronautics and Astronautics
ARP	Aerospace recommended practice
ATC	Air Traffic Control
ATOL	Automatic takeoff and landing
ATTOL	Autonomous taxi, take-off & landing
CAMI	Civil Aerospace Medical Institute
C2	Command and control
CFR	Code of Federal Regulations
CS	Certification Specification
ConOps	Concept of operations
DA	Diamond Aircraft Industries
DGPS	Differential Global Positioning System
DOT	Department of Transportation
DTIC	Defense Technical Information Center
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FbW	Fly-by-Wire
FCC	Flight control computer
FGS	Flight guidance system
FMS	Flight management system
GA	General aviation
GBAS	Ground-Based Augmentation System

GCS	Ground Control Station
GPS	Global Positioning System
HIL	Hardware-in-the-loop
HMI	Human-Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
INDI	Incremental nonlinear dynamic inversion
INS	Inertial Navigation System
MCP	Mode control panel
MIL	Model-in-the-loop
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
OEM	Original equipment manufacturer
OPV	Optionally piloted vehicle
PFD	Primary flight display
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RTK	Real-time kinematic
RTO	Rejected takeoff
SAE	Society of Automotive Engineers
SBAS	Satellite-Based Augmentation System
SOP	Standard operating procedure
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
U.S.	United States
VMC	Visual Meteorological Conditions

1. Introduction

Autopilot systems have evolved considerably over the years, progressing from basic wing levelers to fully integrated flight control systems. However, until recently, autopilot systems in General Aviation (GA) aircraft were not capable of offering advanced capabilities like enabling a fully automatic takeoff operation. A flight deck automated system is defined as any device that replaces human mental or physical activity (Abbott, 2023). While these automated systems may offer some safety benefits, introducing new technology and operational concepts fundamentally changes the nature of the pilot's work.The Federal Aviation Administration (FAA) has a responsibility to ensure safe flight operations in the U.S. National Airspace System (NAS), which includes determining the human factors considerations for new or modified technologies. This report synthesizes existing research on automatic takeoff systems and their associated operational concepts for fixed-wing GA aircraft, providing policymakers, researchers, and practitioners with timely insights as these technologies advance.

According to FAA Advisory Circular (AC) 25.1329-1C “Approval of Flight Guidance Systems,” the autopilot is a component of the Flight Guidance System (FGS) that provides automatic control of the aircraft's flight path and motion. It operates in conjunction with flight directors and autothrust to manage lateral, vertical, and speed modes. When combined with other systems—such as automatic flight guidance systems (AFGS), flight management systems (FMS), and autothrottles—autopilots can automate tasks including maneuvering control, navigation, tracking, takeoff, landing, structural mode control, gust alleviation, and stability augmentation (See & Levy, 1980). An automatic takeoff system represents an advancement in flight deck automation, building upon core autopilot functionalities long used during the airborne and landing phases of flight.

Depending on system design and proposed operational concepts, automatic takeoff systems can enable an aircraft to initiate the takeoff roll, maintain directional control, and rotate with minimal or no control input from the pilot. However, use of an automatic takeoff system may still place significant decision-making on the pilot. Pilots need interfaces that support the demands of the task and situation, whether through traditional flight controls or integrated digital systems. These interfaces allow pilots to monitor aircraft and system status, assess performance, and take manual control when needed. Furthermore, because automated systems are intended to offload tasks normally performed by the pilot, there is often an unrealistic expectation that training requirements can be reduced. In reality, manual flight skills involve complex psychomotor and cognitive processes that require ongoing practice to maintain proficiency and confidence. Pilots must also possess the knowledge and skills to diagnose automation anomalies and respond appropriately. Ultimately, effective automation use requires thorough training in normal and non-normal operations, ensuring pilots understand system design philosophy, recognize failures or unintended behaviors, and execute timely manual interventions. As a result, the introduction of new automated systems on the flight deck requires pilot training curricula to be reevaluated and updated rather than assuming that training requirements will decrease. These training challenges are particularly relevant to General

Aviation (14 CFR 91), where many operations are conducted by a single pilot without a second pilot available for monitoring, and where training requirements are generally less structured than those for commercial air carriers. The wide range of pilot experience and operating environments can further contribute to differences in training needs.

The use of flight deck automated systems has the potential to reduce pilot workload, mitigate fatigue and stress by handling routine operations, minimize minor errors, increase task execution precision, and improve energy management efficiency. However, as outlined in FAA AC 120-123 “Flightpath Management,” any automation-associated shift in workload must be evaluated within the full operational context to determine whether it truly enhances safety or introduces unintended consequences. For example, while automation is advantageous during normal conditions, it can actually increase workload during challenging situations—such as system failures—due to the added complexity of managing the automated system itself. Consider adaptive automation, which dynamically reallocates tasks between the pilot and the automated system based on the type of operation, pilot performance, the flight environment, or other factors. Although intended to help manage workload, adaptive automation can intensify system opacity and mode confusion, making it difficult for pilots to maintain an accurate mental model of the aircraft’s state. Pilots may have difficulty anticipating or understanding automated actions when task allocation changes dynamically. This can make it less clear which functions are being controlled by the pilot and which are being handled by the automated system, especially during high-workload phases of flight. For example, an adaptive automated system that automatically changes pitch or throttle settings during takeoff could leave the pilot uncertain about why the aircraft is responding in a particular way. The pilot may need to determine whether the response is the result of a manual input, an atmospheric disturbance such as windshear or turbulence, or an automated command. During takeoff, low altitude and limited terrain clearance can leave little room for error; even a short delay in determining a need for response can reduce the time available for corrective action.

Another potential risk associated with flight deck automation is pilot overreliance on automated systems, which can lead to complacency and reduced engagement—a state commonly referred to as being "out-of-the-loop." Humans are not inherently suited for prolonged monitoring or vigilance tasks, and numerous aviation accidents and incidents have demonstrated how easily even experienced pilots can lose situation awareness during automated flight operations. These events are often linked to human factors issues such as complacency, automation bias, and mode confusion (Brown, 2016; Endsley, 2023; Gawron, 2019). Consequently, introducing an automated system on the flight deck does not inherently result in a workload reduction, reduced training requirements, improved human performance, or a net safety benefit.

1.1. Functional Description of an Automatic Takeoff System

In modern aviation, pilots increasingly divide their attention between manually flying the aircraft and supervising automated systems. This relationship between pilots and automation can be understood through Sheridan’s (2012) framework of supervisory control. In this framework, the pilot interacts with flight deck computers to process data and execute control

actions. Specifically, the pilot's responsibilities encompass five core functions: (1) planning tasks and operational strategies, (2) programming the computer to execute the plan, (3) monitoring the automated process as it unfolds, (4) intervening when a task completes or if a malfunction/emergency occurs, and (5) learning from the experience to enhance future performance.

While specific system architectures and operational concepts vary, one illustrative implementation of an automatic takeoff system operating under supervisory control begins with the pilot planning the takeoff sequence and engaging the system. Once activated, the flight control computer (FCC) receives inputs from aircraft sensors and calculates output commands for the designated actuators. These actuators manipulate the primary flight control surfaces and autothrottle to produce the desired motion. Aircraft sensors detect the resulting motion and feed updated data back to both the flight computer and the flight deck displays. Throughout this sequence, the pilot monitors primary flight displays, physical control movements, and external visual references to continuously evaluate aircraft state, trajectory, and system performance. If an anomaly occurs, the pilot can disengage the system and resume manual control through primary flight inputs or mode selections (See & Levy, 1980).

Although automated systems can reduce the pilot's need to provide continuous manual control, they do not eliminate the pilot's responsibility for monitoring system behavior, maintaining awareness of system modes and control authority, and intervening when necessary. As flight deck automation becomes more complex, these supervisory responsibilities can present additional human factors challenges. Pilots must thoroughly understand the functions and underlying logic of automated systems to operate them safely (Billings, 1996). However, interdependencies among integrated subsystems are not always transparent to the pilot. This opacity can be further compounded by adaptive automation, which dynamically shifts tasks between the automated system and the pilot based on changing flight conditions or workload. When dynamic task allocation occurs without clear annunciation or feedback, the pilot's information-processing demands may increase. Under high-demand conditions, the pilot may need to expend substantial cognitive effort to determine current system status and control authority, interpret aircraft response, and maintain an accurate mental model of system behavior. If these conditions contribute to mode confusion or an inaccurate mental model, situation awareness may be degraded, potentially reducing the pilot's ability to recognize the need for and execute timely manual intervention.

1.2. Current State of Automatic Takeoff Systems

While automatic landing systems have existed since at least 1965 and are now common in transport category aircraft, the development and operational implementation of automatic takeoff systems have historically progressed at a slower pace (Cross, 2023). Nonetheless, rudimentary forms of automated takeoff assistance date back to at least the mid-twentieth century. One early example was automatic propeller feathering, in which a system could detect a loss of engine power during takeoff and automatically move the propeller blades toward the feathered position to reduce drag following an engine failure (Billings, 1996; Kershaw, 1950). Although such systems were intended to reduce pilot workload and mitigate the aerodynamic

effects of an engine failure, inadvertent or erroneous feathering could have significant consequences if the system incorrectly identified a functioning engine as having failed. These early forms of automation are therefore relevant to the evolution of automatic takeoff systems because they illustrate an important human-machine interaction consideration: automated systems may directly affect aircraft control and performance while, when not appropriately designed, provide the pilot with limited opportunity to assess, anticipate, or intervene in the system's response.

In recent years, several original equipment manufacturers (OEMs) have developed automatic takeoff systems, ranging from targeted takeoff-assist features to more comprehensive systems capable of performing the takeoff sequence with limited pilot control input. Although initially flight-tested on transport category platforms, these developments provide valuable technical foundations for emerging GA applications. For instance, Embraer developed the E2 Enhanced Take Off System, which aims to produce a more precise rotation moment and flight trajectory to optimize field performance and reduce pilot workload ("Embraer Reveals Upgrades," 2024). The E2 utilizes a fail-passive architecture that allows the pilot to override the system and assume manual control at any time, though normal operation still requires the pilot to maintain lateral control via the rudder during the takeoff roll. Similarly, Airbus demonstrated a fully automatic, vision-based takeoff system on an A350-1000 aircraft under its Autonomous Taxi, Take-Off, & Landing (ATTOL) project ("Airbus demonstrates," 2020; Persinos, 2024). Together, these OEM concepts illustrate how different system architectures allocate flight control responsibilities—such as splitting pitch and roll authority or automating full guidance—during the takeoff phase.

In the GA domain, technology developers have engineered automated systems that initially support automated flight phases with an onboard safety pilot, aiming toward eventual uncrewed autonomous flight. Merlin Labs developed a digital flight control system—termed a "non-human pilot"—designed to manage takeoff, en route navigation, and landing phases while an onboard pilot-in-command monitors navigation performance and system execution ("Merlin Progresses Flight Test Campaign," 2025). Reliable Robotics has pursued a comparable supervisory framework, evaluating automated takeoff and landing capabilities with an onboard monitoring pilot (Budman, 2023). Notably, both developers selected the Cessna 208 Grand Caravan, a single-engine GA aircraft, as their primary flight-test platform. This illustrates how GA aircraft can be used to test increasingly automated flight functions, from supervisory control to autonomous takeoff.

1.3. Present Literature Review

Automatic takeoff systems for GA fixed-wing aircraft offer potential operational benefits but also raise new safety challenges. The FAA must consider how these systems could affect technical requirements, regulations and policy, pilot performance and workload, training, operational concepts, and the responsibilities of pilots and flightcrews. To examine these issues, this scientific literature review evaluates research on automatic takeoff systems in fixed-wing GA aircraft and addresses the following seven research questions:

1. **Publication Scope:** How many publications include information on automatic takeoff systems or operations in GA fixed-wing aircraft?
2. **Operational Boundaries:** How is an automatic takeoff operation defined or described (e.g., specific start and end points of the operation)?
3. **Operating Context:** What operating environments have been evaluated in existing research?
4. **Enabling Technologies:** What sensor-based technologies or integrated automated system combinations enable automatic takeoff operations?
5. **Pilot Roles & Responsibilities:** What are the explicit roles and responsibilities of the onboard pilot during an automatic takeoff operation (e.g., when and how does the pilot engage the system, disengage the system, or execute a manual intervention)?
6. **Training Requirements:** Beyond standard pilot training, checking, and currency required by operational rules, what additional knowledge, skills, or experience are required for automatic takeoff operations?
7. **Anomaly Detection & Intervention:** What cues indicate the occurrence of a non-normal, abnormal, or emergency condition during takeoff, and what is the appropriate pilot response?

2. Method

The reporting of this review was guided by the standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodological review framework (Page et al., 2021).

2.1. Search Strategy

The literature review was conducted between March 2024 and May 2025. Eight databases (American Institute of Aeronautics and Astronautics [AIAA]; Defense Technical Information Center [DTIC]; FAA Technical Reports Libraries; Google Scholar; Institute of Electrical and Electronics Engineers [IEEE]; National Aeronautics and Space Administration [NASA] Technical Reports Server; Society of Automotive Engineers [SAE] International; US Department of Transportation [DOT] National Transportation Library) were searched to capture government, industry, and academic publications, using combinations of search terms derived from researcher discussion, FAA stakeholder recommendations, as well as keywords identified from relevant published papers. The search terms included: “aircraft,” “airplane,” “auto takeoff,” “automatic takeoff,” “aviation,” “human-computer interaction,” “hybrid control system,” “optionally piloted,” “performance,” “plane,” “transition procedure,” “unified control strategy,” and “vision-based guidance.” Inclusion criteria included: (a) the reference must be relevant to traditionally piloted aircraft and operations (in contrast with unmanned aerial vehicles [UAVs] or drones); (b) the reference must be relevant to fixed-wing aircraft (as opposed to rotary wing aircraft); and (c) the reference must be relevant to the takeoff phase of flight. Initial search results indicated the vast majority of papers focused on UAVs or drones. Thus, the search strategy was updated to

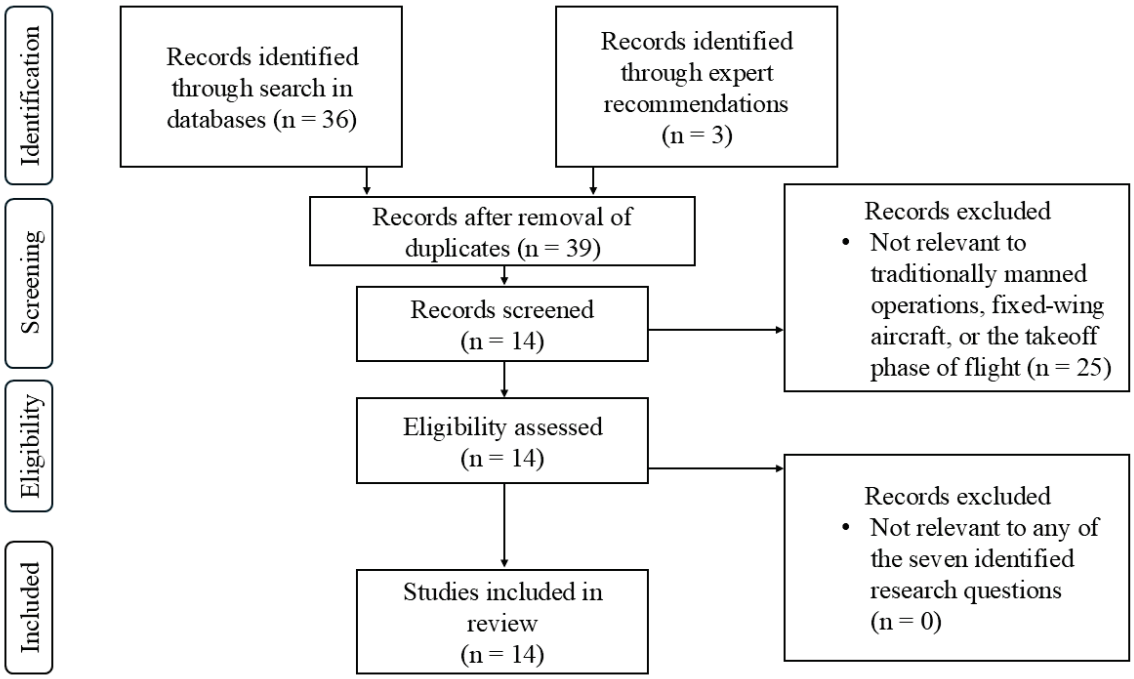
include “unmanned” as an exclusion word. The inclusion criteria were motivated by the goal of providing data and information requested by FAA stakeholders. Publications needed to be available in full text and in English, with no restriction on publication year.

2.2. Search Results

As given in Figure 1, this search identified 36 publications, and FAA stakeholders provided an additional three publications. No duplicates were identified, resulting in 39 publications which were screened against the inclusion criteria. Twenty-five publications were excluded during screening because they weren’t relevant to traditionally piloted aircraft operations, fixed-wing aircraft, or the takeoff phase of flight. The remaining 14 publications underwent full-text review to determine relevance to at least one of the seven identified research questions. All 14 publications met these criteria and were included in this review. All 14 publications were conference proceedings papers, published between the years of 1999 and 2023.

Figure 1

Literature Review Search Results



3. Literature Review Results and Discussion

3.1. Summary of the Literature

Table 1

Summary of the 14 studies meeting the inclusion criteria for automatic takeoff systems or operations in fixed-wing GA aircraft.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Gierszewski et al. (2021)	**Aircraft:** Certification Specification (CS)-23 GA Aircraft Optionally Piloted Vehicle (OPV) **Environment:** Procedure-Based Functional Analysis **Phase:** Initial Climb, Automatic Handover of Control	Procedure-based functional analysis, Concept of Operations (ConOps), Remote pilot supervisory control	**Aim:** Conducted a procedure-based functional analysis to define operational requirements and ConOps for transforming a Part 23 light GA aircraft into a certifiable OPV. **Key Takeaway:** Established that formalizing procedure-based handovers during initial climb reduces operational complexity, preventing unintended or ambiguous automation mode engagement during automatic takeoff and climb-out.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Inagaki et al. (1999)	**Aircraft:** Transport Category Jet Aircraft **Environment:** Manned Flight Simulator **Phase:** Emergency Abort / Go/No-Go Takeoff Decisions	Takeoff decision support, Time-sensitive alerts, Automation surprise, Pilot trust	**Aim:** Evaluated HMI decision-support strategies (direct "Go"/"Abort" directives vs. conventional "Engine Failure" cautions) during time-critical engine failures on takeoff in a piloted flight simulator. **Key Takeaway:** Demonstrated that direct directive alerts significantly reduce overrun accidents compared to status-only alerts; however, dynamic switching between "Abort" and "Go" recommendations as available runway decreases degrades pilot trust unless accompanied by real-time contextual rationale.
Karlsson et al. (2016)	**Aircraft:** Diamond DA42 **Environment:** Real Flight Tests **Phase:** Fully Autonomous Flight Path Control (En Route, Approach)	Auto-flight path control, Automatic guidance, Supervisory oversight	**Aim:** Designed and flight-tested a modular automatic flight path controller—utilizing dynamic inversion and pseudo-control hedging—on a Diamond DA42 testbed for airspeed, lateral, and vertical trajectory tracking. **Key Takeaway:** Demonstrated flightpath tracking and disturbance rejection in turbulent flight conditions, which may inform the core baseline guidance controller intended for future automatic takeoff and landing integration.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Krause & Holzapfel (2018)	**Aircraft:** Diamond DA42 NG (Fly-by-Wire [FbW] OPV) **Environment:** Real Flight Tests & Simulation **Phase:** Multi-mode Automatic Takeoff and Landing (ATOL), Mode Switching	System Automation (SysAuto) state machine, Mode transition logic, Link-loss contingencies	**Aim:** Developed and flight-tested a multi-level finite state machine architecture (SysAuto) for an OPV Diamond DA42 research aircraft to manage complex mode transitions across automated flight phases, including ATOL. **Key Takeaway:** Demonstrated in real flight tests and Hardware-in-the-Loop simulations that structured finite-state automation manages safe mode handovers, reliably triggers contingency procedures during sensor or link failures (e.g., GPS loss or command and control (C2) link loss), and preserves manual pilot override authority under all tested operational conditions.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Kügler & Holzapfel (2020)	**Aircraft:** Diamond DA42 (OPV) & SAGITTA Research Demonstrator (UAV) **Environment:** ConOps Framework & Flight Test **Phase:** ConOps for Piloted vs. Unmanned Automatic Flight	Functional requirements, Control authority, Single-pilot / Uncrewed operational concepts	**Aim:** Evaluated system design principles, operational requirements, and flight-test experiences across two distinct research platforms—the uncrewed SAGITTA flying-wing UAV (150 kg) and the optionally piloted Diamond DA42 (2 tons)—to compare autonomous takeoff and autoland development strategies. **Key Takeaway:** Demonstrated that uncrewed platforms require higher preflight automation robustness, extensive onboard health monitoring, and automated contingency modes due to remote communication latencies, whereas OPVs leverage onboard safety pilot fallback to enable step-wise flight-test validation with reduced operational risk.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Maly et al. (2023)	**Aircraft:** Diamond DA42 (OPV) **Environment:** ConOps Procedure Analysis **Phase:** Standard Operating Procedures (SOPs) for Automatic Flight	Operational procedure development, Supervisory control, System architecture	**Aim:** Adapted a procedure-based development process to establish a ConOps for converting a CS-23 twin-engine GA aircraft (Diamond DA42) into an OPV, incorporating existing Aircraft Flight Manual (AFM) procedures and SAE ARP4754A system safety standards. **Key Takeaway:** Demonstrated that integrating existing flight manual procedures into the OPV ConOps framework supports development and ensures regulatory compliance, while structured standard operating procedures (SOPs) for automatic takeoff and climb-out are needed to maintain operational authority between the onboard safety pilot, remote operator, and aircraft automation.
Nagayama et al. (2004)	**Aircraft:** Diamond HK36 Super Dimona (Powered Glider) **Environment:** Real Flight Tests **Phase:** ATOL	Fully automated takeoff/landing flight control, Sensor-based guidance	**Aim:** Developed and flight-tested a fully automated takeoff and landing system (FABOT) on a Diamond HK36 Super Dimona motor glider using an integrated RTK-GPS/INS navigation and flight control system. **Key Takeaway:** Reported lateral ground-roll tracking within 1 meter of runway centerline on a 20-meter runway, and showed that stick-mounted mechanical levers enabled manual pilot disengagement during automated ground roll and climb.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Olson & McElroy (2015)	**Aircraft:** Cessna 150 (Remotely Piloted / OPV) **Environment:** Real Flight Tests **Phase:** Ground Control Station (GCS) Controlled Departure & Flight	Remotely piloted interfaces, GCS control loops, Flight test techniques	**Aim:** Evaluated GCS pilot control interfaces and flight-test techniques on a remotely piloted Cessna 150 OPV across five control modes. **Key Takeaway:** Observed that command-directed autopilot modes reduced pilot workload during trajectory tracking compared to manual remotely piloted modes, while noting that data-link latency degraded pilot performance during direct remote manual control.
Scherer et al. (2022)	**Aircraft:** PC-Aero Elektra One (Ultra-Light Electric OPV) **Environment:** Real Flight Tests **Phase:** ATOL	All-electric propulsion, manual ground roll with automated rotation, and computationally constrained avionics	**Aim:** Flight-tested an ATOL system on an all-electric light aircraft (PC-Aero Elektra One / ELIAS) using simplified trajectory generation algorithms suited for computationally constrained avionics. **Key Takeaway:** Utilized manual ground-roll steering and braking due to lack of nosewheel actuation and automatic brakes, while demonstrating that the flight control state machine managed automatic pitch rotation, climb-out tracking, and a premature liftoff induced by aerodynamic ground effect.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Schumann et al. (2018)	**Aircraft:** Generic Fixed-Wing UAS / GA **Environment:** Software Simulation Model **Phase:** Takeoff Run Abort / Emergency Braking Distance Prediction	Probabilistic braking distance prediction, Risk-aware takeoff monitoring, Abort automation	**Aim:** Developed a model-based monitoring architecture using particle filters and Monte Carlo techniques to calculate probability density functions for takeoff distance and stopping distance under sensor noise and potential failure conditions. **Key Takeaway:** Showed that real-time probabilistic prediction of stopping distance and distance to screen height provides quantitative risk evaluations to support automated or pilot-initiated go/no-go abort decisions during the takeoff roll.
Steinleitner et al. (2022)	**Aircraft:** Bormatec MAJA UAS (Tailwheel Model) **Environment:** Flight Tests **Phase:** Automatic Takeoff and Landing for Tailwheel Aircraft	Directional ground control, Tailwheel dynamic stability, Automated takeoff roll	**Aim:** Developed and flight-tested guidance and control algorithms using Incremental Nonlinear Dynamic Inversion (INDI) for automated ground roll, rotation, and autoland of a tailwheel aircraft. **Key Takeaway:** Demonstrated that sensor-based acceleration feedback in INDI compensates for ground-effect uncertainties and directional stability challenges during tailwheel ground acceleration without requiring model gain adjustments across flight phases.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Zollitsch et al. (2019)	**Aircraft:** Diamond DA42 (Twin-Engine GA) **Environment:** Real Flight Tests & Simulation **Phase:** Takeoff Performance & Distance Monitoring	Model-based state monitoring, Real-time takeoff distance prediction, Runway excursion prevention	**Aim:** Developed and evaluated a model-based monitoring architecture using particle filters to estimate real-time acceleration, takeoff-roll performance, and stopping distance during automated flight operations. **Key Takeaway:** Showed that automated takeoff execution provides higher trajectory repeatability than manual piloting, enabling real-time distance predictions through rotation and initial climb to screen height to support abort-or-continue decisions.
Zollitsch et al. (2017)	**Aircraft:** Diamond DA42 (FbW Research Aircraft) **Environment:** Real Flight Tests **Phase:** Automatic Takeoff and Ground Roll Runway Centerline Tracking	Multi-phase automatic takeoff control, Safe activation logic, Pilot disengagement/override	**Aim:** Designed and flight-tested a state-machine-based automatic takeoff control system on a FbW Diamond DA42 research aircraft covering runway alignment, ground-roll acceleration, rotation, and initial climb. **Key Takeaway:** Demonstrated that automatic takeoff can be executed by re-using modular baseline flight control functions without dedicated takeoff control laws, while showing that physical stick-mounted disconnect switches provided immediate pilot takeover authority throughout ground roll and climb.

Author (Year)	Platform & Operational Scope	Human Factors & Technical Concept	Aims & Key Takeaways
Zollitsch et al. (2018)	**Aircraft:** Diamond DA42 (GA Testbed) **Environment:** Model-in-the-Loop (MIL) Simulation **Phase:** Experimental Automatic Flight Control Software	Model-in-the-loop simulation, Control law verification, Supervisory logic	**Aim:** Evaluated experimental FbW flight control software for a modified twin-engine GA aircraft (Diamond DA42) within a modular Model-in-the-Loop (MIL) simulation environment in MATLAB/Simulink. **Key Takeaway:** Demonstrated that closed-loop MIL simulation enabled pre-flight verification of state-machine mode transitions, sensor and actuator interfaces, and software logic prior to live aircraft flight testing.

3.2. Concepts of Operation

3.2.1. Beginning and Ending Point of an Automatic Takeoff Operation

Based on examples of GA automatic takeoff operations described in research literature, an automatic takeoff sequence begins after the human pilot-in-command receives an air traffic control (ATC) takeoff clearance, or visually verifies that the runway and departure corridor are clear in non-towered environments. Rather than the aircraft system directly receiving the clearance, the onboard pilot acts as the supervisory decision-maker, interacting with the flight deck human-machine interface (HMI) to initiate the operation. Abstractly, this human-machine interaction typically involves the pilot validating key departure parameters—such as setting the active runway heading, verifying target climb speeds, and confirming the initial cruise waypoint on the flight guidance controller or digital touchscreen interface—before engaging the automatic takeoff mode via a dedicated physical button or soft-key prompt. Once activated, the system automation assumes flight loop authority to execute runway lineup, ground roll acceleration, centerline tracking, pitch rotation, and initial climb-out (see Figure 2).

The automatic takeoff operation concludes when the aircraft completes its departure profile and transitions to standard autopilot cruise commands at a designated altitude or waypoint, where the flight continues along pre-programmed navigation routes (e.g., see Scherer et al., 2022). A primary example in the literature of a GA aircraft with automatic takeoff capabilities is detailed across several publications evaluating a modified Diamond DA42 flight control testbed (see Krause & Holzapfel, 2018; Kügler & Holzapfel, 2020; Zollitsch et al., 2017,

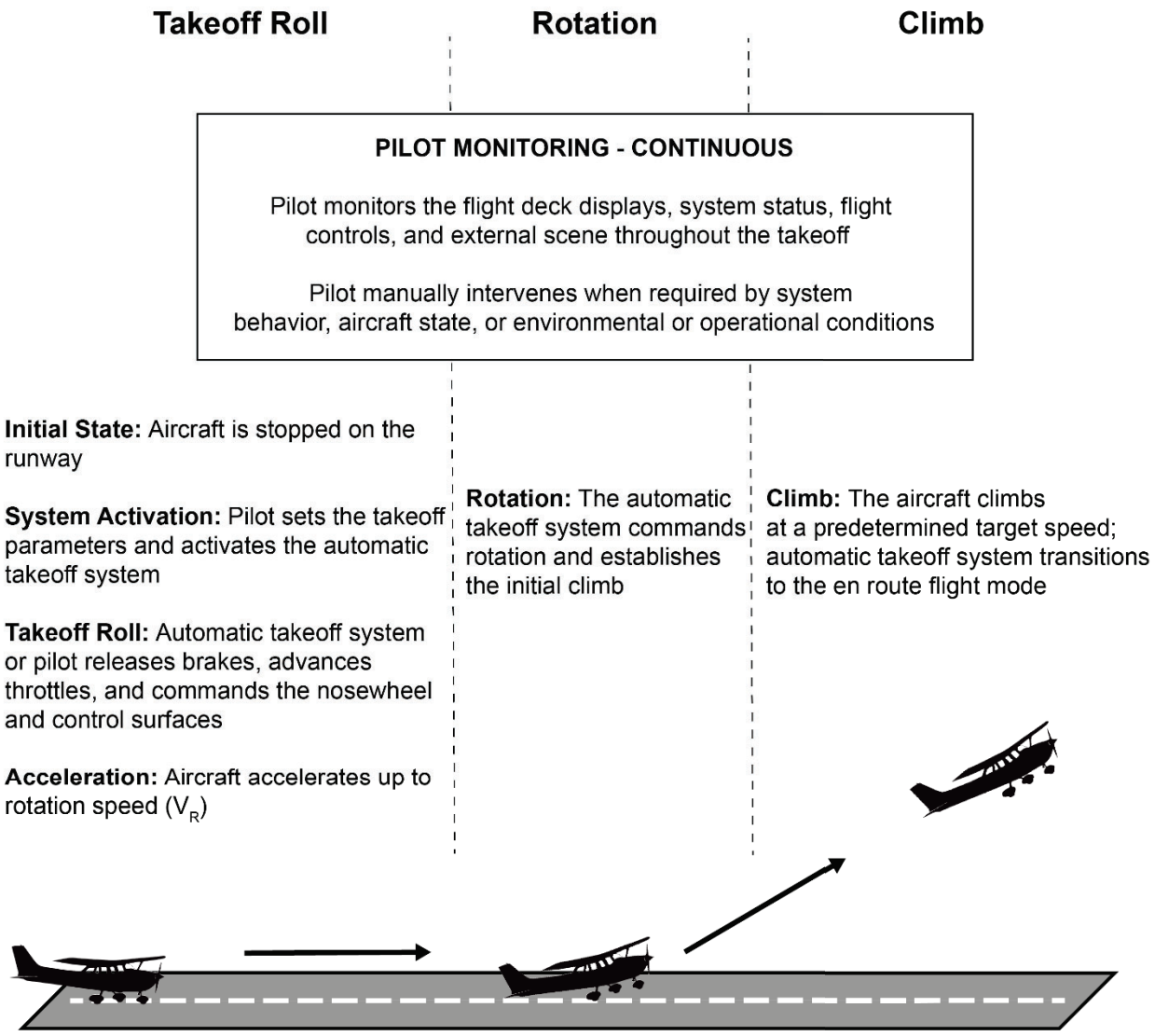
2018). These studies describe an experimental FbW architecture capable of continuous autopilot engagement across automatic takeoff, departure tracking, and landing phases within OPV operational frameworks. When configured for an onboard supervisory pilot, the DA42 operates from a baseline "parking mode"—where control surface commands are disabled, wheel brakes are applied, and thrust is set to idle. Upon pilot initiation via the HMI, the automation releases the brakes, advances thrust, and controls the nosewheel steering and flight control surfaces throughout the takeoff roll, rotation, and initial climb-out before transitioning to GPS-guided autopilot cruise commands for en route flight.

Descriptions of the beginning and ending points of a GA automatic takeoff operation are also documented in literature detailing an automatic takeoff and landing system developed by Fuji Heavy Industries for an HK36 Super Dimona powered glider produced by Diamond Aircraft Industries (DA). Nagayama et al. (2004) document the ConOps for this system, including transition points across flight phases, modes of operation, and automated functions. To begin an automatic takeoff with this system, the pilot activates the system using a physical switch on the control panel while the aircraft is stopped on the runway. The automatic takeoff system advances the throttle to maximum power and controls the nosewheel steering and flight control surfaces throughout the takeoff roll, rotation, and climb-out. The system automatically transitions from takeoff mode to cruise mode when the aircraft reaches the first waypoint programmed into the navigation system.

From a human factors perspective, the takeoff operation is a dynamic, high-workload phase of flight consisting of distinct mechanical and decision-making components—from engine power application, aircraft configuration verification (e.g., flap settings), and directional runway control via rudder inputs during the takeoff roll, to precise V-speed calculation, pitch rotation, and establishing an initial climb (verified by positive rate of climb and target altitude/airspeed capture). When an automatic takeoff system is introduced to manage these dynamic tasks, the pilot's role fundamentally shifts from an active, in-the-loop controller to an on-the-loop supervisory monitor, introducing new human performance risks. Passively monitoring an automated system during a highly dynamic flight phase is notoriously difficult for human operators—often leading to disengagement, mind-wandering, or sudden spikes in task-induced workload when anomalies occur (Warm et al., 2018). With structured training, ongoing practice, and human-centered interface design, automatic takeoff operations in GA aircraft under normal conditions may not significantly alter pilot workload or situation awareness compared to an approved manual takeoff. However, of far greater concern are non-normal conditions or failure modes, where pilots may fail to recognize automation anomalies or experience severe mode confusion and automation surprise during dynamic state transitions.

Figure 2

Illustrative Operational Sequence of an Automatic Takeoff



Note. This sequence represents one illustrative operational concept for an automatic takeoff system. Operational sequences and pilot responsibilities vary across implementations (e.g., full-authority FbW vs. limited-authority retrofits where pilots retain manual rudder or throttle control). If the takeoff is rejected during the ground roll, the pilot or automated system intervenes to retard thrust, apply braking, and maintain directional control to bring the aircraft to a stop on the runway. For an airborne or post-rotation non-normal event, the pilot or automated system executes the appropriate emergency procedure (e.g., landing on remaining runway or continuing the climb in multi-engine operations).

3.2.2. Functions and Operating Environments

Fundamentally, GA automatic takeoff systems represented in the literature are designed to perform aircraft flight control and energy management tasks, including directional control during rollout, pitch attitude control during rotation, and flightpath/energy management during climbout. However, developers and OEMs utilize a variety of system architectures to allocate these control responsibilities. In fully automated systems—such as the experimental Diamond DA42 flight testbeds—all flight control surfaces, nosewheel steering, and autothrottle loops are managed by the automated system. Conversely, partial automation concepts split control authority between the system and the flightcrew; for instance, the Embraer E2 Enhanced Take Off System automates pitch rotation and climb trajectory while relying on the pilot to maintain manual lateral control via the rudder during the takeoff roll ("Embraer Reveals Upgrades," 2024). Throughout these operations, the pilot's primary role is to monitor the automated system (or exercise partial manual control), while continuously evaluating aircraft performance, subsystem integrity, and environmental factors. While automatic takeoff systems represented in existing literature appear consistent regarding a baseline capability to manage the aircraft's flightpath and energy state during a routine takeoff—from a full stop through transition to cruise—there is notable diversity in system control allocation and capability for non-normal procedures, such as automated rejected takeoff (RTO) execution.

Discussions of GA automatic takeoff operating environments in the literature are sparse, as the focus of interest lies primarily in the engineering aspects of onboard aircraft automated systems and HMI; however, Steinleitner et al. (2022) make the point that light aircraft may operate at smaller airports with fewer navigational aids, sometimes in remote areas. As such, automatic takeoff systems for GA aircraft may be less reliant on sophisticated ground-based infrastructure— such as Ground-Based Augmentation System (GBAS) reference stations or local Differential Global Positioning System (DGPS) ground links—and instead rely primarily on self-contained onboard aircraft sensors, Satellite-Based Augmentation Systems (SBAS), and integrated GPS/Inertial Navigation Systems (INS).

From a human factors perspective, the diversity in functionality and operational environments of an automatic takeoff system that may be present across aircraft and operators highlights the importance of initial, recurrent, and refresher training requirements that account for variability in aircraft capabilities, operational environments, and approved operations. This would be of particular importance for training and procedures related to non-normal operations, such as an RTO.

3.3. Flight Deck Displays and Controls

3.3.1. Information Displays

According to the reviewed literature, automatic takeoff systems in GA aircraft typically provide a means to communicate the current and future state of the system to the pilot via flight deck displays and aural annunciations. The literature contains several examples of how displays are used to provide the pilot with awareness of the function and operation of an automatic takeoff system.

Zollitsch et al. (2017) describe the pilot interfaces on a Diamond DA42 aircraft equipped with an experimental autopilot system that is capable of controlling the aircraft in all phases of flight. The primary interface for this system is a touchscreen primary flight display (PFD) that communicates the active phase of the automatic takeoff system (e.g., ground roll, rotation, climbout). The interface communicates aircraft system performance information by displaying the lateral deviation from the centerline during the ground roll and displays annunciations for necessary flap or gear changes. Aural alerts are played upon activation of the takeoff, the transition from ground roll to rotation, and when the abort is triggered. In another paper describing the automation of this Diamond DA42 aircraft, Zollitsch et al. (2018) describe the PFD and mode control panel (MCP) of the aircraft, which communicate information to the pilot during an automatic takeoff. The PFD displays the currently activated modes of the autopilot system.

The literature indicates that an automatic takeoff system in a GA aircraft will likely be accompanied by additional instruments, indicators, and alerts to provide the pilot with awareness of the system's operation. From a human factors perspective, the pilot's visual scanning behavior may differ from that during a manual takeoff, which may impact their ability to maintain awareness of other aircraft and environmental information.

3.3.2. Physical Controls

An automatic takeoff system in a GA aircraft must have an interface that allows the pilot to interact with the system and provide a means to input operational parameters and control system modes. For example, Karlsson et al. (2016) describe an MCP with an integrated control and monitoring display, where the pilot can input system commands such as airspeed, heading, vertical speed, and flight path angle. The specific characteristics of this interface and the types of controls available will depend on the specific operational concepts and system capabilities.

Controls for disengaging aircraft control automation are a fundamental aspect of flight deck design. According to FAA and European Union Aviation Safety Agency (EASA) requirements for transport category aircraft, each pilot must be provided with a readily accessible quick-disengagement function for the autopilot, located on the control wheel or equivalent primary flight inceptor (§ 25.1329(a); EASA CS 25.1329(a)). Safe disengagement modes are similarly important for piloted automatic takeoff operations in GA aircraft and OPVs (Gierszewski et al., 2021). Implementations described in the GA automatic takeoff literature generally align with these transport-category principles by providing disengagement controls directly on the yoke or joystick, such as quick-disconnect switches (Nagayama et al., 2004; Zollitsch et al., 2019). Other implementations use touchscreen interfaces, including a button labeled "activate takeoff" that remains greyed out until the function is available (Zollitsch et al., 2017). Thus, among the GA automatic takeoff systems discussed in the literature, pilots appear to be provided with disengagement mechanisms that are generally consistent with the accessibility and quick-disengagement principles reflected in current FAA and EASA requirements for transport-category aircraft.

From a human factors perspective, physical controls for an automatic takeoff system play a significant role in determining the safety of an automatic takeoff, pilot awareness of the

takeoff procedure, and the process for disengaging the system when a non-normal, abnormal, or emergency event occurs. The intended functions and locations of these controls may impact the pilot's awareness of the system's status and upcoming mode transitions, as well as their ability to intervene when inputs are required. Based on this, the development of pilot training and operational requirements should be carried out with sensitivity to the typical flight deck controls of an automatic takeoff system and the impacts of interacting with those controls during flight operations.

3.4. Non-Normal Automatic Takeoff Operations

During a takeoff, a non-normal, abnormal, or emergency event, such as an aircraft system failure or environmental phenomenon, could arise that requires an immediate pilot response. The literature on GA automatic takeoff systems and operations contains examples of how an automatic takeoff system may operate during these situations. Importantly, the literature states that contingencies and standard operating procedures should be implemented to support high levels of safety, and those mitigations should be implemented in a manner that is consistent with current technologies and procedures in existing aircraft (e.g., see Maly et al., 2023).

3.4.1. Rejected Takeoff

During a routine takeoff, a pilot controls the lateral position of the aircraft, monitors aircraft performance and the external environment to evaluate whether the takeoff can safely continue, and initiates rotation after the aircraft has reached rotation speed. If the pilot determines that the takeoff is no longer safe before the aircraft has reached rotation speed, they must reject the takeoff by retarding the throttle to idle and applying the brakes while continuing to track the runway centerline as the aircraft decelerates on the runway. With the use of an automatic takeoff system, the pilot no longer manually controls the aircraft, but still must monitor the progress of the takeoff, including the performance of the automation, and intervene if an RTO is required.

The literature suggests that automatic takeoff systems may vary in terms of whether they remain engaged during an RTO. Some systems require the pilot to disconnect the automated system and take over manual control of the aircraft, most commonly by pressing the autopilot disconnect switch on the yoke or retarding the throttle to idle (e.g., see Nagayama et al., 2004). One example in the literature suggests that an automatic takeoff system could potentially be capable of monitoring environmental parameters and aircraft performance and autonomously rejecting a takeoff if the probability of a safe takeoff falls below a predefined level (e.g., see Zollitsch et al., 2019). Schumman et al. (2018) discuss the advantages of automating the decision-making and action execution aspects of an RTO and suggest that it enhances safety due to the time-critical nature of deciding whether the aircraft is in a position where a takeoff can be safely rejected, or if the takeoff must be attempted in any case. Automatic decision execution based on monitoring of the environment may be beyond the scope of an automatic takeoff system for GA aircraft. However, the capability to execute an RTO upon receiving a command from the pilot may be a potential related capability. In this case, the automatic takeoff system

would continue controlling the aircraft by idling the throttle, applying the brakes, and maintaining the runway centerline after the pilot commands the system to initiate an RTO.

From a human factors perspective, if an RTO is required during an automatic takeoff operation, there may be impacts on pilot workload and adherence to established RTO procedures, with particular impacts depending on whether the automatic takeoff system is or is not capable of executing an RTO. Past literature on the impacts of flight deck automation indicates that the use of automation reduces mental workload; however, it is associated with decreased scanning of primary flight and energy management information (Causse et al., 2025). These effects may be compounded in cases where the pilot develops an overreliance on the automation and neglects to carry out monitoring duties (Brown, 2016). During an automatic takeoff, the pilot's ability to detect an off-nominal situation during the takeoff roll, determine whether to reject the takeoff or continue, and execute the appropriate response may be compromised compared to a manually controlled takeoff where the pilot is part of the active control loop. To address this concern, Inagaki et al. (1999) investigated decision support information for engine failures on takeoff, finding that providing direct, directive guidance to "go" or "abort" is more effective at mitigating automation surprise and prompting the appropriate pilot response in time-critical situations than providing explanatory-only information, such as an "engine failure" message. Furthermore, in a second experiment, Inagaki et al. observed that participants developed significant mistrust toward the decision support tool when its directive guidance dynamically changed (e.g., a "go" recommendation shifting to a "no-go" as available runway decreased) due to the time-sensitive ("time-fragile") nature of the takeoff roll. The authors demonstrated that this loss of trust could be effectively mitigated by incorporating contextual information alongside the directive message to explain why the decision support state changed.

4. Conclusion

This literature review identified and then analyzed existing research on the topic of automatic takeoff systems and operations in fixed-wing GA aircraft. The intent was to identify literature on this emerging capability and provide insights into operational definitions, technology requirements, considerations for the operational environment, pilot roles and responsibilities, training needs, and system and pilot behavior during non-normal conditions.

Understanding the effects of automating the takeoff operation faces methodological challenges associated with variability in automatic takeoff system design, concepts of operation, and the associated proposed pilot roles and responsibilities. The 14 papers reviewed offered a range of initial findings. Definitions of an automatic takeoff were largely consistent. The start point was when the aircraft is cleared for takeoff (towered airport), or just prior to the takeoff roll when the pilot engages the system. The automatic takeoff ends when the aircraft climbs to 500' above ground level (AGL), or at the altitude where control authority transitions from the automatic takeoff system to the normal autopilot. The pilot must input system parameters, such as runway heading, and engage the system with a button press. During the operation, the pilot must monitor the progress of the operation to ensure the system is functioning as expected

while carrying out other pilot flying duties. When the takeoff is complete, they must interact with flight deck controls to switch from takeoff mode to traditional autopilot for the en route environment. Manual intervention would be required if the automatic takeoff system is not capable of automatically initiating and executing an RTO.

Other details on system and pilot performance in more operationally relevant environments were not a primary focus. The operating environments used during system evaluations (flight tests or simulation) tended to be ideal, at smaller airfields, with few or no ground-based navigation aids, and in visual meteorological conditions (VMC). The technologies (e.g., sensor-based, automated system combinations) required to support automatic takeoffs were not addressed. Further, the literature largely did not address pilot training, checking, and currency requirements. However, some papers allude to a need to develop standard operating procedures and processes to align novel automated flight operations with existing procedures (e.g., Maly et al., 2023).

There was some variability in system behavior during non-normal conditions, such as when an RTO is necessary. As previously stated, automatic takeoff systems were such that the aircraft can complete the entire routine takeoff operation automatically without pilot intervention. However, during non-normal conditions, some systems can continue to operate when an RTO is executed, whereas others require pilot intervention by disconnecting the automation and taking manual control.

Because existing research on GA and OPV automatic takeoff has been predominantly engineering-driven—focused primarily on control algorithm design, state estimation, and proof-of-concept flight testing—a substantial gap remains in empirical human factors research. The literature reviewed demonstrates that automating the takeoff phase fundamentally transforms the operational environment by shifting the pilot's role from an active, in-the-loop controller to a supervisory monitor of an automated system. This transition alters visual scanning strategies, information processing demands, and mode awareness, introducing potential human performance vulnerabilities such as vigilance degradation, automation overreliance, and out-of-the-loop complacency. These supervisory challenges are particularly acute during time-critical non-normal events, most notably RTOs during high-speed ground roll. Because current GA autotakeoff prototypes rely primarily on manual pilot intervention—such as retarding throttles or activating physical disconnect switches—rather than fully automated abort execution, a pilot's capacity to promptly detect anomalies, interpret flight deck alerts, and execute disengagement commands represents a safety-critical concern. Future research should aim to quantify pilot performance and response latency across both normal and non-normal takeoff scenarios. Specifically, empirical studies should evaluate standardized flight deck alerting formats (e.g., "CONTINUE/REJECT" directives versus status-only cautions and warnings), contextual display rationale, and procedure-based supervisory training.

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