Effective Training and Checking Methods for the Emerging Pilot Workforce

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LIST OF ABBREVIATIONS

ACS	Airman Certification Standards
ACT ARC	Air Carrier Training Aviation Rulemaking Committee
ADDIE	Analysis, Design, Development, Implementation, and Evaluation
AI	Artificial Intelligence
APD	Aircrew Program Designee
AQP	Advanced Qualification Program
AR	Augmented Reality
ATC	Air Traffic Control
ATN	Aviation Training Next
ATP	Airline Transport Pilot
CBSD	Concepts-Briefing-Simulation-Debrief
CBT	Computer-Based Training
CFR	Code of Federal Regulations
COE TTHP	Center of Excellence for Technical Training and Human Performance
COTS	Commercial-Off-The-Shelf
CRM	Crew Resource Management
DODAR	Diagnosis, Options, Decide, Assign tasks, Review
EFBs	Electronic Flight Bags
EKT WG	Effectiveness of Knowledge Training Workgroup
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FltDAWG	Flight Deck Automation Working Group
FMS	Flight Management System
FOR-DEC	Facts, Options, Risks, and Benefits—Decide, Execute, Check
FPM	Flight Path Management
FSF	Flight Safety Foundation
FSTD	Flight Simulator Training Device
FTD	Flight Training Device
GED	General Education Development
GPS	Global Positioning System
HMD	Head-mounted Display
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ISD	Instructional Systems Design
ITD	Immersive Training Device
LOE	Line Operation Evaluation
LOFT	Line-Oriented Flight Training
LOS	Line Operational Simulations
LOSA	Line Operations Safety Assessments
MCDU	Multi-Function Control and Display Unit
MFD	Multifunction Display
MFO	Manual Flight Operation
MR	Mixed-Reality

NASA	National Aeronautics Space Administration
NDM	Naturalistic Decision-Making
NextGen	Next Generation Air Transportation System
NPSF	National Pilot Source Forum
OEM	Original Equipment Manufacturer
PC	Personal Computer
PFD	Primary Flight Display
PIC	Pilot in Command
PTN	Pilot Training Next
R-ATP	Restricted Airline Transport Pilot
SA	Situation Assessment
SOPs	Standard Operating Procedures
SPOs	Supporting Proficiency Objectives
STEP	Story, Testing, Evaluation, and Plans
TPOs	Terminal Proficiency Objectives
U.S.	United States
VR	Virtual Reality
XR	Extended Reality

EXECUTIVE SUMMARY

Background

The Part 121 air carrier pilot workforce, which currently includes four generations, will experience a 50% turnover in personnel over the next 15 years due to mandatory retirements. Baby Boomers will depart the workforce within the next ten years, followed by Generation X. The emerging pilot workforce will consist of Generation Y and Z pilots. These self-directed learners value active and cooperative learning. Understanding effective training and checking methods for this workforce is critical to maintaining the level of safety that the traveling public has come to expect from the air carrier industry.

Objective

This research looked to understand the characteristics of the emerging pilot workforce and provide scientific and technical data on effective training and checking methods of the current and projected pilot workforce. Researchers also examined emerging technologies and the design of an experimental training program to evaluate new methods for training the emerging pilot workforce.

Method

To provide empirical evidence on effective training and checking methods and educational technologies used in pilot training, researchers examined the existing literature, focusing primarily on literature from the turn of the century when older members of the emerging pilot workforce may have begun pilot training. Based on findings from the literature review, researchers conducted a field test in collaboration with a Part 121 air carrier that examined the effectiveness and constraints of using entry-level commercial-off-the-shelf (COTS) Virtual Reality (VR) Head-mounted Displays (HMDs) and associated learning methods to train emerging civilian pilots and how an evaluator can determine whether training is operationally effective. Field test participants were *ab-initio* civilian pilot students (Generations Y and Z) enrolled in a collegiate aviation program who had completed their instrument rating as a minimum and were working towards or completing the commercial certificate and multi-engine rating. Twenty-two participants completed the study and learned commercial aircraft preflight procedural tasks using one of three methods. The control group consisted of seven participants who used a combination of traditional classroom lectures and simulator sessions; one experimental group with 10 participants used VR to augment classroom instruction and simulator training; the other experimental group with five participants received classroom instruction and used VR to replace simulator training. Air carrier Aircrew Program Designees (APDs) determined whether training was operationally effective during participant evaluations at the air carrier's training center.

Conclusion

Research suggests a comprehensive blend of classroom instruction, eLearning, simulated scenarios, and hands-on experience in low- and high-fidelity flight training devices and aircraft is

effective for the emerging pilot workforce. The combination of integrated training methods reinforces the retention of information and supports active learning. Recent research suggests that eye-tracking and immersive technologies enhance pilot training.

While immersive technologies and associated learning methods have demonstrated value in military pilot training, there is little research examining the efficacy and limitations of such technologies in civilian flight training. The field test results for this research effort suggest that entry-level COTS VR HMDs may be valuable in learning commercial aircraft preflight flight deck task procedures. Still, more research is needed to fully understand the potential of VR (and other immersive training devices) beyond procedural training and how to integrate these devices into civilian pilot training.

Researchers developed nine recommendations that include further research in training and checking methods for pilot information management, decision-making, command judgment, flight deck automation, and unintended auto flight states; immersive and eye-tracking technologies and their benefits to training; the impact of a multi-generational workforce and the impact to pilot training as new generations of pilots join the workforce; understanding how changes in workforce demographics, training methods, aircraft in service, and airline hiring practices impact pilot training; and the effectiveness of efforts to increase diversity among the pilot ranks. Recommendations also include promoting pilot training cross-sharing forums and expanding airman statistics reporting.

ABSTRACT

The current pilot workforce includes four generations and will lose almost 50% of its eligible pilot population within the next 15 years due to mandatory retirement age, leaving an emerging pilot workforce comprised of Generations Y and Z. Current methods of training pilots include classroom instruction, eLearning, training in flight simulation devices, and aircraft. New technologies and associated learning methods may offer value in training the emerging civilian pilot workforce. This research sought to provide scientific and technical data on effective training and checking methods of the current and projected pilot workforce. It examined emerging educational technologies and the design of an experimental training program to evaluate new methods for training the emerging pilot workforce.

INTRODUCTION

The Federal Aviation Administration (FAA) Center of Excellence for Technical Training and Human Performance (COE TTHP) was established by Congress in 2016 to enhance the training and performance of air traffic controllers, aviation safety inspectors, engineers, technicians, and pilots. COE TTHP research focuses on part-task training, immersive simulation, and adaptive learning technologies.

The FAA's 2013 Flight Deck Automation Working Group (FltDAWG) final report identified five factors projected to impact future aviation operations: 1) an increase in the number of aircraft operations; 2) continuing changes in the demographics of the aviation workforce; 3) evolution in knowledge and skills required by pilots and air traffic personnel; 4) difficulty in making the cost-benefit case for additional safety and regulatory changes is challenging due to the historically low aviation accident rates; and 5) exploitation of new technology and operational concepts for navigation, communication, surveillance, and air traffic management (PARC/CAST, 2013).

This research sought to understand the characteristics of the emerging pilot workforce and the various training and checking methods that may be effective for the emerging pilot workforce.

REVIEW OF THE LITERATURE

Current and Emerging Pilot Workforce

This section examines the composition of the current and emerging pilot workforce.

Overview. The commercial airline pilot workforce includes passenger and cargo pilots who fly for air carriers certified under 14 CFR Part 121. This workforce is subject to volatility in air passenger and cargo demand, both shaped by world events. The terrorist attacks on September 11, 2001, sent shock waves through the aviation industry, decreasing demand for passenger air travel and commercial airline pilots. The decade that followed 9/11 saw multiple airline bankruptcies and mergers, a global recession, and stagnant pilot careers. Fewer prospective pilots entered the pilot training pipeline, and in the early 2000s, FAA-mandated retirement for Vietnam-era commercial airline pilots reaching age 60 began. In 2007, the Fair Treatment of Experienced Pilots Act (Oberstar, 2007) changed the mandatory commercial airline retirement age from 60 to 65 years old, slowing workforce attrition for five years. The exodus of the Baby Boomer generation pilots is being replaced with an emerging pilot workforce comprised of Generation Y and Z pilots.

Demand for air travel rebounded in the decade following the economic recession of 2009, resulting in increased pilot hiring and the pilot workforce growing from 73,494 pilots in 2012 to 91,282 pilots in 2019 (Bureau of Transportation Statistics [BTS], 2021). The onset of the COVID-19 pandemic accelerated retirement for many senior airline pilots in 2020 as airlines worked quickly to cut operating costs to offset the plummeting demand for air passenger travel.

The workforce lost 6,412 pilots in 2020 (BTS, 2021). Pilot hiring picked up in 2021 following the initial wave of the pandemic, and the workforce grew to 87,644 pilots. The total number of pilots in the U.S. pilot workforce is reported annually on Department of Transportation Schedule P-10: Pilots and Copilot Employment. Data for 2012-2021 is provided in Table 1 (BTS, 2021).

Table 1: ***Total Pilots - Major, National, and Regional Domestic Air Carriers, 2012 - 2021***

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Pilot - Total	73,494	74,411	75,778	76,437	80,071	83,310	88,412	91,282	84,870	87,644

Note: The Department of Transportation categorizes air carriers per annual operating revenue. Major: Over $1 billion annual operating revenue; National: Over $100 million to $1 billion annual operating revenue; Large Regional: $20 - $99 million annual operating revenue; and Medium Regionals: less than $20 million annual operating revenues or that operate only aircraft with 60 seats or less (or 18,000 lbs. maximum payload).

Demand for Pilots. Large commercial aircraft manufacturers Boeing and Airbus publish a strategic 20-year forecast each year. Both companies predict that the need for new pilots in North America will remain strong as the commercial aviation industry recovers from the impact of COVID-19. Boeing (2022) forecasts that North America will need 128,000 new pilots over the next 20 years, while Airbus forecasts the need for 97,000 new pilots in North America during the same period (Airbus, 2022).

Pilot Sourcing. Since 2001, the workforce percentage of civilian-trained airline pilots has increased while military-trained pilots hired into the airlines have decreased (U.S. Government Accountability Office [GAO], 2014). The byproduct is a new generation of pilots who are coming in with fewer years of flying (operating) experience. They are building hours in slow, single and multi-engine aircraft that are traditionally less complex. Compare this with military pilots who may have more hours of operational (and flying) experience in technologically advanced, and fast-moving aircraft. The military also provides these pilots with the opportunity to develop and hone skills such as information management, decision-making, and command judgement. This shift is captured in the FltDAWG final report which recognized changes in new-hire pilot flight experience and training background from military and civil aviation to collegiate aviation programs that overall have reduced average new-hire pilot flight time, but have also increased the number of new-entry pilots who have completed highly structured, comprehensive flight training programs that often employ advanced flight deck technology (PARC/CAST, 2013).

Over the last decade, clearly defined civilian pilot pathways have emerged, resulting from new partnerships between airlines, universities, and flight academies (Lutte & Mills, 2020) that accommodate increased hiring from civilian flight training entities. Collegiate aviation programs have played an increasing role in civilian pilot training production since the Colgan Air 3407 accident (Lutte & Mills, 2020), supplying regional airlines with pilots (Smith et al., 2010; Smith et al., 2013; Smith et al., 2017; Smith et al., 2020). Analysis by Lutte and Mills (2020) found that regional airlines had over 175 agreements with more than 70 institutions of higher learning.

Ab-initio, which means "from the beginning" in Latin, refers to a training method where the student is taught practices and procedures from the earliest stages. The *ab-initio* model has been the pilot training approach used by the U.S. military for decades. It is common in commercial flight training outside the U.S. and, until recently, has been given little consideration by U.S. airlines. Some organizations are now exploring its practicality (Byers, 2016). Multiple U.S. air carriers have developed or are in the process of developing *ab-initio* flight training programs that provide aspiring commercial pilots with a high school or General Education Development (GED) diploma the opportunity to follow a clearly defined employment path to an air carrier.

Age. The Airline Transport Pilot (ATP) certificate, with a minimum age qualification of 23, is required to be an airline pilot. Pilots who graduate from FAA-authorized higher education institutions may be eligible to apply for a restricted privileges ATP certificate at age 21. FAA statistics note that the average age of active (airmen who hold both an airmen certificate and a valid medical certificate) ATP pilots was 51.3 in 2021, and data from 2012 – 2021 are presented in Table 2 (FAA, (2023) *U.S. Civil Airmen Statistics*).

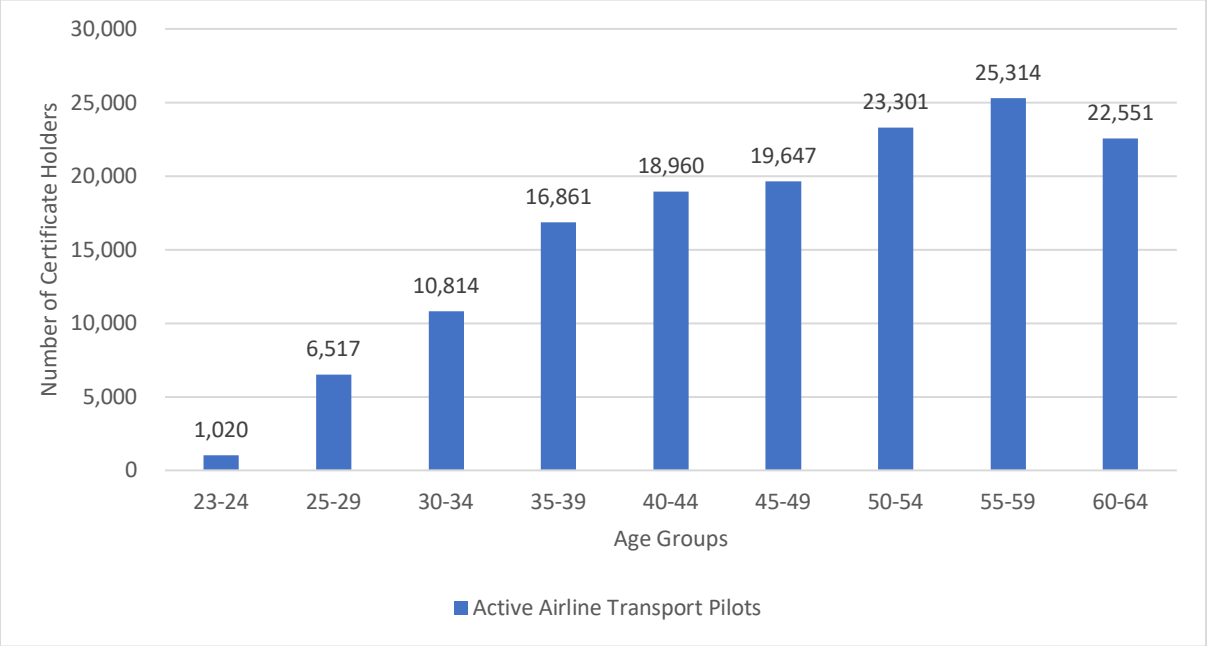
Table 2: ***Average Age of Active Airline Transport Pilots, 2012 – 2021***

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Average Age	49.9	49.7	49.8	49.9	50.2	50.6	51.0	50.8	51.2	51.3

Notes: Includes pilots with an airplane and/or a helicopter and/or a glider and/or a gyroplane certificate as of December 31, 2021. Pilots with multiple ratings will be reported under the highest rating. The FAA does not differentiate average age data between airplane, helicopter, glider, and gyroplane certificates. The minimum age to qualify for the ATP is 23 years old. Restricted privileges ATP data are not reported in U.S. Civil Airmen Statistics.

The estimated active ATP certificates held by age group data are presented in Figure 1. The FAA reports 144,985 active ATP pilots between the ages of 23 and 64 in 2021; of this number, 22,551 (15.6%) will reach age the mandatory retirement age of 65 within five years, and 71,166 (49.1%) will reach age 65 within 15 years (FAA, (2023) *U.S. Civil Airmen Statistics*).

Figure 1: ***Estimated Active Airline Transport Pilot Certificates Held by Age Group, 2021***



Notes: Includes pilots with an airplane and/or a helicopter and/or a glider and/or a gyroplane certificate as of December 31, 2021. Pilots with multiple ratings will be reported under the highest rating. The FAA does not differentiate average age data between airplane, helicopter, glider, and gyroplane certificates. The minimum age to qualify for the ATP is 23 years old. Restricted privileges ATP data are not reported in U.S. Civil Airmen Statistics.

The average age and flight hours of air carrier pilots who entered the Part 121 workforce were unavailable for mainline airlines. The 2018 Pilot Source Study (Smith et al., 2020) examined regional airline pilot hiring between 2015 and 2018 and found that for the five regional airlines that did the most pilot hiring during this period, the average age of 9,776 new-hire first officer pilots was 34.0 years, and the average flight hours at the time of hire was 2,502. Notably, the standard deviation of hiring age was 9.9 years, indicating a wide variance in ages at the time of hire. It is important to note that the hiring period for this study was two years after the new 2013 FAA requirement for first officers to hold an ATP which took effect and created a gap in eligible pilots for a few years.

Gender. Data for estimated active airmen certificates held for commercial, flight instructors, and airline transport pilots (broken out by all pilots and women pilots) are presented in Table 3 (FAA, (2023) *U.S. Civil Airmen Statistics*). FAA U.S. Civil Airmen Statistics indicate that in 2021: women comprised 4.7% of active Airline Transport certificate holders, 7.7% of active Flight Instructor certificate holders, and 8.0% of active commercial certificate holders. These numbers indicate a small increase from 2012, when women comprised 4.0% of active Airline Transport certificate holders, 6.5% of active Flight Instructor certificate holders, and 6.5% of active commercial certificate holders. The 2018 Pilot Source Study (Smith et al., 2020) revealed that 6% of the 9,776 first officer new hires at the leading five regional airlines with the most hiring between 2015-2018 were women, suggesting these regional airlines are hiring women at a rate higher than the percentage of active women Airline Transport Pilot certificate

holders. In a comprehensive study focused on women in aviation, Lutte (2019) found that women comprise 5-10% of the pilot workforce and only 1% of airline captains.

Table 3: ***Estimated Active Airmen Certificates Held, 2012 – 2021***

Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Commercial - All	116,400	108,206	104,322	101,164	96,081	98,161	99,880	100,863	103,879	104,610
Commercial-Women	7,536	6,911	6,685	6,587	6,081	6,267	6,556	7,038	7,724	8,421
Flight Instructor - All	98,328	98,842	100,993	102,628	104,382	106,692	108,564	113,445	117,558	121,270
Flight Instructor - Women	6,371	6,386	6,521	6,669	6,848	7,105	7,335	7,957	8,592	9,340
Airline Transport - All	145,590	149,824	152,933	154,730	157,894	159,825	162,145	164,947	164,193	163,934
Airline Transport - Women	5,818	6,205	6,408	6,554	6,888	6,994	7,136	7,503	7,549	7,698

Notes: Includes pilots with an airplane and/or a helicopter and/or a glider and/or a gyroplane certificate as of December 31, 2021. Pilots with multiple ratings will be reported under the highest rating.

Ethnicity. The FAA does not report the ethnicity or race of pilots. Historically speaking, commercial airline pilots have been predominantly male and white. Efforts to increase diversity have been met with limited success. The industry has long struggled to recruit women and people of color (Morrison, 2020). Ison et al. (2016) reported that in 2011 only 2.9% of employed professional pilots were African American. Stevenson et al. (2020) reviewed data from the American Community Survey using Public Use Microdata Sample from the U.S. Census Bureau for the years 2009-2018, and the results highlighted the consistent lack of racial diversity in the pilot workforce, with Black individuals comprising only 1.6% to 3.4% of the workforce during this period.

Generational Considerations. Howe and Strauss (1991) record that each generation is shaped by its social environment. Typically, generations are grouped into a range of birth years identified by a unique set of events that form shared ideas and beliefs (Dimock, 2019; Howe & Strauss, 1991; Williams et al., 2014). As a result, generations with similar life experiences can have similar traits. There are differences in the actual year groupings of each generation, but the intent is to identify the common characteristics of that group (Carlson, 2009; Dimock, 2019). The exception to this grouping technique is the Baby Boomer generation which was named and bound with beginning and ending years by the U.S. Census Bureau (Hogan et al., 2008). This paper uses the birth year ranges below, as established by the Pew Research Center (n.d.):

Baby Boomer Generation	Born: 1946-1964
Generation X	Born: 1965-1980
Generation Y (Millennials)	Born: 1981-1996
Generation Z	Born: 1997-2012

The flight crew age range on a commercial airline flight deck can range from 21 to 64 years, potentially spanning four generations. Table 4 identifies the estimated number of active

commercial certificates and ATP certificates by generation (FAA, (2023) U.S. Civil Airmen Statistics). Most new hire airline pilot candidates will be from Generations Y and Z (FAA, (2023) *U.S. Civil Airmen Statistics*).

Table 4: ***Estimated Active Airmen Commercial & ATP Certificates Held by Generation, 2021***

Age Group	Generation	Commercial Certificate	ATP Certificate	Total (Commercial and ATP Certificates combined)
20-24	Gen Z	14,481	1,020	15,501
25-29	Gen Y	19,366	6,517	25,883
30-34		12,923	10,814	23,737
35-39		10,667	16,861	27,528
40-44	Gen Y & X	8,262	18,960	27,222
45-49	Gen X	6,493	19,647	26,140
50-54		7,357	23,301	30,658
55-59	Gen X & Baby Boomer	7,829	25,314	33,143
60-64	Baby Boomer	8,096	22,551	30,647
Total		**95,474**	**144,985**	**240,459**

Notes: Includes pilots with an airplane and/or a helicopter and/or a glider and/or a gyroplane certificate as of December 31, 2021. Pilots with multiple ratings will be reported under the highest rating. The FAA does not differentiate average age data between airplane, helicopter, glider, and gyroplane certificates. The minimum age to qualify for the ATP is 23 years old. Restricted privileges ATP data are not reported in U.S. Civil Airmen Statistics.

The total number of commercial and ATP certificates held by Baby Boomers, Generation X, and Generation Y are similar. In contrast, the number of Generation Z pilot certificates is small as its members are just beginning to reach the age requirements to join the Part 121 workforce.

The pilot workforce as of 2022 includes Baby Boomers, Generation X, Generation Y, and Generation Z. Baby Boomers will be exiting the pilot workforce within the next decade, leaving Generations X, Y, and Z at the helm. Generation X pilots are “digital immigrants” who were not “born into the digital world” but had, at some later point in their life, “become fascinated by and adopted many or most aspects of new technology” (Prensky, 2001, pp. 1-2). Generation X pilots will retire from the workforce between 2030 – 2045, leaving an emerging pilot workforce comprised of Generations Y and Z, both of whom are “digital natives” and are “native speakers of the digital language of computers, video games, and the Internet” (Prensky, 2001, p. 1). This research effort focuses primarily on literature since the turn of the century, when older members of the emerging pilot workforce may have begun pilot training.

Research shows characteristics unique to each generation that may influence how training is designed. Some argue that suggested differences do not exist between digital native and digital immigrant generations' ability to use technology to improve learning. These researchers suggest that focusing on generational characteristics during curriculum development is ineffective (Bullen et al., 2011; Kennedy et al., 2007). Table 5 highlights many identifying characteristics when examining each generation in the general population.

Table 5: ***Summary of Generational Characteristics***

Generation X	Generation Y	Generation Z
	Virtual Reality (VR) motivates and engages (Reilly, 2012)	Brains wired to sophisticated, complex visual imagery (Hallowell & Ratey, 2011; Rothman, 2016)
	Attention span 12 seconds (Shatto & Erwin, 2016)	Attention span 8 seconds (Shatto & Erwin, 2016)
Hardworking, independent, skeptical (Lancaster & Stillman, 2002)	Prefers groupwork with hands-on experiences (Eckleberry-Hunt & Tucciarone, 2011); Team-oriented (Howe & Strauss, 1993)	Self-directed learners; thrive on technology (Shatto & Erwin, 2016); Prefers interactive games, collaborative projects, and challenges (Rothman, 2016)
	"How-to" guide for success (Monaco & Martin, 2007; Reilly, 2012); Wants immediate feedback and lacks critical thinking skills (Monaco & Martin, 2007);	Likes Google, lacks ability to vet information (Pew Research Center, 2014; Shatto & Erwin, 2016)
	Less lecture with creative, interactive, fun learning (Eckleberry-Hunt & Tucciarone, 2011)	Prefers less lecture and more interaction (Shatto & Erwin, 2016)
"Digital immigrants" (Prensky, 2001)	"Digital natives" (Prensky, 2001)	"Digital natives" (Prensky, 2001)
	Prefer to multi-task rather than focus on one thing (McCrindle Research, 2006; Worley, 2011)	

Fussell and Thomas (2021) record that little has changed in characterizing flight students over the years. They note research from Campbell et al. (2009), Fitzgibbons et al. (2004), and Gao and Kong (2016) that characterize "pilots and flight students as emotionally stable, highly assertive and conscientious, competitive and striving for high achievement, and tending toward higher levels of extraversion" (Fussell & Thomas, 2021, p. 5). Furthermore, they highlight findings by Harriman (2011) and Kanske and Brewster (2001), who found that "flight students use reasoning, theoretical models, and observations to form explanations and may prefer abstract conceptualization, in which learning occurs through logical thinking and planning" (Fussell & Thomas, 2021, p. 5).

Training the Current and Emerging Pilot Workforce

This section examines the learning characteristics and best training practices for the emerging pilot workforce.

Learning Characteristics. The emerging pilot workforce includes individuals who identify as adult learners (Brady et al., 2001), meaning they are goal-oriented, self-directed learners (Houle, 1961; Knowles et al., 2015) and perform best when their educational

environment is based on adult learning principles (Brady et al., 2001). They embrace active learning (Niemczyk, 2020; Williams et al., 2014), and individual learning can improve using cooperative learning strategies that also aid in preparation for success in a team working environment (J. F. Clark, 2001; Graham, 2017).

Training Strategies. Martinussen and Hunter (2010) describe training as a systematic process of developing knowledge, skills, and attitudes to some specified level of competency. Pilot training involves instruction in procedural and technical skills and education in non-technical skills such as crew resource management, decision-making, leadership, and communication (Sommer, 2014). Scenario-based training is encouraged (Cassens et al., 2011) as it promotes critical thinking and decision-making skills (Craig, 2009). Training organized and presented in the following format is proposed as an effective strategy: 1) information/concepts; 2) demonstration/briefing; 3) practice/simulation (maximize as able – more repetitions equal more decisions, build situation models); and 4) feedback/debrief (self and with instructor) (Salas et al., 2012; Mumaw et al., 2020). A combination of methods is used in pilot training, including classroom instruction, computer-based training, and practical training in flight training devices and aircraft (Schaffernak et al., 2020). Using various instructional methods benefits training (Mavin & Roth, 2015). It ensures the effectiveness of retaining information and allows the learner to test concepts that enable active learning (Thomas et al., 2021). Research suggests that classroom-based instruction methods are effective for human factors instruction (Dusenbury & Olson, 2019), learning aircraft systems (Wilson & Stupnisky, 2022), teaching weather technology (Cobbett et al., 2014), and upset-recovery training (Rogers & Boquet, 2012).

Systematic Approach. Macleod (2001), Martinussen and Hunter (2010), and Kearns (2010) promote pilot training based on sound theoretical principles of learning using a systematic approach such as the instructional systems design (ISD) Analyze, Design, Develop, Implement, and Evaluate (ADDIE) model. ADDIE provides a rigorous iterative framework for training development yet is adaptable since it does not prescribe specific training methods or modes (Martinussen & Hunter, 2010). Currently, over 90% of U.S. airline pilots, particularly at larger airlines, train under the systematic Advanced Qualification Program (AQP), a voluntary training program developed over 30 years ago through a partnership between the FAA and U.S. air carriers (Farrow, 2019; FAA, 2022). AQP, outlined in 14 CFR Part 121 Subpart Y, is a proficiency-based flexible approach to training and checking and a philosophical shift from the traditional prescriptive approach to training and checking (e.g., programmed hours) found in 14 CFR Part 121 Subparts N and O. AQP uses a data-driven systematic approach that allows training program flexibility, incentivizes air carrier participation and integrates scenario-based individual and crew training and evaluation. AQP is chiefly used at large (over 1,000 pilots) and medium-sized (501-999 pilots) Part 121 air carriers (FAA, 2022). In comparison, 95% of small (less than 500 pilots) Part 121 air carriers choose not to use AQP and instead follow traditional training rules (FAA, 2022).

Pilot Selection. Air carrier pilot training begins with airline pilot selection. Following a review of the selection procedures of U.S. and foreign airlines based on publicly available information, Broach et al. (2019) found that the primary job performance criterion is not based on any industry best practice but rather on the success or failure in training.

Aeronautical Decision-Making. Decision-making training modules are predicated on the notion that decision-making entails a conscious choice between alternatives and assumes decision-making should be a team or group activity. As a result, the utilized decision-making procedures and models should help the individual and team ensure the optimal decision will be reached (Harris & Li, 2015). Several of these training models have been developed in the aviation industry and used by major carriers, including DODAR (Diagnosis, Options, Decide, Assign tasks, Review; Walters, 2002) and FOR-DEC (Facts, Options, Risks, and Benefits – Decide, Execute, Check; Hoermann, 1995). However, a critical missing component from these models addresses crewmember expertise and the ability of the crew to recognize and assess the situation and deploy decision-making strategies depending on constraints in their environment (e.g., domain-specific decision-making) (Kanki, 2019). Thus, moving towards training within a naturalistic decision-making (NDM) framework helps trainees develop knowledge to make decisions like experts and emphasizes competencies such as rapid pattern recognition, serious consideration of options, mental simulation of options, and metacognitive skills (Kanki, 2019). Importantly, training within NDM emphasizes the development of situation assessment (SA) skills such as rapid pattern recognition, time and risk assessment, diagnostic skills, and knowledge-based reasoning. With repeated practice and feedback, recognizing danger cues and applying appropriate responses should become automatic.

Another critical skill in training aviation decision-making is metacognition, the awareness and monitoring of one's cognitive processes. Importantly, metacognition allows individuals to assess their own and crew's understanding of the situation, potential flaws with the course of action, and options to manage associated risks (Kanki, 2019). The STEP (Story, Testing, Evaluating, and Plans) model combines recognition and metacognitive elements and describes how decision-makers make decisions as they deal with uncertainty and time pressure in real-world environments (Cohen, Freeman, & Thompson, 1998). STEP emphasizes training under high-fidelity practice conditions to facilitate accurate recognition and automatic performance. Also crucial for establishing effective SA, communication training is especially critical as the medium through which team decision-making and threat management are accomplished. For example, building shared situation models, building a positive crew climate, and engaging in effective monitoring and challenging skills are all communication functions that directly impact effective decision-making (Kanki, 2019). These communication skills can be practiced in low- and high-fidelity simulation environments (Cohen et al., 1998). However, as flight operations become increasingly automated, decision-making training must emphasize the quality of an individual's underlying knowledge structures. This includes instruction in which skills are required to find relevant information, assess the automated system functionality, and build highly accurate mental models of how the automated system functions. Thus, as technology advances, training must also advance to prepare pilots to manage the systems and use them to enhance their decision-making (Kanki, 2019).

Leadership and Command Judgment. Airline captains are designated pilot in command (PIC) for their crew and passengers. If multiple captains are paired on a crew, only one captain will be designated as the PIC. Much emphasis has been placed on the professional development of Part 121 pilots, particularly since the fatal 2009 Colgan Air 3407 accident. In February 2020, the FAA announced updates to Part 121 training requirements: leadership, command, and mentoring training in the PIC upgrade curriculum and ground and flight training

through scenario-based training. This training focuses on leadership, PIC authority and responsibility, adherence to standard operating procedures (SOPs), and decision making. To further enhance the learning opportunities, facilitated discussion modules were designed to examine what was learned in the academic portion of training. Recurrent PIC leadership and mentorship training; and recurrent Line-Oriented Flight Training (LOFT) must allow PICs to demonstrate leadership and command. These efforts are intended to promote adherence to standard operating procedures and encourage professional behaviors. The literature review did not reveal studies specific to pilot command judgment.

Crew Resource Management (CRM). CRM has grown from an early emphasis on interpersonal relations to its current focus on effectively using all resources at the disposal of the flight deck crew (Martinussen & Hunter, 2010). CRM training effectiveness generally results in positive feedback from trainees, enhanced learning, and desired behavioral changes but can be difficult to evaluate on an organizational level (Salas et al., 2001). Organizations need to cast a wider CRM training net and integrate other operational personnel into CRM training programs (Jimenez et al., 2015; Bennett, 2019) to increase organizational safety and efficiency.

To teach and evaluate the application of CRM skills prior to airline training, one collegiate aviation program introduced a CRM jeopardy (pass/fail) Line Operation Evaluation (LOE) simulator event to add a real-world element to a senior-level professional CRM course. They used the Pilot Edge ATC software application, which provides professional air traffic control (ATC) services for flight simulations and found the jeopardy nature adds value to the student experience while the Pilot Edge ATC application offers a real-time element that cannot be manipulated impartially by a single grader (Vance, 2017). It also adds radio communication realism that was identified by Burki-Cohen and Kendra (2001) as a weakness that limited effective training and evaluation of the cognitive and workload skills associated with radio communications.

Flight Deck Automation. Automation can reduce pilot workload and help pilots fly more safely and efficiently; however, automation does not reduce training requirements. Pilots must understand how automation systems operate the aircraft and be prepared for automation surprises (Orlady, 2019).

The underlying principles of flight deck automation systems and their use in multi-crew aircraft can be delivered in a traditional classroom setting (Casner, 2003). Orlady (2019) notes that training and procedures must prepare crews to remember flight priorities and use checklists as appropriate while not abandoning their basic airmanship skills and cognitive abilities and ensuring both pilots have the same mental and cognitive picture.

Based on findings in their longitudinal study of new-hire regional airline pilots, Soo et al. (2021) recommend that automation should not be taught like another aircraft subsystem but rather as a spiraling curriculum with additional practice tools provided and improve prescription on the use of modes in early stages of training, providing new hires with ongoing guidance on using (and when not to use) automation in diverse situations.

There appears to be a gap in the research literature regarding flight deck automation training as it relates to the emerging pilot workforce.

Flight Path Management. Flight Path Management (FPM), as defined by FAA Air Carrier Training Aviation Rulemaking Committee (ACT ARC) recommendation 20-1, is the planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in-flight or on the ground (FAA, 2020). Topics discussed in this section include manual flight operations, upset prevention and recovery, unintended autoflight states, and pilot monitoring.

The 2014 Flight Safety Foundation (FSF) Flight Path Monitoring report (FSF, 2014) provided recommendations regarding the training and evaluation of monitoring skills that include: 1) training pilots as to why they are vulnerable to errors and monitoring lapses; 2) developing and publishing clearly defined monitoring tasks, training objectives, and proficiency standards; 3) ensuring instructors and evaluators are proficient at training and evaluating standards; and 4) incorporating monitoring training into simulator sessions or other device training.

In 2016 the International Air Transport Association (IATA) published guidance for improving flight crew monitoring. This guidance includes ensuring FPM skills are emphasized and incorporated during all phases of training (both ground and flight using different delivery means), beginning with initial training and re-enforced through recurrent training and line operations; improving simulator instructor and line check pilot training to evaluate FPM better; and the inclusion of FPM elements in all briefings and debriefings (IATA, 2016).

Flight deck automation has increased significantly with newer generation aircraft, leading to pilots relying more on these systems. However, this increased reliance on automation can lead to a degradation of manual flying skills (Haslbeck & Hoermann, 2016). The level of practice and training has been found to significantly impact manual flying skills (Haslbeck et al., 2014). A study by Friedrich et al. (2021) found that the level of training affects flight performance, and higher training levels result in better performance, particularly during high workload conditions. It is worth noting that simulator training is essential but only accounts for a small portion of the time pilots have to practice and maintain their manual flight operation (MFO) skills. Pilots may get the most significant amount of practice during actual flight operations, but the operational policies and procedures of the air carrier influence the opportunity and time spent manually flying. Some air carriers encourage manual flying during line operations, while others do not. To reduce manual flight handling errors, flight operators should allocate more time to manual flying in simulator sessions (Haslbeck et al., 2014; IATA, 2020). Casner et al. (2014) suggest providing pilots with more practice with cognitive skills during recurrent training or using computer-based simulators to support better cognitive skills needed for manual flight.

Upset prevention and recovery training is intended to help crews prevent and recover from loss of aircraft control. Research suggests that classroom-based instruction methods (Rogers & Boquet, 2012) and flight simulator training (Leland, 2009; Rogers et al., 2010) are effective for upset-recovery training. Casner et al. (2013) recommend training for surprise, reevaluating testing practices, and turning off automation to prevent pilots from relying solely on rote memorization skills specific to required training situations and practice recognizing non-

required abnormal events and the appropriate response. Gillen (2016) found that crews who received targeted startle effect training consisting of a briefing and simulator practice outperformed those without training, suggesting that targeted training can help crews manage a startling event. In their study of how aircrews deal with surprise situations in training, Landman et al. (2018) determined that including unpredictable and variable scenarios in simulator training improves the transfer of training to unexpected situations in flight. Air carriers must incorporate diverse and unpredictable scenarios into their training programs to enhance their crew's ability to handle unexpected situations. Traditional training methods become less effective as more flight crews undergo standard training, resulting in a predictable routine. Additionally, it is essential to evenly rotate scenarios to maintain the element of surprise and variability, which are vital components of effective training.

Eye-tracking technology can provide objective data for debriefing sessions in the context of upset prevention and recovery training, as this technology enables recording eye gaze and scanning behaviors (Ryffel et al., 2019).

An unintended autoflight state occurs when aircraft automation guides the aircraft's trajectory contrary to the pilot's intentions. There appears to be a gap in the literature for studies examining unintended auto-flight state training.

Based on findings from their study of commercial airline pilot automation monitoring strategies and performance that conclude monitoring failures contribute to breakdowns in pilot-automation interactions, Sarter et al. (2007) call for more conceptual and exploratory approaches to training these skills. Potter et al. (2014) measured the monitoring skills of helicopter pilots during two high-fidelity flight simulator scenarios. They found that pilots who completed an eLearning module before the simulator event improved performance, supporting the hypothesis that eLearning can foster monitoring skill development. Dehais et al. (2017) concluded that eye-tracking technology provides valuable data to understand pilots' performance during go-arounds better.

A 2020 National Aeronautics and Space Administration (NASA) study examined enhanced pilot training for effective pilot monitoring and noted that few robust studies assess pilot monitoring (Mumaw et al., 2020). The most recent study was published in 2004, which may not reflect the current workforce demographics, training practices, or aircraft in service. Notably, a variety of simulations (varying types and fidelity) are used in learning, and often simple simulation (including microworlds and games) offers training impact at much less cost than more expensive simulators (Mumaw et al., 2020). Mumaw et al. (2020) describe a structured, iterative training approach referred to as Concepts-Briefing-Simulation-Debrief (CBSD) that helps pilots learn and practice monitoring skills in active scenarios by building mental models (concepts and theories), practicing flight orientation skills (briefing), developing a portfolio of situation models by performing in multiple flight scenarios (simulation), and reinforcement through reflection and feedback (debrief).

Information Management. Moriarty (2015) describes information processing as the "primary subject upon which the rest of human factors is based" (p. 70). The cognitive function of gathering, processing, and prioritizing seemingly increasing internal sources of information

(e.g., flight deck attitude and systems displays, navigation displays, aural and visual alerts, crewmembers, checklists, maintenance records, etc.) and external information sources (e.g., air traffic controllers, company operations, weather, airport information, and visual and aural observations, etc.) is crucial to safe outcomes.

"Pilots are the product of the information and training they receive" (Orlady, 2019, p. 572), and today's flight students are exposed to advanced technology airplanes and flight decks earlier in their training (Orlady, 2019). Members of the emerging pilot workforce who train on technically advanced airplanes with an electronic Primary Flight Display (PFD) and electronic Multifunction Display (MFD) that includes a moving map using Global Positioning System (GPS) navigation while using Electronic Flight Bags (EFBs) in the airplane may develop information management skills that transfer smoothly to technically advanced multi-pilot aircraft flown by Part 121 air carriers.

Information processing is critical to safe flight. Standard operating procedures (SOPs) establish a shared mental model for the flight crew when information must be obtained, acted on, and verified (Kanki, 2019). A shared mental model is developed during CRM training where the mission is to improve crew performance as a result of refined crew coordination. The lifecycle of CRM training focuses on team building, information transfer, decision-making, situational awareness, automation management, and problem solving (FAA, 2004).

Systems such as EFBs that compile information for processing are becoming increasingly mainstream in commercial and general aviation. In a study of 40 collegiate aviation students performing flight planning duties, EFBs were shown to increase flight planning data interpretation and weather hazard awareness, as well as the need to emphasize training that develops aeronautical decision-making and data interpretation skills for situations when EFBs are unavailable (Misra and Halleran, 2019). Conflicting information from redundant sources poses challenges to crew decision making. Carroll and Sanchez (2021) suggest training for information conflicts by increasing crew experiences with information conflicts using simulation and case studies. Measuring pilot ability to manage information is complex. Dill and Young (2015) suggest eye-tracking data may be an objective measure of a pilot's ability to manage information related to electronic flight bags (EFBs), system state awareness, and events involving inattentional blindness.

Instructor Readiness. Although they play a crucial role in successful training, the instructor can be overlooked in the training process (Lee, 2009), and their role should be specifically addressed as is the case with Chapter 5 in AC 120-54A Advanced Qualification Program (Chg 1).

The Flight Deck Automation Working Group final report (PARC/CAST, 2013), Flight Safety Foundation (FSF, 2014; FSF, 2018), International Air Transport Association (IATA, 2016), and International Civil Aviation Organization (ICAO, 2019) all emphasize the need for instructor development. Subject matter experts serving as instructors and curriculum designers must understand how people learn based on learning principles (Petitt, 2019). Mike Varney, Director of the LOSA Collaborative, and John Scully, Vice President of the Evidence-Based Training Foundation, report having "seen the greatest success in airlines that have understood the

need to train the trainers and concentrate their efforts in this area" (Varney & Scully, 2020, p. 222). Despite extensive research on simulation and fidelity, few studies on the instructor's roles, responsibilities, and overall impact on training outcomes have been conducted (Myers et al., 2018).

Current and Emerging Pilot Training Technology

This section examines current and emerging technologies used for pilot training.

Simulation. Flight simulators and training devices have become widely used in commercial aviation since the 1960s (Schaffernak et al., 2020) and provide increased efficiency, safety, and lower training costs (Harris, 2011). Simulators vary according to the level of fidelity they entail, that is, the degree to which the simulator mimics the real-world task (Myers et al., 2018). The level of fidelity can also be subdivided into physical and psychological-cognitive fidelity fields (Macchiarella & Mirot, 2018). High physical fidelity implies that the device replicates the real-world task regarding sound, visual input, and sensation. High psychological-cognitive fidelity means that the simulator replicates the real-world task's psychological and cognitive aspects (e.g., mental workload, psychological pressure, and attentional demand) to a high degree. Simulation used in training should be appropriate to support the specific aviation knowledge and skills being trained (Salas, et al., 1998). For example, novice learners may experience cognitive overload and derive little benefit from high-fidelity simulation (Jones, 2021). Studies have shown that lower-level fidelity (e.g., desktop computer-based) simulation devices can effectively train initial "stick and rudder" skills (Reweti et al., 2017; Risukhin et al., 2016; Stewart et al., 2008), initial Instrument Flight Rules (IFR) training (Taylor et al., 1999) and maintenance of instrument flight skills (Taylor et al., 2005; Thomas, 2018), and crew resource management (CRM) skills (Brannick et al., 2005; Johnson et al., 1997; Rosa et al., 2021), boosting pilot cognitive and behavioral skills. Lower-fidelity simulation, which complements higher-fidelity simulation, may serve as a resource in developing resilient pilots (Dahlstrom et al., 2009) and help train pilots to cope with information conflicts (Carroll et al., 2021). Higher-level fidelity flight training simulation devices reduce aircraft training requirements (McLean et al., 2016) and effectively support pilot certification task training (Macchiarella et al., 2008), practical, scenario-based training to develop cognitive skills required to avoid midair collisions (Koglbauer, 2015), airport procedures training (Koglbauer & Braunstingl, 2018), and improving working memory and situation awareness training (Zhou et al., 2022). Airline simulation training scenarios can be improved by organizing training using a variable and unpredictable approach (Landman et al., 2018) so that training does not become predictable with little generalizability beyond the training environment (Casner et al., 2013).

eLearning. Computer-based training (CBT) was seen as part of the future of aviation training in the early 1990s, especially in developing technical skills (compared to behavioral skills). A few expert instructors delivered instruction in a lecture format, ensuring all trainees received the same correct information (Orlady, 1993). The concept of CBT has evolved well beyond the desktop computer with the proliferation of the internet and the development of smartphones, tablets, and mobile applications. It is now commonly known as electronic learning or eLearning. It provides organizations with a means to deliver training to many users through multiple channels and formats, and pilots have become increasingly accepting of and confident

in this method (Raisinghani et al., 2005). Learning may be synchronous or asynchronous, self-paced or instructor-led, offered remotely or onsite. Asynchronous eLearning allows the learner to control the content sequence of pacing instruction (Kearns, 2010). Self-pacing may lead to a higher level of motivation (R. C. Clark & Mayer, 2008, as cited in Kearns, 2010) and may be a good strategy for novice skill-based learning (Kraiger & Jerden, 2007). To determine the effectiveness of eLearning, Kearns (2010) reviewed multiple studies (Bernard et al., 2004; R. E. Clark, 1994; Kulik & Kulik, 1991; Russell, 1999; Zhao et al., 2005) and concluded that, in general, one could expect no significant differences in learning outcomes between eLearning and classroom-based courses developed with the same instructional content. Additionally, Kearns (2010) found asynchronous eLearning results in better learning than synchronous eLearning; blended learning results in better education than either synchronous or asynchronous delivery alone; and eLearning is more effective than classroom instruction for teaching declarative knowledge (e.g., ability to cite regulation) and equally effective for procedural knowledge (e.g., learning a standard operating procedure). eLearning may also be an effective instructional method to foster nontechnical flight skills (Bolstad et al., 2010; Kearns, 2011; Potter et al., 2014). Interactive eLearning multimedia tools that provide user feedback, self-testing, construct visualization, and encourage sequential movements, help learners develop procedural knowledge (Matton et al., 2018). eLearning curriculum has traditionally been delivered in the 2D environment, but technological advances make eLearning in 3D more readily available (Kearns, 2010; Kearns et al., 2020). eLearning provides a data-rich environment, and when combined with an intelligent tutor with a training program that automatically increases the difficulty level in response to student performance, a zone of optimal learning occurs known as adaptive learning (Brown, 2020; Kearns et al., 2020).

Gamification. Gamification is the use of game design elements (e.g., rules, goals, challenges, rewards) in non-game contexts (Deterding et al., 2011) and has been shown to contribute to improved learning (Zainuddin et al., 2020). Gamification designs provide immediate feedback (e.g., badges, points) that is often engaging, positive, and constructive (Jain & Dutta, 2019). Feedback plays a significant role in learning (Pashler et al., 2005), especially at the earlier stages. Positive feedback has been associated with higher levels of competence, which can lead to increased motivation and better learning (García et al., 2019; Wulf & Lewthwaite, 2016). Gamification has been shown to benefit Flight Management System (FMS) preflight programming training (Mautone et al., 2008), is believed to be a possible method to supplement simulation-based training (Kuindersma et al., 2015), and has been shown to supplement flight instructor training in assessing pilots' non-technical competencies (Dapica et al., 2022).

Immersive Training Devices. Immersive training devices (ITDs) create a virtual world. Virtual reality (VR), augmented reality (AR), and a combination of both technologies referred to as mixed-reality (MR), have been tested as possible training enhancement methods (Kaplan et al., 2020; Kearns et al., 2020). VR, AR, and MR fall under the umbrella term extended reality (XR), in which the 'X" represents a variable for current or future technologies that combine real and virtual environments (Cross et al., 2022).

Military flight training programs have demonstrated the potential behind immersive devices in pilot training. The U.S. Air Force began an initiative to innovate and improve undergraduate pilot training when it established its first Pilot Training Next (PTN) class in

Austin, Texas, in 2018. This program was designed to revolutionize flight training content delivery using a combination of multimodal immersive learning platforms derived from commercial-off-the-shelf (COTS) technologies and artificial intelligence (AI) tutoring systems (Lewis & Livingston, 2018). The population age demographic for this training was 21 to 28 years old placing them in the same generational category as the emerging civilian pilot workforce (Generations Y and Z). Students had their own synthetic virtual environment training stations in the classroom. They also shared a training station in their housing dormitories, providing easy access to a virtual flight training device to practice piloting skills. Intelligent tutors built into the synthetic training systems allowed PTN to have a higher student-to-instructor ratio and allowed instructors to concentrate on more complex maneuvers where higher levels of judgment and decision-making were required (Lewis & Livingston, 2018). On average, PTN students completed their first solo on their sixth or seventh ride versus the traditional norm of the 13th or 14th ride (Lewis & Livingston, 2018). The Air Force continues to build upon lessons learned to develop an AI-driven adaptive learning framework that engages and motivates learners in individualized ways that traditional pilot training methods cannot, using learning styles, knowledge levels, and skill proficiency while avoiding learning content that the student has already mastered (Lewis et al., 2019). The Air Force applied the PTN model in the Powered Flight Program at the U.S. Air Force Academy. Initial effectiveness data indicated increased perceived self-efficacy related to increased virtual reality simulator time (Pennington et al., 2019). The U.S. Army developed the Aviation Training Next (ATN) program, which employed VR simulation in initial rotary-wing training. They found no statistical difference between traditional and ATN flight student performance in course management plans; however, ATN students continually outperform their peers in aircraft check rides and academics beyond ATN training (McFarland, 2020). The U.S. Navy's Naval Aviation Training Next (NATN) program, also known as Project Avenger, re-imagined conventional training methodologies by employing a competency-based, individually tailored learning approach integrated with emerging technologies (focused on VR) for progressive skills development and flexible training event design based on lessons learned from earlier military efforts (Mishler et al., 2022). The first iteration of NATN suggests that this new method produces a stronger generalized aviator faster than legacy training, and student feedback was overwhelmingly positive (Mishler et al., 2022).

Immersive XR training devices have been introduced in military and commercial pilot training, but academia has generated little empirical evidence of XR effectiveness (Cross et al., 2022). Bauer and Klingauf (2008) suggest that VR may help develop procedural knowledge that improves simulator performance, filling a niche between CBT and the traditional flight simulator that may supplement classroom training activities and simulator procedure training (Cross et al., 2022). Schaffernak et al. (2022) identify the three most promising use cases for MR in pilot training: interactive theory training, cockpit procedure training, and outside check training. Moesl et al. (2021) propose a research agenda for implementing AR-based training into *ab-initio* pilot training focusing on approach and landing, abnormal and emergency procedures, air work, enroute procedures, and flight instructor development. They also propose incorporating eye-tracking technology. Cross et al. (2022) summarizes the benefits of XR compared to traditional flight simulator training devices as reduced cost, flexibility, immersion/realism, and limitations as the degradation of performance due to hardware.

Eye Tracking Technology. The increasing body of research on eye-tracking technology is opening new possibilities for enhancing pilot training. Eye-tracking technology can monitor and record where a pilot is looking, how long they focus on a specific area, and their gaze patterns inside and outside the flight deck, providing insights into pilot behavior and performance. Research suggests eye-tracking technology may improve cockpit monitoring by using a training program based primarily on exposure to eye movement examples from highly accurate pilots (Lefrançois et al., 2021); may be a valuable tool for the explicit training of attention allocation during go-arounds (Dehais et al., 2017), upset prevention and recovery debriefing (Ryffel et al., 2019), promoting situational awareness training in flight operations (Yu et al., 2014), and serve as an objective measure or indicator of a pilot's ability to manage information (Dill & Young, 2015).

While eye-tracking technology can objectively measure eye movements and demonstrates great potential in education research, specifically investigating the visual aspects of learning, it is crucial to understand that while eye movements may indicate cognitive processes, cognitive processes cannot be directly inferred from eye-tracking data because there is still no clear understanding of how cognitive processes can be deduced from eye movements (Kok & Jarodzka, 2017).

Emerging Issues and Trends

This section examines emerging issues and trends that may impact the emerging pilot workforce.

Sharing Best Practices. The accelerated pace of technology development in aviation and training necessitates sharing information between aviation communities that share the common goal of safe and efficient flight operations. New technologies and capabilities (AI intelligent tutors, immersive training devices, remote instructor pilots, etc.), training methodologies, and best practices should be shared between the military and civilian aviation communities (as able). University aviation programs supporting military and civilian pilot workforce pipelines should be included to proactively address industry trends through educational programming, research, and outreach.

The National Pilot Source Forum (NPSF) was established by the Chief of Staff of the Air Force in 2018, serving as a national umbrella for both military and civilian pilot training innovation. An NPSF working group meets regularly to discuss updates from members representing military and civilian aviation, collegiate aviation, and K-12 members interested in priming and improving the pilot training pipeline. NSPF efforts parallel recommendations made by the ACT ARC Effectiveness of Knowledge Training Workgroup (EKT WG) Recommendation 20-12 Outreach & Information Sharing meant to promote industry communication and collaboration regarding eLearning between aviation training stakeholders (FAA, 2020a).

Access to Training Tools. Cognitive and procedural skills are more prone to decay over periods of disuse than control-oriented skills and may be exacerbated by automation which puts pilots in a passive, pilot monitoring mode (Child & Spears, 1986; Martinussen & Hunter, 2010).

Pilots have complained that they did not get enough basic system training, particularly flight management systems (FMS) training, since the beginning of the advanced technology era in aviation (Orlady, 1993). Flight Training Devices (FTDs) and CBTs have become commonplace in airline training. Yet, twenty years later, the Flight Deck Automation Working Group's final report noted that current training devices, methods, and time allotted might not provide crews with the knowledge, skills, and judgment to manage flight management systems successfully (PARC/CAST, 2013). Recommendations in the Flight Deck Automation Working Group final report include providing pilots with opportunities to refine manual flight operations knowledge and practice outside of training programs that focus on passing tests/check rides and spending more time allowing pilots to make mistakes and find their way out of a scenario and learning what not to do during actual line operations (PARC/CAST, 2013).

A study on pilot training for transition to glass flight decks in transport aircraft examines the increasing cost airlines face in the purchase of increasingly complex FTDs and describes:

> *What seems to be missing in the array of training devices would be a device so small and so inexpensive that it could be provided, along with the software, to each pilot, not only for transition training but for recurrent and for incorporation of new devices (p. II-18) (Wiener, Chute & Moses, 1999).*

In the two decades that have elapsed since this study, technology has evolved rapidly with products such as smartphones and tablets, augmented reality, and virtual reality systems.

METHOD

Experimental Design

This research effort, approved by the authors' Institutional Review Board, examined the efficacy and limitations of new immersive technologies and associated learning methods, in training the civilian emerging pilot workforce, and how an evaluator can determine whether training is operationally effective. More specifically, this effort evaluated interactive, immersive asynchronous eLearning using a VR headset and software to train general Airbus A320 flight deck orientation and operation of systems preflight tasks described in FAA Airline Transport Pilot Airman Certification Standards (ACS) and FAA Advanced Qualification Program (AQP) Job Task Listings Terminal Proficiency Objectives (TPOs) and Supporting Proficiency Objectives (SPOs) examples found in FAA Advisory Circular 120-54A Advanced Qualification Program (Chg 1).

The control group used a combination of traditional classroom lectures and simulator sessions in an Airbus A320 procedures trainer to learn system preflight tasks. In contrast, the experimental groups used A320 flight deck procedural trainer software installed on virtual reality headsets to learn and rehearse tasks in a guided virtual environment. One experimental group used VR to augment classroom and simulator training; the other used VR to augment classroom training and used VR as a replacement for simulator training. The three groups are summarized below.

- Control group: the traditional classroom training combined with simulator training.
- Experiment group #1: classroom training, simulator training, and VR on a head-worn device to augment baseline classroom and simulator training.
- Experiment group #2: classroom training and VR on a head-worn device as a replacement for simulator training (no simulator training).

Task instructions were based on two aircraft preflight checklist procedures, Preliminary Flight Deck Prep (Module 1) and Flight Deck Prep (Module 2) and presented in two modules developed for this project (outlined below).

Module 1 TPO is Preliminary Flight Deck Prep and includes 7 SPOs (with 29 subtasks):

1. Aircraft setup (5 subtasks)
2. Batteries, external power (2 subtasks)
3. APU fire test, start (5 subtasks)
4. Cockpit lights (1 subtask)
5. EFB initialization (3 subtasks)
6. Aircraft acceptance (4 subtasks)
7. Before walkaround (9 subtasks)

Module 2 TPO is Flight Deck Prep and includes 5 SPOs (with 46 subtasks):

1. Overhead panels (15 subtasks)
2. Center instrument panel (4 subtasks)
3. Pedestal (12 subtasks)
4. Glare shield (6 subtasks)
5. Lateral console, instrument panel (9 subtasks)

Sample

The population for this study was *ab-initio* civilian pilot students (Generations Y and Z) enrolled in a collegiate aviation undergraduate flight degree program at a 14 CFR Part 141, FAA Restricted Airline Transport Pilot (R-ATP) approved institution, who had completed their instrument rating as a minimum, were working towards or completing the commercial certificate and multi-engine rating and enrolled in the program's airline transport category systems and procedures capstone course. This course is a 4-credit (3 classroom hours + 1 lab hour) course focusing on Airbus A320 systems and operational procedures and 14 CFR Part 121 air carrier flight and crew management. Procedural content presented in Modules 1 and 2 was not previously taught in this course and was added for this study. Course students are members of the emerging pilot workforce. The research team assumes that study participants plan to join the air carrier pilot workforce but recognizes that not every participant may do so. Those who choose this career path will join the 14 CFR Part 121 air carrier pilot workforce upon reaching as little as 1,000 flight hours, typically within 12-18 months of university graduation. None of the participants had Airbus A320 flight experience.

The study spanned two semesters of the capstone course to increase the number of research participants. The baseline control group included Fall semester 2022 students. The experimental groups included students from the Spring semester 2023 course. Spring course sim blocks were predesignated (before student signup) for Module 1 and Module 2 instruction methods, either using head-worn VR devices to augment classroom and simulator training (experimental group #1) or classroom with no simulator training and VR head-worn device as a replacement for simulator training (experimental group #2). Participants self-selected their course simulator schedule based on their academic schedule, not knowing which experimental group they would be assigned to. All students had approximately two weeks to learn Modules 1 and 2 before being evaluated. Twenty-six students opted into the study, beginning with seven in the control group, 10 in experimental group #1, and nine in experimental group #2. Four students in experimental group #2 opted not to complete the field test, leaving a total of 22 participants who completed the field test final evaluation.

Tools

The VR device was a commercial off-the-shelf (COTS) virtual reality headset. The headset is a fully mobile, wireless/untethered, all-in-one VR system (headset and two controllers) that allows users to train anywhere, anytime. A personal computer (PC) or console was not required. This system is inexpensive to purchase compared to higher-end VR devices and is widely available to the general public for approximately $400. The VR system weighs about four pounds, uses a Fast-Switch LCD Display, has 1832 x 1920 resolution per eye, and supports 60 Hz, 72 Hz, or 90 Hz refresh rates. This system is eyeglass compatible and uses six degrees of freedom tracking. The headset tracks the movement of both head and body, then translates them into VR with realistic precision.

The experimental groups used commercially available software developed specifically for A320 pilot training. The software provides a 3D virtual flight deck that responds and behaves like a real aircraft (including sounds, lights, screens, etc.) to provide the user with a realistic training environment. The software provides training and exam modes to guide procedural learning and check if the procedure has been learned correctly. The software provides student feedback on procedure performance and shows the time taken to complete the procedure. Training content is stored locally on the VR device and can be transmitted to a learning management system (LMS) with Wi-Fi connectivity or collected manually. VR headsets were managed using a VR management platform and “locked down” to prevent other software use on the VR devices. Devices were distributed at the beginning of the course, along with a quick start VR user’s guide developed by a graduate student.

The commercially available Airbus A320 procedures trainer simulator is a spatially correct, functionally accurate, precise tactile feel flight deck with an instrument panel, glare shield, aisle stand, primary and aft overhead, flight controls shell/interior, and crew/observer seating. The flight deck is integrated with a collimated 10’ dome visual system (Level D compliant), flight data package, and imaging system. The trainer uses control-loaded rudders and a sound system with dual 800-watt subwoofers and custom surround sound to simulate accurate and directional wind noises, vibrations, engine sounds, and aerodynamic drag. This A320 procedures trainer is FAA Level 4 compliant but not FAA-certified since the university does not

type-certify students in the A320. The simulator is used primarily for human factors training focusing on crew resource management (CRM) using LOFT scenarios.

Data Collected

Participants took a pretest to measure A320 systems and procedures knowledge and a pretest survey to collect the following information:

1. Demographics
2. Flight experience
3. Career pathway program participation
4. VR experience
5. Gaming experience
6. Eyeglasses or contact lenses use.

Control and experimental group participants participated in a modified Line Oriented Simulation (LOS) in a Level 7 Flight Simulation Training Device (FSTD) at a partner 14 CFR Part 121 air carrier using Aircrew Program Designees (APDs) as evaluators. The APDs used grading sheets for each module, developed by the researchers, based on modified AQP grading criteria (2 – not proficient (error not managed), 3 – competent (managed error), 4 – proficient (no errors)) to evaluate individual task proficiency and the overall performance of experimental and control group members. APDs were blind to the training intervention and did not know whether the participants they evaluated were from an experimental or control group. Airbus Original Equipment Manufacturer (OEM) A320 procedures were used to standardize all devices' training and evaluations.

The experimental groups had an early morning LOS and spent the night near the air carrier's training center to minimize fatigue. The control group used one FSTD, and the experimental group used two FSTDs simultaneously for evaluations. APDs initialized the flight deck the same for each participant's LOS, with either a graduate assistant or faculty member familiar with A320 aircraft procedures in the left seat and the research participant sitting in the right seat. Participants performed both checklists alone initially at their own pace. When complete with the checklist, the individual in the left seat read the checklist with challenge and response. As researchers observed, air carrier APDs scored task performance during each participant's LOS. Researchers collected LOS scores from the APDs and recorded the time to task completion.

Following the LOS, participants completed a post-test survey to capture user experience data:

1. Self-confidence in execution (Likert, 1-7)
2. Time (minutes) spent studying to feel confident in the procedural ability
3. Perceived difficulty (Likert, 1-7)
4. Intrinsic Motivation Inventory (Isen & Reeve, 2005): Learning …
    a. …Stimulated my curiosity (Likert, 1-7)
    b. …Was interesting (Likert, 1-7)

   c. …Was fun (Likert, 1-7)
   d. …Was enjoyable (Likert, 1-7)
   e. …Made me want to explore further (Likert, 1-7)
5. Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993): Symptoms affected you …
   a. General discomfort (None, Slight, Moderate, Severe)
   b. Fatigue (None, Slight, Moderate, Severe)
   c. Headache (None, Slight, Moderate, Severe)
   d. Eye strain (None, Slight, Moderate, Severe)
   e. Difficulty focusing (None, Slight, Moderate, Severe)
   f. Salivation increasing (None, Slight, Moderate, Severe)
   g. Sweating (None, Slight, Moderate, Severe)
   h. Nausea (None, Slight, Moderate, Severe)
   i. Difficulty concentrating (None, Slight, Moderate, Severe)
   j. Fullness of the head (None, Slight, Moderate, Severe)
   k. Blurred vision (None, Slight, Moderate, Severe)
   l. Dizziness with eyes open (None, Slight, Moderate, Severe)
   m. Dizziness with eyes closed (None, Slight, Moderate, Severe)
   n. Vertigo (None, Slight, Moderate, Severe)
   o. Stomach awareness (None, Slight, Moderate, Severe)
   p. Burping (None, Slight, Moderate, Severe)
6. VR experience questionnaire
   a. How long could you wear the VR at a session (minutes)?
   b. If you wear glasses, was using VR an issue (Y/N)?
   c. Keep a VR log; how long did you use VR? Any issues?
   d. Open-ended response (anything the user wants to add)

RESULTS

Data Analysis

The data were analyzed using descriptive statistics, Kruskal-Wallis tests, Mann-Whitney U tests, and Spearman's rank correlations. A total of 21 of 22 participants completed the pretest survey, 22 of 22 participants completed the field test at the partner air carrier, and 21 of 22 participants completed the post-test survey.

Gender of Participants. Participants were predominantly male (81.82%) with 18.18% female. The distribution of participants by gender is shown in Table 6.

Table 6
Distribution of Participants by Gender

Gender	*n*	*%*
Male	18	81.82
Female	4	18.18

Note: N = 22

Generational Composition of Participants. Participants were primarily members of Generation Z (95.24%). One participant was a member of Generation Y. The distribution of participants by generation is shown in Table 7.

Table 7
Distribution of Participants by Generation

Generation	*n*	*%*
Generation Z (born 1997-2012)	20	95.24
Generation Y (born 1981-1996)	1	4.76

Note: N = 21

Flight Certificates and Ratings. Participants reported having flight certification as a Private Pilot (ASEL) or Commercial (AMEL) Pilot. All participants held an Instrument Rating. Participants were primarily Private Pilots with an Instrument Rating (76.19%) and 23.81% were Commercial Pilots with an Instrument Rating. The distribution of participants by highest flight certification achieved is shown in Table 8. There were no Commercial (ASEL) pilots in this study.

Table 8
Distribution of Participants by Highest Flight Certification Achieved

Highest Flight Certification Achieved	*n*	*%*
Private Pilot, Instrument Rating	16	76.19
Commercial Pilot, Instrument Rating	5	23.81

Note: N = 21

Total Flight Time. Participants' total flight hours ranged from 180 to 615, with a mean of 327.62 total flight hours and a standard deviation of 98.13 total flight hours ($M = 327.62$, $SD = 98.13$, $N = 21$). A total of 9.52% of participants reported having less than 250 flight hours, 85.72% reported having 250-500 flight hours, and 4.76% reported between 501-1000 flight hours. The distribution of participants by total flight hours is shown in Table 9.

Table 9
Distribution of Participants by Total Flight Time

Total Flight Hours	*n*	*%*
Less than 250 hours	2	9.52
250-500 hours	18	85.72
501-1,000 hours	1	4.76

Note: N = 21

A Kruskal-Wallis test was used to determine if there was a difference in total flight hours based on training method (Classroom and Simulator Training, Classroom and Simulator Training with VR to augment, and Classroom with No Simulator Training and VR as a replacement for Simulator Training) assignment. The total flight time by training method is shown in Table 10.

Table 10
Total Flight Time by Training Method

Total Flight Hours	*M*	*SD*	*n*	*df*	*H*	*p*
Classroom and Simulator Training	355.71	125.11	7	2	3.97	0.137
Classroom, Simulator, and VR Training	279.44	59.71	9			
Classroom, No Simulator, and VR Training	375.00	90.14	5			

Note: N = 21

No significant difference was found in total flight hours based on the training method group assignment ($H(2) = 3.97$, $p = 0.137$).

Career Pathway Program. No participants disclosed they had accepted a qualified job offer, or offer to join, or had been accepted to participate in an air carrier Career Pathway Program.

Gaming Experience. Only one participant reported having gaming experience (i.e., Esports, EGaming, Xbox, PlayStation, Online Gaming, etc.) and reported having an estimated 10,000 hours of lifetime experience.

VR Experience. Only one participant (the same participant with gaming experience) reported having experience with Virtual Reality (VR) technology and reported having an estimated 800 hours of experience.

A320 Systems and Procedures Knowledge. A Kruskal-Wallis test was used to determine if there was a difference in A320 pretest scores based on the training method, comparing the control group (Classroom and Simulator Training), experimental group #1 (Classroom and Simulator Training with VR to augment), and experimental group #2 (Classroom with No Simulator Training and VR as a replacement for Simulator Training). Three of the seven 5-question A320 pretests given to the control group were invalidated due to an administrative error in handing out the test and were not included in the data analysis. A320 pretest scores by training method are shown in Table 11.

Table 11
A320 Pretest Scores by Training Method

A320 Pretest Score	*M*	*SD*	*n*	*df*	*H*	*p*
Classroom and Simulator Training	80.00	0.00	4	2	2.69	0.261
Classroom, Simulator, and VR Training	60.00	35.28	10			
Classroom, No Simulator, and VR Training	52.00	17.89	5			

Note: N = 19

No significant difference was found in A320 pretest scores based on the training method group assignment ($H(2) = 2.69$, $p = 0.261$).

Task Performance. A series of Kruskal-Wallis tests were used to determine if there was a difference in Preliminary Flight Deck Prep and Flight Deck Prep task performance and

combined task completion time based on training method (Classroom and Simulator Training, Classroom and Simulator Training with VR to augment, and Classroom with No Simulator Training and VR as a replacement for Simulator Training). Preliminary Flight Deck Prep task performance by training method is shown in Table 12, Flight Deck Prep task performance by training method is shown in Table 13, and combined task completion time by training method is shown in Table 14.

Table 12

Preliminary Flight Deck Prep Task Performance by Training Method

Preliminary Flight Deck Prep Task Performance Score	*M*	*SD*	*n*	*df*	*H*	*p*
Classroom and Simulator Training	3.80	0.11	7	2	2.81	0.246
Classroom, Simulator, and VR Training	3.69	0.12	10			
Classroom, No Simulator, and VR Training	3.63	0.24	5			

Note: N = 22

Table 13

Flight Deck Prep Task Performance by Training Method

Flight Deck Prep Task Performance Score	*M*	*SD*	*n*	*df*	*H*	*p*
Classroom and Simulator Training	3.77	0.14	7	2	1.31	0.519
Classroom, Simulator, and VR Training	3.75	0.09	10			
Classroom, No Simulator, and VR Training	3.62	0.21	5			

Note: N = 22

Table 14

Combined Task Completion Time by Training Method

Combined Task Completion Time (Minutes)	*M*	*SD*	*n*	*df*	*H*	*p*
Classroom and Simulator Training	13.27	2.11	7	2	5.54	0.063
Classroom, Simulator, and VR Training	15.37	1.65	10			
Classroom, No Simulator, and VR Training	18.39	4.52	5			

Note: N = 22

No significant difference was found in Preliminary Flight Deck Preparation task performance based on the training method ($H(2) = 2.81$, $p = 0.246$), Flight Deck Preparation task performance based on the training method ($H(2) = 1.31$, $p = 0.519$), or the task completion time ($H(2) = 5.54$, $p = 0.063$).

Task Performance by Gender. The control group consisted of six males and one female. Experiment group #1 consisted of seven males and three females. Experiment group #2 consisted of five males. A series of Mann-Whitney U tests were used to determine if there was a difference in Preliminary Flight Deck Prep and Flight Deck Prep task performance and combined task completion time based on gender across all three groups combined. Preliminary Flight Deck Prep task performance by gender is shown in Table 15, Flight Deck Prep task performance by

gender is shown in Table 16, and combined task completion time by gender is shown in Table 17.

Table 15
Preliminary Flight Deck Prep Task Performance by Gender

Gender	*M*	*SD*	*n*	*df*	*Z*	*p*
Male	3.71	0.16	18	22	0.30	0.765
Female	3.71	0.14	4			

Note: N = 22

Table 16
Flight Deck Prep Task Performance by Gender

Gender	*M*	*SD*	*n*	*df*	*Z*	*p*
Male	3.72	0.15	18	22	0.73	0.468
Female	3.77	0.12	4			

Note: N = 22

Table 17
Combined Task Completion Time by Gender

Gender	*M*	*SD*	*n*	*df*	*Z*	*p*
Male	15.17	3.35	18	22	1.11	0.268
Female	16.39	2.14	4			

Note: N = 22

No significant difference was found in Preliminary Flight Deck Preparation task performance based on gender ($Z(22) = 0.30$, $p = 0.765$), Flight Deck Preparation task performance based on gender ($Z(22) = 0.73$, $p = 0.468$), or the task completion time, based on gender ($Z(22) = 1.11$, $p = 0.268$).

Self-confidence Using VR Technology. Experimental group participants were asked to rate their self-confidence in the execution of VR technology to learn the Preliminary Flight Deck Preparation and Flight Deck Preparation training modules on a scale from 1 (Not Confident) to 7 (Extremely Confident). A Mann-Whitney U test was performed to compare self-confidence ratings by experimental training method. Self-confidence ratings by training method are shown in Table 18.

Table 18
Self-confidence Rating by Training Method

Self-confidence Rating	*M*	*SD*	*n*	*df*	*Z*	*p*
Classroom, Simulator, and VR Training	5.11	1.69	9	14	0.14	0.892
Classroom, No Simulator, and VR Training	5.20	1.64	5			

Note: N = 14

No significant difference was found in self-confidence ratings based on the training method ($Z(14) = 0.14$, $p = 0.892$).

Time Spent Studying to Feel Confident. Experimental group participants were asked approximately how much time (in minutes) they spent studying with VR to feel confident in their procedural ability. A Mann-Whitney U test was performed to compare time spent studying by experimental training method. The time spent studying by training method is shown in Table 19.

Table 19

Time Spent Studying to Feel Confident by Training Method

Time Spent Studying to Feel Confident (minutes)	*M*	*SD*	*n*	*df*	*Z*	*p*
Classroom, Simulator, and VR Training	116.11	77.85	9	14	1.76	0.078
Classroom, No Simulator, and VR Training	231.20	101.72	5			

Note: N = 14

No significant difference was found in time spent studying to feel confident in procedural ability based on the training method ($Z(14) = 1.76$, $p = 0.078$).

Perceived Difficulty. Experimental group participants were asked to rate the perceived difficulty in the execution of VR technology to learn the course material on a scale from 1 (Not Confident) to 7 (Extremely Confident). The mean score for the two experimental groups combined was 3.79, with a standard deviation of 1.67 ($M = 3.79$, $SD = 1.67$, $N = 14$). A Mann-Whitney U test was performed to compare perceived difficulty by experimental training method. Perceived difficulty ratings by training method are shown in Table 20.

Table 20

Perceived Difficulty Rating by Training Method

Perceived Difficulty Rating	*M*	*SD*	*n*	*df*	*Z*	*p*
Classroom, Simulator, and VR Training	4.00	1.80	9	14	0.69	0.491
Classroom, No Simulator, and VR Training	3.40	1.52	5			

Note: N = 14

No significant difference was found in perceived difficulty ratings based on the training method ($Z(14) = 0.69$, $p = 0.491$)

Motivation. Experimental group participants were asked to rate five elements of the Intrinsic Motivation Inventory (Isen & Reeve, 2005) on a scale from 1 (Not Motivated) to 7 (Extremely Motivated). 13 of 14 complete participant responses were recorded. Ratings for the five elements for the two experimental groups combined are shown in Table 21.

Table 21
Combined Intrinsic Motivation Ratings

Element Rating	*M*	*SD*	*n*
Learning stimulated my curiosity	5.54	1.45	13
Learning was interesting	5.62	1.19	13
Learning was fun	5.23	1.83	13
Learning was enjoyable	5.23	2.00	13
Learning makes me want to explore further	5.85	0.99	13

Note: N = 13

A Mann-Whitney U test was performed to compare each element by experimental training method. Ratings for the five elements broken out by the two experimental groups are shown in Table 22.

Table 22
Intrinsic Motivation Ratings by Training Method

Element Rating									
	Classroom, Simulator, and VR Training			Classroom, No Simulator, and VR Training			*df*	*Z*	*p*
	M	*SD*	*n*	*M*	*SD*	*n*			
Learning stimulated my curiosity	5.88	1.13	8	5.00	1.87	5	13	0.83	0.406
Learning was interesting	5.88	0.99	8	5.20	1.48	5	13	0.91	0.361
Learning was fun	5.50	1.69	8	4.80	2.17	5	13	0.45	0.652
Learning was enjoyable	5.50	2.00	8	4.80	2.17	5	13	0.53	0.598
Learning makes me want to explore further	6.13	0.83	8	5.40	1.14	5	13	1.22	0.222

Note: N = 13

No significant difference, based on the training method, was found for the Intrinsic motivation element ratings for curiosity ($Z(13) = 0.83$, $p = 0.406$), interesting ($Z(13) = 0.91$, $p = 0.361$), fun ($Z(13) = 0.45$, $p = 0.652$), enjoyable ($Z(13) = 0.53$, $p = 0.598$), want to explore further (fun ($Z(13) = 1.22$, $p = 0.222$).

Simulator Sickness Questionnaire. Experimental group participants were asked to rate symptom effects for 16 elements of the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993) on a scale from 1 (None) to 4 (Severe). Ratings for the sixteen elements combined for the two experimental groups are shown in Table 23.

Table 23
Simulator Sickness Questionnaire Ratings

Element Rating	*M*	*SD*	*n*
General discomfort	1.93	0.83	14
Fatigue	1.71	0.61	14
Headache	1.93	1.00	14
Eye strain	2.07	0.92	14
Difficulty focusing	1.93	0.92	14
Salivation increasing	1.00	0.00	14
Sweating	1.00	0.00	14
Nausea	1.57	0.76	14
Difficulty concentrating	1.79	0.70	14
Fullness of the head	1.50	0.94	14
Blurred vision	2.29	1.33	14
Dizziness with eyes open	1.79	1.12	14
Dizziness with eyes closed	1.43	0.94	14
Vertigo	1.21	0.58	14
Stomach awareness	1.14	0.36	14
Burping	1.00	0.00	14

Note: N = 14

A Mann-Whitney U test was performed to compare each element by experimental training method. Ratings for the 16 elements broken out by the two experimental groups are shown in Table 24.

Table 24

Simulator Sickness Questionnaire Ratings by Training Method

Element Rating	Classroom, Simulator, and VR Training			Classroom, No Simulator, and VR Training			*df*	*Z*	*p*
	M	*SD*	*n*	*M*	*SD*	*n*			
General discomfort	2.00	1.00	9	1.80	0.45	5	14	0.42	0.881
Fatigue	1.78	0.67	9	1.60	0.55	5	14	0.51	0.649
Headache	2.00	1.12	9	1.80	0.84	5	14	0.35	0.832
Eye strain	2.44	0.88	9	1.40	0.55	5	14	2.38	0.034
Difficulty focusing	1.89	0.93	9	2.00	1.00	5	14	-0.21	0.776
Salivation increasing	1.00	0.00	9	1.00	0.00	5	14	0.00	1.00
Sweating	1.00	0.00	9	1.00	0.00	5	14	0.00	1.00
Nausea	1.56	0.73	9	1.60	0.89	5	14	0.00	1.00
Difficulty concentrating	1.67	0.50	9	2.00	1.00	5	14	0.66	0.510
Fullness of the head	1.56	1.01	9	1.40	0.89	5	14	0.42	0.676
Blurred vision	2.33	1.41	9	2.20	1.30	5	14	0.14	0.888
Dizziness with eyes open	2.11	1.27	9	1.20	0.48	5	14	1.41	0.158
Dizziness with eyes closed	1.67	1.12	9	1.00	0.00	5	14	1.39	0.164
Vertigo	1.22	0.67	9	1.20	0.45	5	14	0.33	0.743
Stomach awareness	1.11	0.33	9	1.20	0.45	5	14	0.44	0.661
Burping	1.00	0.00	9	1.00	0.00	5	14	0.00	1.00

Note: N = 14

Based on the training method, no significant difference was found for the Simulator Sickness Questionnaire element ratings, with one exception. There was a significant difference between training groups for eye strain ratings ($Z(14) = 2.38$, $p = 0.034$), with the Classroom, Simulator, and VR Training group having a higher eye strain mean score than the Classroom, No Simulator, and VR Training group.

A Mann-Whitney U test was performed to compare each Simulator Sickness Questionnaire element by gender. Ratings for the 16 elements broken out by gender are shown in Table 25.

Table 25
Simulator Sickness Questionnaire Ratings by Gender

Element Rating	Male			Female			*df*	*Z*	*p*
	M	*SD*	*n*	*M*	*SD*	*n*			
General discomfort	1.82	0.87	11	2.33	0.58	3	14	1.31	0.190
Fatigue	1.73	0.65	11	1.67	0.58	3	14	0.09	0.929
Headache	2.00	1.10	11	1.67	0.58	3	14	0.33	0.742
Eye strain	2.00	1.00	11	2.33	0.58	3	14	0.74	0.548
Difficulty focusing	1.91	1.04	11	2.00	0.00	3	14	0.50	0.618
Salivation increasing	1.00	0.00	11	1.00	0.00	3	14	0.00	1.00
Sweating	1.00	0.00	11	1.00	0.00	3	14	0.00	1.00
Nausea	1.55	0.82	11	1.67	0.58	3	14	0.53	0.599
Difficulty concentrating	1.73	0.79	11	2.00	0.00	3	14	0.77	0.442
Fullness of the head	1.55	1.04	11	1.33	0.58	3	14	0.00	1.00
Blurred vision	2.18	1.33	11	2.67	1.53	3	14	0.49	0.622
Dizziness with eyes open	1.73	1.19	11	2.00	1.00	3	14	0.69	0.487
Dizziness with eyes closed	1.36	0.92	11	1.67	1.15	3	14	0.54	0.588
Vertigo	1.09	0.30	11	1.67	1.15	3	14	1.15	0.250
Stomach awareness	1.18	0.40	11	1.00	0.00	3	14	0.77	0.442
Burping	1.00	0.00	11	1.00	0.00	3	14	0.00	1.00

Note: N = 14

No significant differences were found for the 16 Simulator Sickness Questionnaire element ratings based on gender.

VR Wear Per Session. Experimental group participants were asked approximately how long (in minutes) they could wear the VR device continually in each session. The mean time for the two groups combined was 37.86, with a standard deviation of 24.86 (M = 37.86, SD = 24.86, N = 14). Two Mann-Whitney U tests were performed to compare VR wear per session by experimental training method and VR wear per session by gender. VR wear by training method is shown in Table 26, and VR wear by gender is shown in Table 27.

Table 26
VR Wear by Training Method

VR Wear (minutes)	*M*	*SD*	*n*	*df*	*Z*	*p*
Classroom, Simulator, and VR Training	37.22	24.25	9	14	0.20	0.839
Classroom, No Simulator, and VR Training	39.00	28.81	5			

Note: N = 14

No significant difference was found in VR wear per session based on the training method ($Z(14) = 0.20$, $p = 0.839$).

Table 27
VR Wear by Gender

VR Wear (minutes)	*M*	*SD*	*n*	*df*	*Z*	*p*
Male	40.00	27.11	11	14	0.32	0.751
Female	30.00	15.00	3			

Note: N = 14

No significant difference was found in VR wear per session based on gender ($Z(14) = 0.32$, $p = 0.751$).

VR Usage Time. Each experimental group participant's VR training mode and exam mode usage time was captured and exported from the VR platform management system. A Mann-Whitney U test was performed to compare each VR usage mode's time by training method. VR usage time for each mode, broken out by training method, is shown in Table 28.

Table 28
VR Mode Usage by Training Method

VR Mode Usage (minutes)									
	Classroom, Simulator, and VR Training			Classroom, No Simulator, and VR Training			*df*	*Z*	*p*
	M	*SD*	*n*	*M*	*SD*	*n*			
Training mode	33.81	31.22	10	52.69	32.60	5	15	1.35	0.178
Exam mode	23.87	38.62	10	13.41	15.80	5	15	0.44	0.658

Note: N = 15

No significant difference, based on the training method, was found for VR usage in the training mode ($Z(15) = 1.35$, $p = 0.178$) or exam mode $Z(15) = 0.44$, $p = 0.658$).

A series of Spearman's rank correlations were computed to assess the relationship between VR usage modes, task performance, and combined task completion time. There was no significant relationship between the VR training mode and Preliminary Flight Deck Prep ($r(13) = -.07$, $p = 0.794$), Flight Deck Prep task performance ($r(13) = .13$, $p = 0.652$), or combined task completion time ($r(13) = .30$, $p = 0.277$). Additionally, there was no significant relationship between the VR exam mode and Preliminary Flight Deck Prep ($r(13) = .34$, $p = .220$), Flight Deck Prep task performance ($r(13) = 0.30$, $p = 0.270$), or combined task completion time ($r(13) = 0.08$, $p = 0.784$).

Eyeglasses. Eyeglass wear was captured on the pretest and post-test surveys. Most participants in the two experimental groups who used HMDs did not wear eyeglasses (93.33%). Only one participant reported wearing eyeglasses. The distribution of experimental group participants by eyeglass wear is shown in Table 29.

Table 29
Distribution of Experimental Groups Participants by Eyeglass Wear

Eyeglass Wear	*n*	*%*
No	14	93.33
Yes	1	6.67

Note: N = 15

The one participant who wore eyeglasses reported purposely wearing contact lenses because wearing glasses with the VR HMD was irritating. The participant's full comment is available in Table 30.

Open-ended Comments. The post-test survey prompted participants for other open-ended feedback that participants felt was important but not already considered in the research project. Participants in the Classroom and Simulator Training control group provided no additional comments. Participants in both experimental groups provided additional comments including issues related to VR usage they logged during the field test. A summary of open-ended comments by training method is shown in Table 30.

Table 30
Open-Ended Comments by Training Method

Open-Ended Comments	*Comment*
Classroom and Simulator Training	N/A (*n* = 0)
Classroom, Simulator, and VR Training	*The simulator program could use some improvements with regards to actually handling the switches, rather than just clicking them and moving on in the checklist. Wearing glasses was irritating for the headset, I purposely wore contacts to prevent the headaches. The tutorial to use the headsets could be a little bit better, maybe a demo could help. Overall, solid software and I learned a lot. It's the side effects from the headset that could use more work and attention to detail for me.* (*n* = 1) *Simulator training was way more efficient than VR.* (*n* = 1) *I think it would be important to ask about the environment in which we were using the VR goggles to see if that changes and how it could decrease our motivation.* (*n* = 1)

	The VR was pretty blurry, and it was hard to see what the buttons were. It also made me feel off for about 30 minutes after I used it. (*n* = 1)
	The VR headsets were definitely beneficial, but I think an overview of how to use then and set them up could have benefited the experience. (*n* = 1)
	Eye discomfort was a big factor it seems like in talking to other students. (*n* = 1)
Classroom, No Simulator, and VR Training	*The Virtual Reality we used for this research was 100% beneficial in regard to cockpit familiarization, however, did a poor job of explaining the why's behind each button pressure, and definitely did not replace in person instruction from an instructor. I would definitely recommend this product to other pilots looking to gain general familiarization with a A320 cockpit. With that said, a few of my complaints in regard to the Quest 2 are mainly hardware limitations, such as the screen resolution being somewhat blurry, which hindered my learning a bit. Another negative would be the headset strap itself not being very comfortable to wear for prolonged periods, and the relatively small field of view being poor on the quest definitely made it difficult to wear the headset for a long time. I found myself and fellow classmates having to take breaks every 10 minutes or so due to some type of discomfort. Overall, the product that was used during this research was adequate but with a few improvements in the right areas could be a highly regarded learning tool.* (*n* = 1)
	The program used is not very intuitive. (*n* = 1)
	The VR allows you to do the procedure, but you lack understanding of why you are doing the procedure. This can lead to confusion of what positions stuff needs to be in on the real airplane. Also, it takes a while to figure out all the controls and best set up the VR experience.

	The MCDU in the VR does not allow you to do anything on it, so when it came to tasks in the sim (such as IRS align) I had no idea what actually to do. (*n* = 1)
	Some tasks in the VR were as simple as pressing the MCDU, whereas the actual checklist has you program information into the MCDU. (*n* = 1)

Note: N = 21

DISCUSSION

Experimental Training Program

The current Part 121 air carrier pilot workforce, which consists of four generations, is expected to experience a 50% turnover in the next 15 years due to retirements. Baby Boomers and Generation X will retire first, followed by Generation Y and Z pilots. Empirical evidence from previous research suggests that effective training and checking methods for the emerging pilot workforce include classroom-based instruction (Casner, 2003; Rogers & Boquet, 2012; Cobbett et al., 2014; Dusenbury & Olson, 2019; Wilson & Stupnisky, 2022), eLearning (Bolstad et al., 2010; Kearns, 2011; Potter et al., 2014; Matton et al., 2018), lower-fidelity simulation (Taylor et al., 1999; Brannick et al., 2005; Taylor et al., 2005; Dahlstrom et al., 2009; Risukhin et al., 2016; Reweti et al., 2017; Thomas, 2018; Rosa et al., 2021), and higher fidelity simulation (Macchiarella et al., 2008; Koglbauer, 2015; McLean et al., 2016; Koglbauer & Braunstingl, 2018; Zhou et al., 2022). Immersive virtual reality (VR) technologies have shown promising results in military pilot training, as evidenced by studies published by Lewis and Livingston (2018), Pennington et al. (2019), McFarland (2020), and Mishler et al. (2022). These technologies may also hold significant potential for civilian pilot training. However, limited research is available on the effectiveness and limitations of VR in civilian flight training, as noted by Cross et al. (2022).

Air carrier pilots undergo intensive training to develop the range of skills necessary for safe and efficient flight. Fundamental among these skills, and to safe operations, is the correct execution of standard operating procedures. In the present work, we developed an experimental training program to examine the effectiveness and constraints of using entry-level commercial-off-the-shelf (COTS) Virtual Reality (VR) Head-mounted Displays (HMDs) for air carrier procedural training and how to determine whether this training is operationally effective. All participants were *ab-initio* civilian pilot students enrolled in a collegiate aviation undergraduate flight degree program at a CFR Part 141, FAA R-ATP-approved institution who aspire to become professional pilots. Twenty-two participants (*N* = 22) completed the field test, with seven (*n* = 7 of 22, 31.82%) in the control group (Classroom and Simulator Training), 10 (*n* = 10 of 22, 45.45%) in experimental group #1 (Classroom, Simulator, and VR Training), and five (*n* = 5 of 22, 22.73%) in experimental group #2 (Classroom, No Simulator, and VR Training).

Most participants were male (n = 18 of 22, 81.82%), members of Generation Z (n = 20 of 21, 95.24%), earned the highest flight certification of Private Pilot Certificate and Instrument Rating (n = 16 of 21, 76.19%), and logged between 250-500 flight hours (n = 18 of 21, 85.72%). No participants reported being members of a career pathway program (n = 0 of 21, 0%). Only one participant (n = 1 of 21, 4.76%) reported having electronic gaming experience. That same participant was the only one (n = 1 of 21, 4.76%) to report experience using VR technology.

Competency and Proficiency

All three groups had similar flight experience ($H(2) = 3.97$, $p = 0.137$) and A320 systems and procedures knowledge ($H(2) = 2.69$, $p = 0.261$). All groups learned the required tasks and had mean scores between the competent and proficient levels. No significant difference was found in Preliminary Flight Deck Preparation task performance ($H(2) = 2.81$, $p = 0.246$), Flight Deck Preparation task performance ($H(2) = 1.31$, $p = 0.519$), or the task completion time ($H(2) = 5.54$, $p = 0.063$) based on training method. Across the training methods combined, no significant difference was found in Preliminary Flight Deck Preparation task performance ($Z(22) = 0.30$, $p = 0.765$), Flight Deck Preparation task performance ($Z(22) = 0.73$, $p = 0.468$), or the task completion time ($Z(22) = 1.23$, $p = 0.268$), based on gender.

User Experience

Comparing the two experimental groups, there was no significant difference in self-confidence in the execution of VR technology based on the training method ($Z(14) = 0.14$, $p = 0.892$). There was no significant difference in time spent (minutes) studying with VR to feel confident in procedural ability based on the training method ($Z(14) = 1.76$, $p = 0.078$). Participants in the two experimental groups combined rated the perceived difficulty in the execution of VR technology as 3.79 on a scale from 1 (Least) to 7 (Most). No significant difference was found in perceived difficulty ratings based on the training method ($Z(14) = 0.69$, $p = 0.491$).

Examining learning motivation, experimental group participants (N = 13) reported that using VR to learn makes them want to explore further as the highest-ranking element of the five Intrinsic Motivation Inventory (Isen & Reeve, 2005) elements rated. On a scale from 1 (Not Motivated) to 7 (Extremely Motivated), the Intrinsic Motivation Inventory (Isen & Reeve, 2005) elements in descending order, based on intrinsic motivation rating are: Learning makes me want to explore further (M = 5.85); Learning was interesting (M = 5.62); Learning stimulated my curiosity (M = 5.54); Learning was fun (M = 5.23); and Learning was enjoyable (M = 5.23). Comparing the two experimental groups, no significant difference, based on the training method, was found for the Intrinsic Motivation Inventory element ratings for curiosity ($Z(13) = 0.83$, $p = 0.406$), interesting ($Z(13) = 0.91$, $p = 0.361$), fun ($Z(13) = 0.45$, $p = 0.652$), enjoyable ($Z(13) = 0.53$, $p = 0.598$), want to explore further ($Z(13) = 1.22$, $p = 0.222$).

Of the 16 elements of the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993), experimental group participants combined rated blurred vision (M = 2.29) as having the largest symptom effect on a scale from 1 (None) to 4 (Severe). Combined group (N = 14) SSQ element ratings in descending order, based on the severity of symptom effect, are

Blurred vision (M = 2.29); Eye strain (*M* = 2.07); Headache (*M* = 1.93); Difficulty focusing (*M* = 1.93); General discomfort (*M* = 1.93); Difficulty concentrating (*M* = 1.79); Dizziness with eyes open (*M* = 1.79); Fatigue (*M* = 1.71); Nausea (*M* = 1.57); Fullness of the head (*M* = 1.50); Dizziness with eyes closed (*M* = 1.43); Vertigo (*M* = 1.21); Stomach awareness (*M* = 1.14); Salivation increasing (*M* = 1.00); Sweating (*M* = 1.00); and Burping (*M* = 1.00). No significant difference was found in comparing each SSQ element by training method group, with one exception. There was a significant difference between training groups for eye strain ratings ($Z(14) = 2.38$, $p = 0.034$), with the Classroom, Simulator, and VR Training group having a higher eye strain mean score than the Classroom, No Simulator, and VR Training group. Each SSQ element was also compared by gender. No significant differences were found for the 16 Simulator Sickness Questionnaire element ratings based on gender.

Experimental group participants combined reported a mean time for the ability to wear the VR device at one setting as 37.86 minutes with a standard deviation of 24.86 minutes (*M* = 37.86, *SD* = 24.86, *N* = 14). No significant difference was found in VR wear per session based on the training method ($Z(14) = 0.20$, $p = 0.839$) or gender ($Z(14) = 0.32$, $p = 0.751$).

Reviewing VR platform management system training mode and exam mode usage data, the Classroom, No Simulator, and VR Training group used VR more than the Classroom, Simulator, and VR Training group. Training mode was used more by the Classroom, No Simulator, and VR Training group, while the Classroom, Simulator, and VR Training group used the exam mode more. However, no significant difference, based on the training method, was found for VR usage in the training mode ($Z(15) = 1.35$, $p = 0.178$) or exam mode $Z(15) = 0.44$, $p = 0.658$). There was no significant relationship between the VR training mode and Preliminary Flight Deck Prep task performance ($r(13) = -.07$, $p = 0.794$), Flight Deck Prep task performance ($r(13) = 0.13$, $p = 0.652$), or combined task completion time ($r(13) = 0.30$, $p = 0.277$). Additionally, there was no significant relationship between the VR exam mode and Preliminary Flight Deck Prep task performance ($r(13) = 0.34$, $p = 0.220$), Flight Deck Prep task performance ($r(13) = 0.30$, $p = 0.270$), or combined task completion time ($r(13) = 0.08$, $p = 0.784$).

Only one participant ($n = 1$ of 21, 4.76%) reported wearing eyeglasses. This participant purposely chose to wear contact lenses while using VR due avoid irritation caused by the VR HMD while wearing glasses. Other comments related to eye comfort were included in the open-ended participant comments.

Other open-ended participant comments can be categorized as positive and areas for improvement. Positives center on VR being beneficial to cockpit and aircraft familiarization, particularly with improved visual quality. Areas for improvement include improving the VR system tutorial, minimizing eye discomfort and blurred vision, improving screen resolution, head strap comfort, flight deck switch handling, Multi-Function Control and Display Unit (MCDU) interfaces, and providing accompanying systems instruction to improve understanding behind each procedural step.

Overall, the experimental training program's empirical findings suggest that VR HMDs are effective for air carrier procedural training but may have user limitations.

Research Limitations

Limitations noted in reviewing the literature for effective training and checking methods include that many studies often have small sample sizes, limiting their generalizability to the entire pilot workforce; did not indicate whether participants were Part 121 air carrier pilots or aspired to be Part 121 pilots; did not include age in the demographics, limiting generational considerations; and were often conducted by collegiate aviation faculty who conducted studies using their institution's student pilots, limiting the visibility on pilot development through non-collegiate pathways (e.g., flight academies).

Reviewing the literature specific to training pilot information management, decision-making, command judgment, flight deck automation, and unintended auto flight states training revealed few studies, particularly relating to Generations Y and Z. Older studies reviewed may not reflect the current workforce demographics, aircraft in service, and training practices, especially when considering Generation Z now being a part of the pilot workforce.

Field test findings may not represent a larger population, and the results may only apply to the specific group studied. It is worth noting that the participants in this study were self-selected into the group and were not randomly selected, which means that the findings may not be generalizable to a larger population. Furthermore, it is possible that those who chose to participate were more interested in immersive technologies than those who did not. It is also important to consider that four of the nine VR-only experimental group participants did not complete the field test, resulting in unequal sample sizes between the experimental groups.

Individual performance differences between the control and experimental groups may exist because of fatigue, as the two groups underwent the field test at varying times of the day.

Participants noted VR software limitations in their user experience feedback, particularly the differences between programming the MCDU using VR software versus performing the same task in the simulator.

This research examined preflight activities that are highly proceduralized. While VR training may be effective for these activities, findings may not carry over to other flight activities such as information management, decision-making, command judgment, or conducting an instrument approach. More research is needed in these areas as the researchers posit that using mobile immersive technology for procedural training may allow more efficient use of limited simulator resources to focus more on information management, decision-making, and command judgment in a crew setting, where pilots learn, train, and work together.

CONCLUSION

Summary

The current 14 CFR Part 121 air carrier pilot workforce includes pilots who belong to four generations. Due to the mandatory retirement age, this workforce will undergo an almost 50% turnover during the next 15 years, resulting in an emerging pilot workforce consisting of pilots who are members of Generations Y and Z. These individuals tend to be goal-oriented, self-directed learners who embrace active learning and can improve their individual learning using cooperative learning strategies.

Pathways to the Part 121 flight deck have changed over the last two decades. Since 2001, the percentage of civilian-trained pilots has increased while the number of military-trained pilots hired has decreased. Over the last decade, the declining percentage of military pilots who train in highly structured training environments has been offset by new, clearly defined networks of pathways developed through partnerships between airlines and select university and civilian flight academies. These programs may accelerate the development of the cognitive and behavioral skills required of professional pilots. Multiple air carriers have recently developed their own *ab-initio* flight academies within recent years, supplying another pathway to the flight deck that has not traditionally been part of pilot development in the U.S.

The high pilot workforce turnover rate may result in hiring new pilot workforce members at air carriers with less flight hour experience compared to generations past. Improved pilot development may offset the lack of experience compared to preceding generations of pilots since the emerging pilot workforce is training in an industry that has evolved much concerning human factors over the last thirty-plus years.

This project examined effective pilot training and checking methods. Previous research suggests that the emerging pilot workforce should be trained using a combination of traditional classroom instruction, eLearning, and hands-on scenario-based practical training in lower- and higher- and high-fidelity flight-training devices and aircraft and that the combination of integrated training methods reinforces the retention of information and supports active learning. Empirical findings from the field test phase of this project suggest that Virtual Reality HMDs are effective for air carrier procedural training as well but have may user limitations.

Study participants, who were *ab-initio* civilian pilot students enrolled in a collegiate aviation program, learned commercial aircraft preflight tasks using one of three methods. The control group used a combination of traditional classroom lectures and simulator sessions; one experimental group used VR to augment classroom instruction and simulator training; the other received classroom instruction and used VR to replace simulator training. Participants' performance was evaluated at a partner air carrier, and results indicate that all three types of training were equally effective, suggesting VR HMDs may have value in learning commercial aircraft preflight flight deck task procedures. As a group, participants were confident in their ability to use VR and reported that using VR motivated them to learn. There were concerns regarding the use of VR as users experienced slight-to-moderate blurred vision and eye strain. VR is not one size fits all, and VR systems have varying price points and capabilities. This study

used an entry-level COTS VR HMD. Additional research is required to understand better the many capabilities VR and other immersive training devices offer and how to best integrate these devices into civilian pilot training with existing training methods.

Regardless of the instructional setting (e.g., classroom, simulator) and technology, instructors play a crucial role in pilot training and must meet the rapidly evolving needs of a younger workforce and evolving technology. Instructor development is necessary to ensure instructors are not only subject matter experts but effective teachers. New technologies may change the role of the instructor, but their expertise is needed, particularly in an operating environment with high workforce turnover that generates wide-ranging training requirements. New concepts can be taught using various methods. They might not have to be instructor-led, freeing up instructors to focus more on online-oriented scenario-based training that requires elevated levels of judgment, crew resource management, and decision-making. Active learning and debriefs led by effective instructors in a collaborative crew setting will help learners develop and sharpen their knowledge, skills, attitudes, and expertise.

Desired results can be assessed at multiple levels during training, culminating in a holistic line-oriented evaluation. Ideally, training occurs systematically and iteratively, fostering continual improvement and resulting in higher pilot and air carrier performance levels.

Recommendations

Based on information learned during this research effort, recommendations for improving pilot training and checking are provided below.

Recommendation 1. After reviewing the literature on training pilots in information management, decision-making, command judgment, flight deck automation, and unintended auto flight states, it becomes evident that there is a gap in the research, especially concerning Generations Y and Z. Therefore, further research is necessary to fill this gap and shed more light on these areas.

Recommendation 2. Based on our research and a need for more information in the literature, research is required to understand better the many capabilities VR and other immersive training devices offer and how to integrate these devices into civilian pilot training best. Consideration should be given to, but not limited to, the type of tasks to train (e.g., procedural, technical skills, non-technical skills), mobility of device (e.g., tethered or untethered), and technical characteristics (e.g., resolution, refresh rates, degrees of freedom tracking), and time required to develop a desired level of competency.

Recommendation 3. To fully understand the potential benefits of eye-tracking technology in pilot training, it is necessary to expand the body of research aimed at exploring how this technology can be utilized in flight simulators and immersive training devices. At present, there is some but limited information in the literature on this topic.

Recommendation 4. Further research is needed to comprehensively evaluate the impact of a multi-generational workforce on pilot training and checking needs, particularly in light of the influx of new generations of pilots entering the workforce and limited literature on this topic.

Recommendation 5. Updated research is necessary as the air carrier industry evolves to understand how changes in workforce demographics, training methods, aircraft in service, and airline hiring practices impact pilot training. Older studies that guide pilot training and evaluation practices may not reflect the emerging workforce, training practices, or aircraft in service.

Recommendation 6. Encourage appropriate forums that promote cross-sharing pilot training and checking practices between commercial airlines, military branches, collegiate aviation, and flight academies.

Recommendation 7. Study the effectiveness of FAA and industry efforts to increase gender, ethnic, and racial diversity among the pilot ranks.

Recommendation 8. Expand FAA U.S. Civil Airman statistics reporting to include ethnic and racial data to track workforce changes through benchmarking.

Recommendation 9. Include R-ATP data in FAA U.S. Civil Airman statistics for a complete picture of the pilot workforce.

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