Bolstering safety and resilience with an AI-based pilot training technology.

Recent serious incidents reinforce the case for enhancing flight crew training using immersive flight simulation technology.

This paper advocates for the widespread implementation of a simulation technology (SATCE) in pilot training, including an outline of operational threats, current flight simulation shortcomings, a brief description of the technology, key drivers, and an exploration of the benefits. We answer 'why' SATCE is needed, and call for it to become a required part of ground-based pilot training, offering a pathway for its adoption at scale.

14 August 2023

Written by Michael Varney and Jeremy Goodman
in collaboration with: Larry McDonald, Michael Langer, John Tobin, John Frearson, John Bent, Nick Papadopoli, Gary Pearson, Henry Emery, Gary Pallett, Stefan Sobol, Kyle Johnston, Barry Gaines and Mark Dransfield.

Executive Summary

- Recent runway incidents in the United States and globally highlight the significant risks posed to flights by communication issues and errors by controllers and other traffic, yet these operational threats remain poorly represented in pilot training using current flight simulator technology.
- Continued growth of aviation worldwide will drive the need for pilots that can operate within increasingly busy and complex air traffic systems, while the average experience level of the pilot workforce is declining. Maintaining flight safety is only possible if incoming pilots receive effective and relevant training, and the proficiencies of existing pilots are maintained.
- Simulated Air Traffic Control Environment (SATCE) is an immersive training technology that simulates air traffic control and other traffic. Having already been defined by industry, SATCE is currently in use by early adopters and yielding positive results. The technology benefits pilots and flight crews, providing its highest value during real-time scenario-based training, and is applicable across all aviation sectors; commercial, military, fixed-wing, rotary-wing, and emerging markets.
- Current practice, which includes ATC role-play by the instructor with little or no moving traffic due to simulator limitations, does not deliver the operational complexity needed to realize the full potential of scenario-based flight training. With SATCE providing the missing simulation of a busy operational environment, pilots in training can build the competencies necessary to identify and manage known threats, especially in high risk flight stages exposed by recent incidents on or near runways.
- AI-based training technologies, including SATCE, offer powerful new tools that enhance flight training and provide comprehensive training data. Continued investment growth in AI, alongside further development, offers an exciting potential for SATCE to deliver increasingly effective training through more complex scenarios, heightened realism and immersion.
- The paradigm shift in flight training from a largely outcome-based testing approach towards an evidence- and competency-based training philosophy is arguably the single largest industry driver that necessitates SATCE. SATCE has a crucial role to play in the ongoing development and continued evolution of modern flight training, including Evidence-based Training (EBT) and the Advanced Qualification Program (AQP).
- In the emerging Advanced Air Mobility (AAM) sector, SATCE will be valuable, not only for pilot training, but also to support vehicle manufacturers and operators obtaining the necessary regulatory approvals before introducing commercial services.
- This paper proposes a proactive initiative, involving both industry and regulatory agencies, to facilitate the widespread incorporation of SATCE into flight training, including its regulatory requirement in flight crew licensing and training programs. The FAA's recent initiation of a collaborative research program evaluating SATCE is an encouraging step forward on the path toward this goal.

Table of Contents

Flight Safety Concerns

In the first few months of 2023, several serious high-profile civil aviation incidents, including near-misses, occurred in the United States, resulting in a sharp increase in media coverage, press interest and commentary. Concerns have been raised about the overall health of the U.S. aviation system and safety climate, stimulating a renewed focus on runway and terminal area operational safety within the global aviation community.

The National Transportation Safety Board (NTSB) and the Federal Aviation Administration (FAA) are investigating these recent incidents and, at the time of writing, have released several preliminary reports. While none of these incidents resulted in any injuries, loss of life, or damage, they have raised concerns about a system under significant strain or even deterioration.

Current investigations are likely to produce recommendations for changes to be implemented in the United States that may also influence the global aviation system. Risk mitigations are expected to include a combination of changes to processes, operational procedures and training. As part of a safety management approach, air traffic controller, pilot, and ground vehicle driver training will likely be scrutinized, resulting in recommended enhancements.

With global air passenger demand recovering, market confidence returning[1], and a predicted return to growth on pre-pandemic figures[2], there is a justifiable fear that without adequate measures to bolster flight safety, with increasing traffic and congestion, a serious accident may occur.

Recent Incidents in the United States

There have been eight notable and high visibility incidents between January and early March 2023 in the U.S. national airspace. All occurred on or near runways, with many involving evasive action to avoid a collision.

By mid-February, these incidents had become significant enough to prompt the Acting Administrator of the Federal Aviation Administration (FAA), Billy Nolan, to issue a call-to-action[3], urging a review of safety measures and an examination of the country's aerospace system. The FAA organized a safety summit in mid-March, which brought together over 200 leaders from the aviation industry to discuss safety measures[4]. In late March, the FAA issued a rare and wide-ranging 'Safety Alert for Operators' (SAFO) bulletin[5] as a broad call for the aviation community 'for continued vigilance and attention to mitigation of safety risks'.

Changes to training are already becoming evident. In late June, the FAA launched a monthly training series for its controller workforce. Mandatory in-person briefings, due to start in July, and will focus on

---

[1] For example, Turkish Airlines (THY) expect to expand their fleet to 435 aircraft by 2023 and to over 800 aircraft by 2033. 'Turkish Airline's Strategy and Targets for 2023-2033 Period', 13 April 2023.
[2] IATA, 'Airlines Cut Losses in 2022; Return to Profit in 2023', 6 December 2022.
[3] Reuters, 'U.S. FAA forms safety review team after near miss incidents', February 14 2023.
[4] Readout from the FAA Aviation Safety Summit Breakout Panels, Wednesday, March 15, 2023.
[5] FAA, Safety Alert for Operators (SAFO) 2023 002.

relevant safety topics aimed at strengthening the proficiency of controllers in all FAA facilities. Initial topics include airfield safety aimed at reducing events on the surface.[6]

While the total number of runway incursions nationally recorded by the FAA over the two quarters January to June 2023 was slightly down on the same periods in 2022[7], the number of incidents, categorized as serious or where there is a significant potential for collision, has been noteworthy.

Investigations ongoing

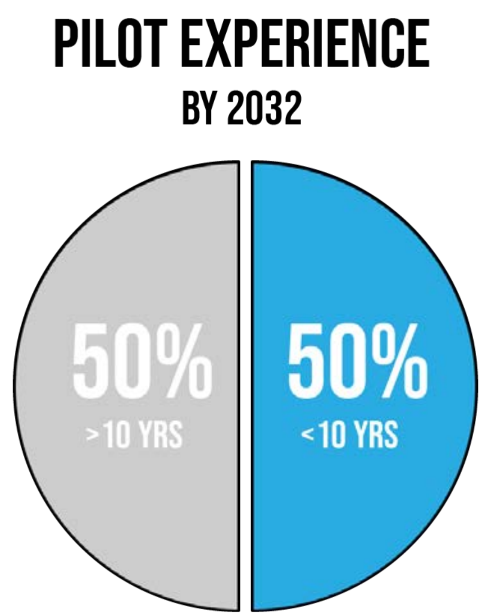
It is important to allow investigations to continue and for these processes to reach a conclusion on causal factors and provide expert safety recommendations. However, preliminary findings from open-source surveillance data, aircraft, and air traffic audio recordings indicate a variety of radio communication issues and errors by air traffic controllers, flight crews, and ground vehicle drivers.

The patterns observed from recent U.S. incidents are not isolated. Incidents from other areas of the global aviation system over recent years are prevalent, also highlighting the same threats arising from communications issues, ATC and other traffic.

A summary of recent U.S. incidents and two others, one serious incident from France last year of a near controlled flight into terrain (CFIT), and the other from the UK, are provided in the Appendix to this paper.

Changing Demographics

The global aviation industry is undergoing significant changes in pilot demographics and turnover, that are in turn leading to a gradual loss of flying experience. It is crucial to recognize the impact of these changes on flight safety and consider measures in pilot training that can help mitigate their effects.



Data Source: CAE, 2023.

In June 2023, CAE released its Aviation Talent Forecast, predicting that 99,000 of the 351,000 active civil aviation pilots worldwide will be lost through attrition over the following ten years, representing a 28% loss in the workforce. Additionally, another 153,000 pilots will be needed for new growth over the same period[8].

In total, the global aviation industry is expected to need 252,000 new airline and business jet pilots by 2032. A significant proportion of these new pilots are expected to be non-native English speakers.

[6] FAA, 'FAA Launches Controller 'Stand Up for Safety' Campaign' June 21, 2023.
[7] FAA, National runway incursion totals by quarter FY2023 vs FY2022. Runway incursions are grouped into four categories: Operational Incidents (OI), Other, Pilot Deviations (PD), and Vehicle or Pedestrian Deviations (VPD).
[8] CAE, '2023 Aviation Talent Forecast', June 20, 2023.

These trends may result in half of the civil pilot workforce globally having 10 years or less operational experience by 2032[9].

To address the ongoing pilot shortage, U.S. airlines are adopting various measures, such as offering higher salaries, recruiting internationally, and requesting lower training standards[10]. During these efforts or any other responses, it remains critical to maintain high safety standards and uphold the quality of flight training.

Loss of experience

Demographic changes in the aviation industry are already causing staffing challenges for regional airlines in the U.S.

According to Boeing 737 pilot Sam Weigel, "*It's not just that regional airlines are losing captains to the likes of Delta and United; they are also losing first officers to Spirit and JetBlue and Atlas, sometimes after as little as a year of employment*". He also notes "*brand new line pilots still on probation have been awarded captain upgrades… and pilots with a mere two years of seniority are getting the Boeing 757/767 left seat (i.e. captaincy)*"[11].

The industry is facing pressure to either reduce experience and proficiency requirements or find ways to improve training to enhance the competencies of new pilots. Calls for changes, such as extending the mandatory retirement age for commercial pilots, are already being made by elected officials[12].

Cadet training

In a recent article taking a critical look at primary pilot training, flight training veteran, experienced pilot and industry consultant John Bent calls for training improvements, commenting "*the pandemic-induced challenge of reduced experience on flight decks around the world has few mitigants except improved training*"[13].

He is not alone in this assessment, reporter David Schaper, writing for NPR notes that aviation industry experts "*...argue that it's not the amount of time in the air that matters, but the quality of the training, and training in a commercial jet simulator will actually be more valuable to an aspiring airline pilot than flying a few hours in a small airplane…*"[14].

In 2006, ICAO created the Multi-crew Pilot License (MPL) as a way to provide cadet pilot training, 'from the beginning' (*ab initio*), designed to be more appropriate to the highly automated crew environment of the modern airliner flight deck. The MPL is a competency-based approach over previous task-based syllabi, and takes advantage of flight simulators and instructional systems design.

---

[9] The 50% figure comes from CAE's forecast of 252,000 new pilots / 504,000 total global pilots by 2032.
[10] Business Insider, April 24 2023, Taylor Rains, 'Airlines are trying to combat the pilot shortage by paying pilots more, making it easier to become one, and hiring from Australia'.
[11] Flying, 'Game Over for Regional Airlines?' Sam Weigel, November 4, 2022.
[12] Lindsey Graham Press Release, 'Graham, Senators Reintroduce Bill To Address Pilot Shortage', March 21 2023.
[13] Halldale Group, 'Same Old, Same Old?', Cpt. John Bent, FRAeS, Feb 21, 2023. 'The slow and reactive regulatory paradigm has probably outlived its usefulness in terms of industry safety'.
[14] NPR, 'Proposals would ease standards, raise retirement age to address pilot shortage', David Schaper, August 10, 2022.

Although many MPL courses involve fewer training hours in real aircraft compared to traditional approaches, the primary drivers behind the MPL were not to reduce training costs or increase throughput to meet pilot demand[15].

During the development of the MPL, 'ATC simulation' (an early term for SATCE) was recognised as a critical training component. In 2011, the European Union Aviation Safety Agency (EASA) mandated the inclusion of ATC simulation for flight simulation training devices (FSTDs) for use with MPL training programs[16].

Although the MPL license is not issued in the United States, it has gained adoption by major carriers in Europe, the Middle East and Asia, for instance the Etihad Airways' Boeing 787 Dreamliner MPL program[17]. To our knowledge, no training providers offering the MPL have sourced SATCE systems to meet EASA's requirements, but instead have chosen other acceptable means of compliance, such as instructor role-play and exposure to local air traffic control operations.

Perhaps this was an opportunity lost for the industry?

Let's talk about hours

Demographic changes are leading to a decrease in the experience of pilots worldwide measured in flying hours. In addition, an aging workforce and growing pilot shortages are driving change in the traditional career progression that young cadets may expect.

Pilots with instructional and general aviation experience are increasingly making a 'jump' into the right hand seat of a commercial airliner, skipping traditional steps that would have tested their skills on numerous levels and added varied and valuable hours of flying experience.

Major airlines are supporting fast-tracked training programs, such as Delta's Propel Pilot Career Path offering an accelerated timeline for pilots to progress to Delta, in 42 months or less, after flying for one of the airline's regional carriers or flying military aircraft. Delta has recently reported that nearly 100 participants have completed since 2018 and are now flying with the airline, and a further 700 are enrolled[18].

> ***"For decades, pilots have arrived at airline doors fully trained with years of experience. The tables have turned and now airlines are having to dig deeper and provide extra layers of training."*** *- Erika Armstrong, Author of 'A Chick in the Cockpit', airline and business jet pilot and trainer*

[15] IATA, 'Frequent Asked Question of Multi-crew Pilot Licence (MPL)', v1.4, 24 February 2010.
[16] EASA Part-FCL V1 June 2016
[17] Etihad Airways, 'Etihad Airways marks significant milestone in Middle East's first Boeing 787 Dreamliner Multi-Crew Pilot License (MPL) Programme', 05 April 2023.
[18] Delta, 'Delta launches Propel Flight Academy to train next generation of airline pilots', Staff Writer, March 21, 2023.

Historically, relatively inexperienced pilots gained exposure to different operations and aircraft types, all while learning from more experienced pilots. This helped build their skills and resilience before being hired by an airline. However, as author, airline and business jet pilot and trainer Erika Armstrong and many others have pointed out, recent increases in the number of 'low hours' pilots on accelerated or 'short' career paths does not necessarily make for bad pilots[19].

When measuring experience, not all hours are equal. Time spent flying routine line operations in normal uneventful conditions are not the same as hours in varied aircraft types and diverse operations, or spent in effective and constructive training using high fidelity simulation.

The global decrease in experience in the pilot workforce and changes in traditional career routes for cadets, further emphasizes the necessity of providing effective flight simulator training that includes a realistic operational environment.

There are calls from experienced industry leaders for the overhaul of current pilot training and a rebalancing in the assignment of training credit.

Former FAA Administrators, Randy Babbitt and Dan Elwell stated, in their 18 April letter to leaders of the House of Representatives' Transportation and Infrastructure Committee, that "*The US pilot training paradigm is flipped from where it should be*". They continue "*Today's approach maximizes 'simple flight hours' but allows minimal credit for the use of advanced simulator and ground training devices; we strongly believe it should be the other way around*"[20].

The allowance of an increased credit for training using advanced training devices would support more efficient and effective training, helping to overcome pilot shortages, and bolster flight safety and resilience. When coupled with a robust SATCE system, a more realistic operational environment would further enhance the quality of training and add valuable aeronautical experience credited in a simulator.

Operational Threats

Q: What are the threats outside of the aircraft faced by flight crews in real world operations?

> **Short answer:** Amongst other threats from the external environment, radio communication issues, ATC and other traffic present operational threats to a flight. Occurrences involving these threats are unlikely to go away in the next few years - if anything, with industry recovery and forecast growth, they're likely to increase.

Operational threats to a flight are events outside the aircraft and require the flight crew's attention and management to maintain safety margins. This definition aligns with the concept of Threat and Error Management (TEM)[21], which emphasizes the proactive identification and management of threats to aviation safety.

---

[19] LinkedIn, Erika Armstrong, May 26, 2023. Author of 'A Chick in the Cockpit'.
[20] 'Former FAA administrators call for pilot training regime overhaul', Pilar Wolfsteller, Flightglobal, April 18, 2023.
[21] University of Texas Human Factors Research Project, The LOSA Collaborative, December 12, 2006. 'Defensive Flying for Pilots: An Introduction to Threat and Error Management', Ashleigh Merritt, Ph.D. & James Klinect, Ph.D.

Increasing complexity can be considered a threat. Examples include challenging ATC clearances, or other aircraft queuing up on taxiways, as well less obvious threats, such as recent changes to airports and procedures. In addition to adverse weather and operational pressures, threats can also include external human error, for example, an unsafe ATC clearance or other aircraft or ground vehicle movements that erode safety margins.

Threats generally increase workload for flight crews leading to a greater prevalence of errors and the possibility, where errors remain undetected or mismanaged, of an undesired aircraft state. An example may be, an unclear ATC instruction (threat) leading to misinterpretation (error) resulting in a runway incursion (undesired aircraft state).

For the purpose of this paper, threats related to (i) radio communications, (ii) air traffic control, and (iii) other traffic will be discussed.

As air travel rebounds internationally following the global COVID-19 pandemic, airspace and airports are expected to remain busy and get busier. The International Civil Aviation Organization (ICAO) forecasts that air passenger demand in 2023 will rapidly recover to pre-pandemic levels on most routes and that growth of around 3% on 2019 figures will be achieved by the end of the year[22].

Threats to flights from radio communications, ATC, and other traffic evident in recent incidents are likely to persist or increase in frequency as traffic levels rise. Air-ground communications are already fast-paced and highly-pressured in many regions of the world, given complex airspace and concentrated traffic, especially during peak periods at international and national hub airports.

Radio Communications

Communication issues, both within the cockpit and between pilots and controllers, are widely acknowledged as a significant threat to flight safety[23].

Current air traffic management (ATM) relies heavily on radio communications between controllers and pilots at most controlled airports and airspaces worldwide, although data communications are increasingly being introduced to alleviate busy frequencies. Audio communication relies on clear understanding between the transmitting and receiving parties as they exchange spoken information, such as clearances, instructions, state and intentions.

Despite internationally and nationally agreed language, phraseology standards and best-practices, miscommunications and errors still arise. Poor signal quality, and other factors, including weather effects and technical issues can also contribute to radio communication difficulties.

---

[22] ICAO, 'ICAO forecasts complete and sustainable recovery and growth of air passenger demand in 2023', 8 February 2023.
[23] Flight Safety Foundation, 'Failure to Communicate', Hearing — and understanding — the spoken word is crucial to safe flight. Dale Wilson, October 20, 2016.

Several high-profile recordings of controller-pilot miscommunications have drawn wide interest and commentary online, for example, the difficulties experienced between Air China 981 and ATC after the long-haul flight landed at JFK International Airport, New York, from Beijing, China, in 2006[24].

Language barriers

Language barriers can be challenging, especially between native and non-native speakers. While the ICAO Language Proficiency Requirements (LPRs) have established a minimum standard of English language proficiency, pilots and controllers continue to struggle with heavy foreign accents and inadequate English language skills.

These challenges are present everywhere, but may be most apparent at airports and in airspaces used by both national and international carriers. In exceptional cases, pilots and controllers may experience 'language apprehension' and avoid communicating, not wishing to appear incompetent on a frequency with many people listening[25].

Large aviation markets such the United States and China are currently experiencing a rebound in international traffic flows post COVID-19. For example, at the end of April 2023, international bookings in China were 8% below 2019 levels[26]. Flight crews commonly arrive at international hub airports tired with many having traveled through multiple time zones.

In addition to the challenges of unfamiliar airports and ATC procedures, foreign accents, local jargon, shortcuts and unwritten rules all add complexity, making the task of flight management across cultures more challenging.

Speaking, listening and comprehension difficulties where language and cultural challenges exist can prompt repeated or revised radio transmissions, adding to complexity and creating congestion. This increases workload for all parties on frequency and can also cause delays.

Use of more than one language on frequency

This safety issue arises when pilots and controllers use different languages at the same time on the ATC frequency. Despite English being the default language in international aviation, local languages are also used concurrently for air-ground communication in many parts of the world, including many European countries and those across Latin America.

EASA has recognised the use of multiple languages in radio communications as a new risk to aviation safety in the ATM / ANS safety risk portfolio of the European Plan for Aviation Safety (EPAS) 2023-25[27].

---

[24] Aviation English Matters, website page, 'A selection of incidents / accidents where language has been a factor.'
[25] ERAU, Appendix A - Examples of How Language Impacts Flight Safety, Mathews, Elizabeth; Brickhouse, Anthony T.; Carson, Joan Ph.D.; and Valdes, Enrique, "Language as a Factor In Aviation Accidents and Serious Incidents: A Handbook for Accident Investigators ed. 2" (2021). Handbooks. 2.
[26] IATA, Air Passenger Market Analysis, April 2023.
[27] EASA, Vol III Safety Risk Portfolios, 2023 Edition of the European Plan for Aviation Safety (EPAS) - See "Use of more than one language on frequency (SI-2029) (New)"

Where this practice occurs, aircrews may not understand clearances given to another aircraft in the same airspace or on the ground, leading to a loss of situation awareness. This identified risk is not currently simulated in flight training or supported by flight simulation training devices (FSTDs).

A SATCE system could be used to simulate multiple languages on frequency between ATC and other traffic during training scenarios so that situation awareness is intentionally degraded, which will add realistic workload and complexity for the training flight crew.

Phraseology

Pilots and controllers should use commonly agreed phrases and terminology in their radio communications. However, the widespread use of non-standard phraseology is a long-standing and persistent risk to flight safety globally. Non-standard phraseology is often a shorthand, an abbreviation, or at worst, even slang. Its use can be especially difficult for those unfamiliar with local procedures or unusual expressions, adding ambiguity, increased complexity and delay.

When standard phraseology is not the practiced norm, poor phraseology may be used in critical maneuvers, such as an aircraft go-around, with recorded examples including the flight crew transmitting '...ON THE GO' instead of the international standard 'GOING AROUND' (ICAO[28]).

Additionally, poor radio etiquette and discipline, such as oversteps, rushed, and clipped transmissions can add to difficulty for all those monitoring a frequency. Finally, human error may also creep into communications, such as bias, readback and hearback errors[29].

Air Traffic Control

Air traffic control (ATC), although responsible for safely managing aircraft movements, may itself pose a threat to a flight. Examples can range from minor issues such as a garbled or rushed transmission, or information provided late, or blocked transmissions, to more serious threats such as omitted or wrong information, such as an unsafe clearance.

A realistic radio environment is absent in the vast majority of flight simulator training, so when trainees are first exposed to real world operations, listening and speaking on a busy radio frequency in addition to handling the aircraft is often overwhelming. This is true for all trainees, regardless of their level of English language proficiency.

Clear radio communications can be eroded due to various social and operational pressures.

In initial pilot training, cadets are encouraged to question ATC, and promptly clarify controller transmissions should they be missed or unclear or there's any doubt over information or a clearance. Operationally, the habit of questioning and clarifying ATC transmissions may be suppressed by conformity, especially where an unspoken culture of pilots accepting ATC instructions and clearances

[28] ICAO Document 4444, 'Procedures for Air Navigation Services, Air Traffic Management', 16th Edition 2016.
[29] 'Readback' is where a receiver reads back information to the transmitter, to confirm the content of the transmission. 'Hearback' is where the original transmitter listens to the readback to confirm it matches what was originally transmitted.

without question is prevalent. Pilots may be unwilling to ask for clarification, decline an instruction, or question a clearance.

> ***"Practice with SATCE should help reluctant pilots gain the necessary confidence to act when needed, especially when safety is at risk, regardless of cultural factors."***
> *- Nick Papadopoli, SATCE subject matter expert*

Busy operations can also exert a pressure on flight crews, such as numerous heading, level and speed instructions, frequency congestion, overly rapid speech, or controllers issuing too many instructions per transmission.

In a recent analysis of one thousand air-ground transmissions from four international airports, longer messages from ATC were found to increase the number of communication errors[30].

These communication issues may be particularly evident when local controllers are communicating with foreign flight crews who are unfamiliar with the airspace, procedures, or the layout of the airport. In such cases, clear communication becomes even more critical as any misunderstandings or confusion can have serious consequences.

Michael Varney, an experienced pilot, instructor and industry leader in evidence- and competency-based training, comments: "*Listen to any major airport in the world and there are multiple misunderstood clearances with incorrect readbacks and controller frustration and rapid repetition. Not only is this a direct risk in itself, the distraction of trying to understand a clearance to a crew with poor understanding of the language increases the potential for other unassociated errors and undesired states*".

Thankfully, high risk threats and errors from air traffic controllers only occur rarely. However, radio communication transcripts from recent incidents in the U.S. and worldwide demonstrate that when controller errors do occur, they can pose a serious risk to flight safety. Pilot awareness and mitigation adds the resilience needed to avoid these threats further developing into incidents and accidents.

Other Traffic

Other aircraft can pose a potential distraction or threat to a flight, especially at busy airports or in congested airspace. This is because they may not always follow the expected ground routes or perform airborne maneuvers predictably. Monitoring the position, movements, and radio communications of traffic can help flight crews to build situation awareness and identify any emerging threats early.

For instance, if an aircraft ahead on approach self-initiates a go-around, it may raise questions about the landing runway's condition or availability to a flight following. A potentially more serious example is a runway incursion by another aircraft or ground vehicle, which could occur during take-off or landing.

---

[30] Y Hetti Pathiranalage Sulakshika Ashari Yapa Dissanayaka, Brett R. C. Molesworth & Dominique Estival (2023) 'Miscommunication in Commercial Aviation: The Role of Accent, Speech Rate, Information Density, and Politeness Markers' The International Journal of Aerospace Psychology, 33:1, 79-97

Runway incursions are caused by various factors, for example, miscommunication, unsafe ATC clearances, or an aircraft or vehicle taking a wrong turn during ground routing.

Remaining vigilant and proactive in monitoring traffic can help flight crews to anticipate potential threats and take appropriate action to maintain safety margins. Examples of proactive mitigation in a number of recent U.S. incidents in early 2023 demonstrate that these skills were essential in avoiding multiple serious accidents.

Current Flight Simulation Technology

Q: How is the ATC environment simulated for the purpose of today's pilot training?

> **Very short answer:** Inadequately.
>
> **Short answer:** While adverse weather is simulated realistically by current flight simulator technology, other operational threats, including radio communications, ATC and moving traffic are poorly replicated. Radio communications are partially simulated, involve the instructor, and other moving traffic remain largely absent. The inadequate simulation of a full operational environment, especially for real-time flight training scenarios, is a widely recognized significant deficit that SATCE can and should address now.

> ***"The lack of moving traffic in current FSTDs and associated ATC radio communications has always amazed me."***
> *- Mark Dransfield, global FSTD regulatory affairs expert*

Radio Simulation

Radio silence

In modern flight simulators, the cockpit radio equipment is either physically present or virtually simulated, allowing basic operations like power on / off, frequency selection and switching. However, in most cases, the frequency itself remains silent.

To fill this gap, flight instructors typically role-play ATC and provide radio communications to the training aircraft, but other traffic air-ground communications on the same frequency are rarely, if ever, simulated.

Inadequate fidelity in radio communications simulation is not new. Over 40 years ago, the flight simulation industry attempted to address this by designing systems to reproduce background radio traffic. These and several other notable attempts to improve realism since have also had limited success due to technical limitations and a lack of correlation between audio and visual cues.

Even in today's highest fidelity flight simulators, there is an option to play pre-recorded or sampled background radio communications (often known as 'ATC chatter') that are neither location relevant or operationally accurate.

> ***"Let's be honest ATC chatter, if turned on, is not really any good; if anything you end up teaching crews to ignore the chatter and just listen out for the instructor's voice rather than their call sign."***
> *- Barry Gaines, experienced FSTD and flight training consultant*

This feature arguably has a negative training impact; by almost all accounts it is hugely annoying, and can be ignored by the flight crew in training, as it is essentially out-of-context background noise.

Despite varied attempts within the flight training industry to improve radio simulation, the lack of an automated realistic radio communications environment simulation remains a widely recognised shortcoming.

Flight simulators also include an accurate reproduction of aircraft sounds from inside the cockpit as an audio cue for trainees. However, a common practice during training is for the instructor to turn down the volume. Barry Gaines, an experienced FSTD and flight training consultant, comments: "*while this is valid when teaching certain points… it [turning the audio down] does distract from the immersive environment*".

ATC Simulation

Yes, instructors are still role-playing ATC

There are several significant challenges associated with the instructor or evaluator role-playing ATC during pilot training.

Challenges include:

1. The instructor needs to concentrate on providing a part of the simulation, which means they may not be free to focus on observing the flight crew, training or assessment.
2. While instructors are often experienced pilots, they are unlikely to have experience as controllers, and may not be familiar with recent air and ground traffic management procedures and phraseology.
3. Role-play by a single individual does not provide the cue that different controller voices provide between control sectors or frequencies, nor expose the flight crew to local accented English.
4. Human-provided ATC is bound to be variable, with some excellent performances and others sadly falling below expectations. As a result, the experience for trainees is unlikely to be standardized, or where it is, it may be fully scripted in scenario plans and somewhat inflexible.

Monitoring trainees' performance in the simulator is a task requiring the instructor's full attention, especially when assessing competencies.

Role playing is a demanding task. Anecdotal evidence suggests that by half-way through a typical four hour session, best efforts to continue a 'real world' flavor have started to taper off.

In busy Flight Information Regions (FIRs), there can be 20 or 30 aircraft with the commensurate quantity of radio communications. This places a large responsibility on flight crew to monitor all relevant communications to maintain situation awareness. In addition, radio frequencies at busy airports can be extremely congested and selecting a gap to transmit can be challenging, especially during crucial flight phases. These conditions are impossible to simulate using instructor role play.

Even without any other tasks, it is not possible for an instructor to simulate multiple aircraft and controller communications.

Although role-play offers the flexibility to quickly tailor scenarios to training needs, it has a serious shortcoming: as all ATC communications are initiated by the instructor, the flight crew do not need to monitor the frequency or filter transmissions for their callsign. In addition, it is often difficult for the crew in training to recognize whether the instructor is wearing their instructor 'hat' or their ATC 'hat' during role-play, adding potential for confusion and further reducing realism.

Live ATC services

Some solutions providing 'live' ATC services to training devices have seen limited success, particularly for online General Aviation (GA) flight training and gaming ecosystems. The systems utilize experienced individuals, located remotely, to serve as air traffic controllers for all training devices that are online with the service provider in real time.

While this enables the trainee to speak with a human controller, arguably delivering the highest fidelity in terms of controller-pilot communications, the model has some serious limitations.

Scalability of the system is challenging as it relies on the availability of trained personnel to role-play ATC services. Unlike a fully synthetic system, training is not available 24 / 7 unless there is a very large pool of available controllers.

As with in-person instructor role-play, trainees may not experience standardized or up-to-date ATC procedures and phraseology, or an appropriate variety of voices or local accents.

Generally, only a limited number of airports and regions can be supported at any one time. In addition, the instructor does not have direct control over the quantity or timing of traffic, airport operating procedures (such as modes of operation), or the ability to override traffic to meet training needs as scenarios develop. Given limited other traffic simulation, control of injected 'intentional' threats from traffic for specific training objectives is also problematic.

In summary, while these services may improve the fidelity of ATC simulation over instructor-role play, they are not sufficient or scalable for typical commercial pilot training.

Lights on, lights off

Similarly, instructors are responsible for manually configuring and controlling ground lighting in sync with associated ATC clearances for the training flight, such as changing the state of runway stop bars. A SATCE system can assist by automatically changing airport ground lighting in the visual scene, for both the simulator flight (ownship) and other traffic.

This negates the instructor having to spend 'heads down' time at the Instructor Operating Station (IOS), often away from the crew seating, when they could be more effectively engaging with monitoring the unfolding scenario. Automatic ATC and lighting control also frees up instructors to conduct more effective in-seat training, where they are role-playing a flight crew member during one-to-one training.

Simulating airport ground lighting, including systems that are autonomous and those controlled by ATC, will enhance the training experience by delivering necessary lighting cues. This will be of particular benefit to low hours cadets in training, and for pilots wishing to gain familiarization with non-local airports.

SATCE systems provide a major benefit by relieving instructors of the need to manually control airport ground lighting. This allows instructors to focus on observing trainees, provide tailored training scenarios, and conduct effective in-seat training, resulting in more realistic and efficient training.

Traffic Simulation

Minimal regulatory requirements

Current flight simulator qualification standards, such as FAA Part 60[31] and EASA CS-FSTD, contain requirements for moving ground and air traffic simulation.

For example, FAA Part 60, Table A1A 'General Simulator Requirements' (Section 4.d.), for Level C & Level D simulators, requires '*The simulator must provide the instructor or evaluator the ability to present ground and air hazards*', with a note '*For example, another aircraft crossing the active runway and converging airborne traffic*'.

However, other traffic is rarely effectively simulated. Current requirements are minimal, in part, due to historical visual system limitations. As regulatory requirements are updated, they must take account of limitations in older visual systems still in use, which can have a restraining effect as technology develops. Modern visual systems are able to display many other moving traffic models, but this increased capacity has not been reflected in recent regulations.

In addition, little regulatory guidance currently exists on how moving ground and air traffic simulation should be implemented in an FSTD to support pilot training.

Parked up

Where ground traffic is simulated, the majority of ground vehicles and aircraft are restricted to predetermined (predictable) movements, with aircraft mostly remaining stationary or parked in the visual scene. Some simulators support other moving traffic triggered specifically for scenarios that include runway incursions, but this traffic is normally simulated without radio communications.

In the real world, other aircraft typically move in line with ATC clearances and instructions, and in some uncontrolled ground environments, may initiate movements themselves. Current ground traffic

[31] FAA 14 CFR Part 60, Attachment 1 to Appendix A to Part 60—General Simulator Requirements, Table A1A - Minimum Simulator Requirements - General Simulator Requirements, Entry Number 4.d.

simulation is unrealistically simple, and does not generate the cognitive workload or complexity that should be present in training during ground flight phases.

Moving ground traffic present during simulator training, especially at large, complex, busy airports, could help highlight high risk areas and conditions, and contribute towards reducing the number of ground collisions between aircraft and between aircraft and ground vehicles. This may be one of the many cost benefits of introducing SATCE for operators and air carriers, which could be reflected in lower insurance premiums, given proven reduced ground operations risk, for example.

In the air

Other aircraft are simulated airborne, but this is mainly limited to supporting collision avoidance, such as Traffic Collision Avoidance System (TCAS) training scenarios. The sudden appearance of traffic on cockpit displays during certain flight phases, such as en route, can be a cue to trainees that they are about to encounter traffic they need to avoid. Although this rather crude and transitory simulation of airborne traffic meets a key training requirement, it can also be predictable.

When simulated, other airborne traffic is often out of context, radio silent, and display unrealistic flight paths. In contrast, SATCE can simulate traffic during all flight phases with contextual radio communications along routing that correlates with air traffic procedures. This enhancement could support more realistic TCAS training, for example, during certain flight phases or in hotspots and regions where TCAS maneuvers occur more frequently, helping to improve preparedness and prompt and correct responses to alerts.

Moving on

Flight crews anticipating the impact of other traffic is a key skill not generally practiced in simulator training.

The presence of other traffic may not be necessary or useful for all simulator sessions, depending on the training objectives. However, traffic should be present during relevant training scenarios, especially for those designed to reflect line operations. This way, nearby traffic would be indicated on cockpit instruments and displayed visually out of the window during clear weather. This would support situational awareness and present a realistic threat during all flight phases, reducing some of the predictable nature of today's airborne collision avoidance training.

Training designers and instructors should be able to control the volume of traffic present during scenarios to support the training. For example, a higher or lower volume will influence pilot decision making, such as descent planning.

Some modern simulators support moving traffic with limitations to prevent the traffic conflicting with the ownship. What this approach lacks, however, is any ATC related content.

Global FSTD regulatory affairs expert Mark Dransfield notes, "*I see traffic (on the navigation display or visually) but I don't hear it, and thus my situation awareness is partially compromised.*" Synthetic traffic generated by SATCE also produces contextual radio communications with ATC on appropriate radio frequencies, which provides a correlated radio simulation.

Standard phraseology used in transmissions between simulated ATC and other traffic would also help to embed best practice and good habits, such as correct radio etiquette, especially early in a pilot's training.

Furthermore, as SATCE engages real world listening and speaking skills in the work context, it enables valid observations of operational language use which can serve as a powerful complement to language testing for safe radiotelephony communications in accordance with the ICAO LPRs.

SATCE can also automatically control the configuration and lighting state of other aircraft. For example, other traffic parked, pushing-back or taxiing should display appropriate anti-collision and taxi lighting, and traffic landing or taking off should display their landing lights and flaps configured correctly. These subtle but important details provide flight crews in training with a visual cue to other traffic states, and contribute to realism, workload, as well as situation awareness.

AI Technology & SATCE

Q: What is SATCE? What is cognitive computing and how does it relate to SATCE? What benefit does it provide?

> **Short answer:** SATCE provides a more realistic and immersive synthetic environment during flight simulator training scenarios. This gives instructors a new toolkit of possible variations that better reproduce operational risks faced in real world flights (there may be nothing wrong with the airplane but it is just a 'bad day at the office'). Cognitive computing and cognitive AI are umbrella terms for a collection of technologies, several of which are currently used in SATCE systems. Others, such as machine learning, are likely to further enhance SATCE. AI technologies can be used to augment pilot training, and are likely also to play a role in future assistive technologies that support flight, ATM, air navigation services (ANS), and airport operations.

What is SATCE?

SATCE, short for Simulated ATC Environment, is an AI-based immersive technology that provides pilots with a more realistic and complete simulation environment during training using flight simulators.

SATCE is defined in ICAO's Document 9625[32] and more recently in EASA NPA 2020-15 as 'an automated flight training technology, in which air traffic control services and other traffic entities are simulated as part of the synthetic environment provided by the FSTD'[33].

SATCE involves the synthetic reproduction of ATC services, including radio telephone and data communications between ATC service providers and all traffic. Instructor role-play is outside scope, since this traditional method of simulating communications is not an automated feature of the flight simulation training device.

[32] ICAO Document 9625 "Manual of Criteria for the Qualification of Flight Simulation Training Devices" 4th Edition, 2016.
[33] EASA NPA 2020-15 "Notice of Proposed Amendment 2020-15, Update of the flight simulation training device requirements".

Future implementations of SATCE, especially as natural language recognition and synthesis develop, could see its scope expanded beyond ATC-pilot communications to include communications with other services outside the cockpit, including ground and cabin crews, dispatch, company operations and other external parties.

A new toolbox

SATCE introduces synthetic entities into the simulated environment for the first time, which opens a toolbox of possible variations previously unavailable to training designers and instructors. Synthetic ATC and traffic can be programmed to behave in different ways that support the training, including normal or abnormal behaviors and standards-compliant or non-standard communications.

Both ATC and traffic can also be used to inject threats and errors that better reflect operational complexity and evidence-based risks, making training more comprehensive and effective.

What is Cognitive Computing & AI?

Cognitive computing, also known as cognitive artificial intelligence (AI), are umbrella terms that describe a range of systems and applications that mimic human brain function mainly used to help improve or augment human decision-making[34]. Technologies include natural language processing, reasoning, machine learning, speech recognition, speech generation, anomaly detection, risk assessment and other forms of AI.

While the term AI, more broadly, may incorporate many of the same technologies as cognitive computing, it is more commonly applied to decision-making and performing tasks in complex situations, often minimizing or replacing the role of humans.

Where a system is added to augment and support human decision-making, cognitive computing is arguably the more appropriate term.

Market Applications

Cognitive computing and AI technologies can be used to enhance personnel training, including those directly involved in operations such as air traffic controllers and flight crew, throughout commercial and military market segments.

In addition to its potential to strengthen training, cognitive computing and AI technologies may also play a role in new assistive technologies that augment flight, ATM, air navigation services (ANS), and airport operations. For example, a recent collaborative research study investigated using ASR of both pilot and controller transmissions to augment controller situation awareness by highlighting recognised callsigns on controller displays [35].

---

[34] Wikipedia 'Cognitive computing'
[35] Aerospace 2023, 10, 433. García, R.; Albarrán, J.; Fabio, A.; Celorrio, F.; Pinto de Oliveira, C.; Bárcena, C. Automatic Flight Callsign Identification on a Controller Working Position: Real-Time Simulation and Analysis of Operational Recordings.

This article will focus on the application of cognitive computing to enhance flight simulation, and within this domain, the provision of a full environment simulation that includes a realistic radio communications environment, automated ATC simulation and synthetic traffic (SATCE).

There are other promising applications of AI technology within flight simulation, such as adaptive learning systems, advanced metrics and data analytics, and the use of synthetic actors, such as co-pilots and instructors.

SATCE & AI

Q: How does SATCE use AI technology? What does the future look like?

> **Short Answer:** Several independently developed SATCE systems have been fielded and are in use, having been built using elements of AI. With expected continued exponential growth in AI technologies, and their continued incorporation into SATCE, the future looks very exciting.

SATCE has been in development over several decades.

Early iterations failed to gain wide adoption due to their inability to simulate a realistic radio environment along with correlated traffic. However, more recently systems have incorporated elements of cognitive computing and AI, including speech recognition, speech generation (also known as text-to-speech), and anomaly detection to create expert systems that simulate the knowledge and analytical skills of human experts, such as controllers and pilots.

Over the last ten years, several SATCE systems have been independently developed, tested and fielded by early adopters within the flight training industry. Currently, a growing number of civil and military pilot training organizations are using SATCE.

A bright future

The future of SATCE is very promising.

It is likely to benefit from continued exponential global investment and growth in cognitive computing and AI expected over the next few years[36]. Algorithmic improvements, increasing processing power, wider access, lower costs, and cloud-based architectures, are all likely to further enhance SATCE features, functionality, adoption, and deployment.

Emerging AI technologies such as machine learning (ML) and deep learning (DL) are likely to be incorporated into SATCE, enabling synthetic entities to exhibit increased behavioral complexity and extending the scope of SATCE systems' support during simulator flight training.

For example, advances in large language models should improve the processing of free language use, including communications outside standard phraseology, and increased automated decision-making should facilitate better ATC prioritization during emergency conditions.

[36] Our World in Data, Max Roser March 29, 2023. 'Artificial intelligence has advanced despite having few resources dedicated to its development – now investments have increased substantially'

Enhancing Flight Training

Improving pilot training provides a relatively fast and agile short-term measure that can serve as part of a longer-term system-level strategy that helps protect flight safety. SATCE used in real-time simulator training scenarios provides a realistic training environment currently missing, that will exercise and strengthen piloting skills necessary to help maintain safety margins.

Why Training?

Q: How can better pilot training help, and what should be the focus?

> **Short answer:** Better training can provide a prompt way to address known system weaknesses. To ensure aviation system safety and resilience, pilot training should focus on developing core competencies, using operational data to identify areas for improvement and enhancing training methods, procedures and programmes, with new technology chosen based on training outcomes rather than its novelty.

Agility

The aviation system is highly complex, and there can be many different reasons and contributory factors that lead to incidents and accidents.

Changes in processes, procedures or operational technology tend to be introduced slowly due to the complex nature of the system. Changes must be carefully researched, designed, and are normally implemented in a step-by-step manner to avoid unintended consequences.

Unlike introducing operational changes, changes to training can provide a relatively prompt, agile way to increase awareness, develop skills, and inject measures designed quickly to address known system weaknesses and build resilience.

Training leads, technologies should follow

To ensure flight safety, it is crucial to focus on building resilience into each area of the aviation system, and protect against factors that contribute to incidents and accidents.

In pilot training, this involves exercising and developing core competencies that ultimately help to reduce errors and build flight crew resilience. The goal of leveraging flight simulation technologies should always be to produce more skilled, proficient, and competent pilots. While new technologies like AI, SATCE, extended reality (XR), and motion solutions are exciting, they should not be the driving force behind their adoption. Instead, training outcomes should always guide the tools selected, including any new technology.

In the context of runway safety, operational data from incidents and accidents can be used to identify competencies and skills that flight crews need to develop or strengthen. By enhancing training methods, procedures, programmes, and training technology, better training can help pilots to identify and mitigate common and high-risk threats, helping to reduce errors and unsafe conditions.

Protecting against future shocks

The COVID-19 pandemic has underscored the importance of both flexibility and resilience in the flight training sector. To ensure a stable and sustainable future, the industry must continue to innovate and adapt to meet changing needs, some of which may arise unexpectedly, while others can be anticipated. By incorporating immersive technologies, such as AI, SATCE and XR, the industry can provide more effective, efficient and engaging solutions that add flexibility and build resilience against future disruptions. For instance, integrating SATCE into mobile or fixed devices can enable training in remote regions closer to pilot's homes and help maintain pilot skills during furlough periods.

What SATCE Offers

Q: Would introducing SATCE have an impact? What would it look like? Where could it add the most value?

> **Short answer:** Flight simulators have become an important tool in pilot training, with higher levels of simulation realism resulting in more effective training experiences. However, there is a fidelity gap when it comes to radio communications, ATC and traffic simulation. SATCE bridges this gap, providing significant benefits by introducing added complexity, distractions, and threats previously not possible to simulate using the instructor. Consensus standards defining SATCE are mature, and the industry has a unique opportunity to invest in an immersive technology that could become a game-changer. A few examples are provided.

Fidelity matters

The use of flight simulators in pilot training has been built on the closeness of the simulation to the real world. The level of realism matters. The higher the simulation realism, including the fidelity of the aircraft and, importantly, the surrounding environment, then the higher the flight crew immersion, engagement, and the training transfer because of the experience.

Over the last four decades, the fidelity of flight simulators has risen in almost **all areas** except in the delivery of a full realistic traffic and ATC environment. For example, qualified simulators around the world are regularly evaluated against precise tolerances using qualification test guides (QTGs). These tests necessarily demonstrate just how accurately simulators replicate the aircraft and other aspects. There is much detailed focus and measurement on what is currently simulated, yet a huge blind spot concerning what is missing.

Aircraft performance and function, including malfunctions, and weather are all well simulated, including high threats such as thunder clouds, microbursts, and reduced visibility. As image generation software and hardware have advanced, so has the out-the-window scene. Modern gaming engines, increasingly used in flight simulators, include visual details such as wet surface reflectivity, water spray, and moving sea states.

However, the huge gap in fidelity when it comes to radio, ATC and traffic simulation has largely remained unchanged.

Airport operations

One notable consequence of the lack of active traffic simulation, is that airport operations are effectively **unsimulated**. This means that important factors such as which runways are active, the direction and type of runway operations, traffic flow, busyness, and time pressure are all absent from the scenario. Instead, what is simulated is a fictional day where there is no other moving traffic, and all runways are available, which lacks realism and complexity.

This lack of realism would be obvious and shocking to trainers in other fields of expertise.

In real world flying, airport operations, ground movement procedures, and traffic are critical considerations for flight crews, adding complexity, constituting a key part of managing a flight and foundational to effective TEM. With SATCE, flight crews can experience an approach into or departure from an airport that might not be familiar, such as mixed-mode operations due to a runway closure, and train for unusual operations and procedures, even at familiar airports. This helps crews better manage the unexpected when it occurs in real world operations.

Furthermore, the location and movement of traffic on and around an airport contribute to situation awareness, which is critical for flight safety. They also help warn of any abnormal conditions. For example, if the ownship is on approach and there is traffic ahead, the position and communications from that traffic provide important situational context and expectations. If that traffic is instructed by ATC to go around or reports adverse weather, it would serve to highlight potential threats to the flight crew in training.

Industry opportunity

As a new immersive technology, SATCE presents a unique and timely opportunity for the flight training industry to bridge the fidelity gap. Recent incidents have highlighted the need for training technology that can simulate real world threats evident in operations but currently missing in flight simulation

The adoption of SATCE is set to have a profound impact on flight simulation and training - this is possibly the largest jump in fidelity in the last 20-30 years. Even with a small proportion of flight simulators globally equipped with SATCE, a distinct difference between those with and without it will quickly become apparent.

SATCE-enabled training sessions will offer traffic visible on cockpit displays and in the visual scene, especially when close to airports or during ground maneuvers. Those without SATCE will remain on their own in an empty virtual world. Training flights with SATCE will exhibit a full radio simulation, with background radio communications on all active ATC frequencies providing valuable cues and situation awareness, along with interruptions from ATC and the distraction that minor delays can bring. Those without, will offer an unrealistic radio silence, only broken by the voice of the instructor role-playing ATC.

Industry standards

Over the last decade, industry has agreed on a consensus standard for SATCE functionality in ARINC Specification 439B[37]. This document was created through an international collaborative effort between training device manufacturers, training organizations, universities and technology vendors, and regulators including the FAA and EASA.

Workloads during training scenarios will be more realistic with SATCE, which introduces added complexity, distractions and new-to-simulation threats. In a multi-crew cockpit, SATCE will also necessitate a more realistic distribution of workload between crew, exercising the need for effective workload management.

A few examples

SATCE provides significant benefits in training scenarios related to runway safety, especially in light of recent incidents. These kinds of scenarios are impossible to simulate effectively without SATCE, as they involve multiple elements including ATC procedures, radio communications and other traffic that cannot be easily replicated without an automated system.

An instructor cannot effectively simulate a radio environment or multiple other traffic, observe the flight crew, and provide any timely prompts and training. Some expert training practitioners have suggested additional instructors would be necessary in order to provide an adequate level of both simulation and instruction for advanced scenario-based training.

For instance, SATCE can simulate traffic threats and errors, such as a runway incursion from another aircraft or ground vehicle. Weather permitting, a trainee pilot or flight crew may not only see an incursion out-the-window, but may also hear the associated radio communications that led to the event, given it occurs on their tuned frequency.

Alternatively, an unexpected or erroneous response from another aircraft to an ATC instruction can be injected into scenarios. For example, another aircraft could readback incorrectly to an ATC clearance and then fail to implement it correctly, thereby posing a threat to the training flight.

In both examples above, the flight crew in training may have identified the potential threat or error from the context before it occurs, and be in a position to more effectively manage their flight.

Alternatively, ATC threats and errors can be injected into training scenarios. Examples could include:

- multiple ATC instructions at once
- a late clearance to the ownship, and
- an unexpected command such as a go around, or an erroneous QNH pressure value.

All these can be triggered in a realistic populated traffic environment - making the threat much more realistic, and exercising flight crew observation, identification and mitigation skills.

---

[37] ARINC Industry Activities, 'ARINC Specification 439B - Simulated Air Traffic Control Environments in Flight Simulation Training Devices', Aug 31, 2020. This document provides guidance on provision of SATCE in FSTDs for flight crew training.

Where Does SATCE Fit?

Q: How does SATCE fit into current and future flight training programmes?

> **Short answer:** Pilot training programs are rapidly modernizing. This includes the adoption of new training approaches and technologies, such as: evidence-based and data-driven training, remote training and self-learning, and the introduction of new device types and immersive technologies including virtual reality. SATCE supports both current and emerging training programs by providing a more realistic environment for scenario-based training, reducing instructor workload, and offering contextual and objective trainee performance data. Looking ahead, SATCE may prove necessary to support certification and pilot training for advanced air mobility.

Industry mega-trends

Flight training and assessment worldwide is experiencing a significant transformation. This ongoing mega-trend is shifting the focus from primarily assessment and testing towards a training-centered approach. The emphasis now lies in developing underlying core competencies and improving team processes.

The principle of ‘train the way you fly, and fly the way you train’ ensures training reflects real world operations as closely as possible, and real world flying expresses the competencies and proficiency gained through rigorous and effective training.

In this context, scenario-based learning using flight simulation has proven to be the most effective and cost-efficient method for cultivating these competencies. It provides a safe and controlled environment for pilots and flight crews to develop their skills by exposing them to operational threats in real time.

SATCE, in particular, offers a highly realistic learning environment, unavailable until recently, that facilitates the progressive adoption of training-centered approaches globally.

Competency-based training

The paradigm shift in flight training from an outcome and check-based approach towards an evidence- and competency-based philosophy is the single largest industry driver that necessitates wide scale adoption of SATCE.

In a Competency-based Training and Assessment (CBTA) program, a framework of competencies becomes the primary focus. Instead of simply assessing the quality of defined maneuvers and tasks, instructors target the development of underlying competencies, to drive effectiveness across a range of activities. This is a substantial shift from rehearsed performances with defined outcomes.

Through the training process, trainees are faced with increasing levels of complexity (threats) and variability close to actual line operations, where there are no predefined outcomes. The purpose is to allow pilots and crew to develop robust processes for managing varying levels of complexity in the flight deck. Instead of completing a simple pre-defined test, the trainee must complete a final assessment phase based on a standardized framework across a range of activities. This serves as a more reliable performance indicator in line operations.

In alignment with ICAO objectives, implementing CBTA is a strategic objective for the European Union Aviation Safety Agency (EASA) concerning aircrew priorities over 2023-2025[38].

CBTA training programmes emphasize the use of flight simulators for real-time scenario-based training, which is exactly where SATCE can add most value - largely in terms of simulation fidelity, but also from the generated performance data.

Simulating line flying

SATCE offers the highest level of benefit in flight training scenarios where the training flight is progressing in real-time as it would in line operations, such as during Line Oriented Flight Training (LOFT).

A LOFT-type session is typically fully crewed and may include a flight from gate-to-gate, or just a significant portion of a flight. These training sessions are performed as if they were real world operations, allow for minimum or no input from the facilitator or instructor, and should contain all the complexity that real operations can present, including abnormal conditions and events.

However, LOFT without SATCE falls short of the original LOFT concept and intent[39].

If the instructor is taken up with role-playing ATC, then they are involved in delivering the simulation rather than remote objective observation. If the radio environment is inadequately simulated, and there are no other moving traffic - then how can the complexity of real world operations be reproduced?

> ***"Instructors cannot provide a realistic ATC environment in any sense."***
> *- Michael Varney, experienced pilot, instructor and industry leader*

SATCE is necessary to realize the full potential of real-time flight simulation training.

Applications in LOFT include exposing experienced pilots to realistic workloads and local conditions (including jargon, shortcuts and regional accents) while practicing manual flying, and offering cadets the experience of a busy communications environment in training before they enter line operations. Both of these use cases would help bolster flight safety.

Practicing manual flying

Manual flying without automation has been a fixture in training, however it is rarely performed during line operations. The practice of manual flying during line operations has been growing in popularity, especially during and after the COVID-19 pandemic, which saw pilots wishing to regain practical skills degraded over lengthy periods not flying.

---

[38] EASA European Plan for Aviation Safety (EPAS) 2023-2025, Volume I.
[39] The concept of LOFT was introduced in ICAO Circular 217 AN/132 'Human Factors Digest No 2' in 1989 and republished in its original form as UK CAA Publication CAP 720 in 2002.

The long timespan between mandated training and the lack of realistic workload in flight simulators have both been arguments used by those promoting increased manual aircraft handling. The use of SATCE during simulator LOFT scenarios will provide a safe opportunity to exercise manual handling in a more realistic operational environment and with representative workloads, resulting in stronger skills development and retention.

Newly qualified airline pilots

First exposure of a newly qualified First Officer (FO) often involves Pilot Monitoring (PM) duties, often at a busy dometic or international airport. Initial responsibilities include managing communications with ramp control, clearance delivery and ground control. However, the busy external environment can lead to confusion, reduced situation awareness, and an increase in workload for the Pilot Flying (PF), as they are effectively also often providing in-cockpit on-the-job training to the FO.

Many line training captains overseeing Initial Operating Experience (IOE) or Line Flying Under Supervision (LiFUS) have shared that they feel like they are flying as a single pilot when paired with a newly qualified FO. This is as much a potential flight safety issue as it is an optimal training issue.

Tasks including adapting to runway changes at short notice, managing parallel runway operations with visual separation, and navigating the challenges of descent and deceleration are all part of the dynamic environment in which IOE/LiFUS is expected to take place. A training captain has to take each opportunity to ensure the trainee gets the best value from the key learning points while at the same time managing the flight safely.

> ***"In our most recent LOSA projects, ATC has become the number 1 threat in operations. We now have the technological capability to bring a realistic ATC environment into training. Choosing to ignore this [SATCE] is like choosing to operate without a visual system. If we expect pilots to develop their capabilities during IOE/LiFUS [without SATCE] we are significantly increasing the risk to operations."***
> *- Michael Varney, experienced pilot, instructor and industry leader*

LiFUS or IOE should not be used as a tool to help newly qualified pilots gain exposure to the ATC and traffic environment. The technology now exists for this critical component of flight training to take place ahead of line operations, better preparing cadets.

Better prepared cadets will create more time for 'teaching moments' during supervised line flying, and further enhance the training provided by training captains. The use of a SATCE-enabled simulator during initial training would provide realistic operational exposure, enhance LiFUS / IOE phases, and reduce the risks outlined above.

Integrating SATCE into LOFT

SATCE could be initially integrated in LOFT scenarios, offering an immediate enhancement with more realistic ATC communications and traffic environment. Through further development and increased incorporation of AI technologies, SATCE could support increasingly complex LOFT scenarios, including abnormal and emergency conditions and those that may involve multiple outcomes depending on flight crew decision-making. SATCE has the potential to become a significant component in future recurrent pilot training.

In summary, LOFT without SATCE is a partial, low-workload simulation of line operations.

Evidence-based training (EBT)

Modern pilot training approaches such as EBT, and established air carrier training programmes such as the Advanced Qualification Programme (AQP), are both based on the underlying use of operational data and risk analysis to inform and tailor training.

EBT is a programme founded on CBTA principles that emphasizes training over checking and promotes developing the overall capability of a trainee across a range of core competencies rather than measuring their performance in individual events or maneuvers. Flight crews develop competencies through LOFT training delivered using flight training devices that accurately represent both the aircraft and the external environment.

SATCE adds significant value to EBT real-time training scenarios by:

- unloading the instructor
- providing realistic flight crew workload
- delivering operational threats that include ATC or traffic
- enhancing training scenario variety, and
- providing data that supports instruction and debriefing.

Training data

'Data for training' is a new aircrew priority item alongside CBTA within EASA's European Plan for Aviation Safety (EPAS) 2023-25. This calls for the use of operational data for training delivery and the use of predictive data from training.

SATCE can help provide highly valuable training data and metrics for trainees, instructors and training providers. Along with data currently available from training devices, such as flight path telemetry, flight crew interactions and aircraft status, SATCE can provide contextual data about the flight, such as the phase of flight, procedures, ATC clearance status, communications, and the state of other traffic.

Contextual data collected during a training scenario makes data from other sources meaningful. SATCE data may be able to provide an indication of external threat levels, complexity and crew workload, adding important context to data from the training device itself.

SATCE can be used to help answer important questions, such as:

- Which flight phases or procedures or communications are most challenging for flight crews?
- Are there certain conditions, traffic management procedures, or airport operations that present a raised threat level to flights?, or
- Are there common crew competencies that require more training time?

CBTA-based training programmes around the world could begin to integrate SATCE into simulator training scenarios and benefit from more varied threats, a fully simulated realistic environment and rich contextual training data.

Early training (*ab initio*)

Flight simulation training that accurately reproduces airspace, procedures, and ATC communications can help build a pilot's confidence early in their career. Communication skills learned and practiced in the simulator, such as standard phraseology, become second nature with repeated exposure, and form life-long good practice.

Exposure to multiple local English accents, and where appropriate, multiple languages on frequency, using a SATCE system could help trainees become accustomed to a greater variety of English and other languages they may encounter in operations. This would help build familiarity and higher levels of comprehension as well as confidence, for both native and non-native English speakers.

SATCE is already making an impact in civil *ab initio* pilot training, and military trainers are showing interest in adoption to increase training efficiency. Early adopters, such as Embry-Riddle Aeronautical University (ERAU), are reporting reduced training time for general aviation cadets where SATCE is used alongside other innovative training technologies, including virtual reality (VR)[40].

SATCE's adoption in initial pilot training is also likely to benefit from the younger generation's keenness to adopt new technology.

Experienced airline pilot and flight instructor Kyle Johnston has observed SATCE adding realistic work loading during simulator scenarios. Kyle has direct experience of using SATCE in *ab initio* training, and notes ATC communications ‘happen when they happen’ as they would in operations. This can add loading on trainees during moments when perhaps an instructor role-playing ATC may hold back out of empathy, to avoid temporary overloading. This level of realism is valuable not only during advanced stages of cadet training, by adding challenge and preparation for the real world, but also for type rating and recurrent training.

> ***“We have involved our experienced flight instructors, cadets and graduates in a trial using a high-fidelity fixed-base FSTD. I am convinced that SATCE will become a commonplace technology in training devices. This technology leads the way forward in completing the simulated environment...”***
> *- Kyle Johnston, experienced airline pilot and flight instructor*

[40] Embry-Riddle Aeronautical University (ERAU), ‘Improved Pilot-Training Program Yields Promising Results’, 21 January 2022.

Self-learning

As flight training devices become more advanced and user-friendly, self-learning or self-training has become an increasingly popular option for both single pilots and multi-crew teams. In this type of training, the instructor is absent but may still configure and monitor the training remotely.

Self-learning offers trainees greater flexibility, autonomy, and the ability to tailor their training to meet their specific needs and pace. However, for real-time scenario-based training, an immersive, fully automated environment simulation is required to maximize training effectiveness.

Without SATCE, key aspects of the environment simulation are unavailable, limiting the training experience. Trainees can only practice in a silent environment without realistic radio communications. Unless the instructor is available remotely to role-play ATC, there are no simulated ATC instructions, clearances or ground lighting controls. In addition, the training flight is likely to be the only moving traffic in a sterile visual scene.

Training without an instructor role-playing ATC has significantly reduced simulation realism. Arguably, there may even be unintended outcomes to practicing real-time line operations in a limited environment. With SATCE, the environment simulation is fully automated, and can also be configured to support the desired level of training, workload or training outcomes. SATCE can also provide feedback in near real-time to trainees, enhancing the effectiveness of self-learning.

Remote instructor station

New immersive technologies, such as virtual, augmented and mixed reality (VR/AR/MR) and compact motion systems, require the physical separation of the instructor operating station (IOS) from the trainee and the device. Although not new, this concept has been proposed many times as a way to increase realism and improve training efficiency.

A remote IOS opens up the possibility for the instructor to be either nearby in the same facility or located at distance. Remote working presents several advantages for both instructors and training providers. Instructors can enjoy improved working conditions, reduced travel, lower costs, and time savings. Meanwhile, training providers can access a larger pool of instructor talent, potentially reducing costs and the environmental impact of training.

However, with the instructor remotely located, their interaction with the trainee or flight crew is necessarily different as all voice communications need to be routed via the device communications system, including traditional ATC role-play and instruction.

SATCE provides fully automated ATC simulation, allowing a remote instructor to focus on the task of monitoring and instruction, reducing their workload and enhancing the value they can add. In addition, an instructor is no longer tied up in individual training sessions, and can be freed to supervise multiple sessions simultaneously. Should regulation support this approach for pilot training, it could potentially increase training efficiency.

Live-Virtual-Constructive (LVC)

LVC and mission rehearsal training creates a unique challenge to simulate an operationally realistic mission environment, which can involve extensive air and ground spaces. Utilizing interoperability standards, such as Distributed Interactive Simulation (DIS), LVC involves linking multiple training entities, including flight simulators, together in real time. The training ecosystem can also be dependent on the integration and availability of a mission command-control.

For military pilot and flight crew training, SATCE could support by providing realistic synthetic other traffic and ATC services across both civil and military airspaces, as well as augmenting the mission command function, helping to increase realism and training efficiency.

Advanced Air Mobility (AAM)

AAM promises a new era in urban transport. Air vehicles typically associated with AAM operations include electric Vertical Takeoff and Landing (eVTOL) aircraft, electric Short Takeoff and Landing (eSTOL) and hybrid-electric aircraft.

Initial aircraft designs and infrastructure is being planned and developed around, at least initially, human-piloted vehicles, which will require a qualified new pilot workforce. New FSTDs, alongside modern training and instruction approaches, are being proposed to meet the expected need.

Amongst other benefits, SATCE will help overcome some of the limitations of remote instructor operating stations, and enable more efficient utilization of limited instructor resources. SATCE supports self-learning and monitored learning without the instructor present, aligning with the planned adoption of XR technologies.

AAM pilots are expected to operate in busy and diverse traffic environments using yet-to-be defined procedures. Amongst others, Concept of Operations (ConOps) published by Boeing and Wisk, suggest that the communications environment for eVTOL pilots may involve a hybrid of voice and data exchanges, with voice radio communications with ATC remaining necessary in the near and mid-terms.[41] SATCE could meet the training needs for this sector by delivering realistic traffic and communications simulation in complex airspaces, providing trainees necessary exposure to new procedures prior to operations.

SATCE will provide the added benefit of ensuring standardized conformance to ATC procedures, including phraseology where radio communications are necessary, considering the majority of instructors will likely have limited or no prior experience operating in this new environment.

eVTOL vehicle manufacturers and operators may also use SATCE for testing standard operating procedures (SOPs) alongside new ATM rules and procedures. SATCE offers a tool to validate new SOPs, including their influence on pilot workloads.

---

[41] Wisk (Boeing), ‘Boeing and Wisk Unveil Concept of Operations for Urban Air Mobility’, Table 1 ‘Comparison of Current and Future State of UAM Operations’. September 20, 2022.

SATCE will be valuable, not only to train the cadet pilots needed for this emerging aviation sector, but also to support vehicle manufacturers and operators in obtaining the necessary regulatory approvals before introducing commercial services.

Why No SATCE Today?

The incorporation of SATCE into flight training has been slow coming. However, more recently, early adopters have seen clear benefits to their training outcomes. The question remains - why hasn't SATCE become standard issue on all professional flight simulators and widely in use across other training devices?

There may be many reasons for this lack of progress, including past technology limitations, acceptance of current practices, regulatory constraints, low expectations of technical feasibility, and a lack of adequate industry investment in research and development (R&D).

Constrained R&D

SATCE involves significant technical innovation. The flight simulation and training sector has been adept at integrating new technologies, developed (and paid for) elsewhere by large industries such as gaming, and adapting them for flight training. However, with the exception of SATCE, there are few examples of sizable novel development from inside the industry, especially over recent decades. This has perhaps not been aided by falling training device prices, substantial third-party software and data licensing costs, and high levels of competition between manufacturers constraining R&D budgets.

The status quo

Instructor, pilot and product manager Matt Littrell observes the sector as having certain cultural traits, such as a "*...historical tendency to settle for the status quo being 'good enough', when it comes to facing innovation and change that is not driven by regulatory mandates or a significant safety risk (or even a loss of life)*".

Resistance to the introduction of SATCE may include legitimate reference to past experiences and failed previous attempts to introduce the technology. Fears may include adding complexity to already sophisticated training devices, and for instructors, concerns over a loss of control and erosion of their contribution. More generally, and not specific to SATCE, there also exists some hesitancy towards the introduction of any kind of new technology.

> ***"I don't know why it has taken the industry so long. Anyone with the patience for me to attempt to explain SATCE to them can see it's obviously necessary and long overdue!"***
> *- Jeremy Goodman, SATCE subject matter expert*

Navigating the regulatory landscape

The flight training industry operates within strict worldwide regulations. While these rules and oversight are designed to ensure flight safety, they can create a draw-back.

Device operators, often focused on financial oversight, become reluctant to invest in new simulation and training features that are not required ‘above and beyond’ what is regulated. There is little incentive for them to do so, especially where the current regulations do not allow for additional training credit.

Regulations also develop very slowly, and almost always retrospectively when it comes to new training technologies. This lag can inadvertently stifle innovation and impede development.

SATCE has faced a challenge over the past decade. Without being mandated, it doesn't offer immediate financial benefits for training organizations or air carriers bound by regulation. However, it is difficult to prove its efficacy and benefits to regulators without widespread adoption and support.

The need for more flexible ways to qualify emerging flight training technologies is recognized globally. In March 2023, EASA published the FSTD Special Conditions development and assessment process to provide general guidance and a basis for the qualification of new technologies, including VR, used in training devices[42]. The same, or a similar mechanism, could be applied as the basis for qualifying SATCE in training devices.

Currently, SATCE remains a technology embraced by industry innovators and those who strive to exceed minimum regulatory standards in their training.

However, simulation technology enhancements are not always performed out of necessity or regulatory requirement. For example, many visual system updates on qualified FSTDs are being performed, not because they are required, but because the training provider wishes to improve the training experience. In the short term, given the current absence of regulatory requirement, SATCE should be treated similarly - as a proactive training improvement that addresses a potential safety risk.

However, until the industry collectively calls for SATCE to be incorporated into flight training programs and as a regulatory requirement in qualified simulators, progress is likely to remain slow.

Should SATCE be mandated?

In short, yes.

We advocate for the widespread incorporation of SATCE into flight training via a proposed pathway.

This approach would involve several crucial steps to ensure its successful adoption and implementation, along with regulatory support and industry consensus. While the technology is currently implemented with a number of early-adopters, further development alongside some established visual systems, and integration with common industry platforms will be necessary to support adoption at scale.

---

[42] EASA ‘FSTD Special Conditions development and assessment process published by EASA’ 16 March 2023

The proposed pathway for widespread adoption into flight training includes:

1. **Testing**: Thorough ongoing testing of the technology to assess capabilities and compatibility with existing systems.
2. **Technology validation**: Validation of effectiveness and value in enhancing training, growing from today's small base of early adopters.
3. **Training benefit / value validation**: Demonstrating the tangible benefits in improving pilot training outcomes (including training transfer to real world operations).
4. **Cost-benefit analysis**: Comprehensive evaluation of the costs and benefits, including consideration of operational efficiencies, cost-savings and flight safety.
5. **Regulatory guidance**: Development of regulatory guidelines and industry best practices to ensure effective implementation.
6. **Regulatory requirement**: Incorporation into flight crew licensing, training programs, and adoption of industry consensus technical specifications for qualified flight training devices.
7. **Regulatory support during adoption**: Sustained support from regulatory agencies to facilitate extensive use.

Incorporating SATCE can add value to flight training now, and further delays introducing it will only serve to extend current deficits and deprive the industry of many potential benefits. Steps along the proposed pathway do not necessarily have to be completed in series, but work on each could start and continue in parallel to help expedite the technology's introduction.

To promote this initiative, the industry can petition ICAO and regulatory agencies, seeking their encouragement and facilitation. Various approaches can be considered, such as promotion, recognizing early adopters, publishing a roadmap to adoption, or providing financial support and incentives.

It is essential to take the initiative rather than passively wait for accidents to drive regulatory changes. By following the initial steps of the proposed pathway and demonstrating SATCE's value in enhancing flight safety, the industry can help avoid preventable loss of life and proactively ensure safer skies.

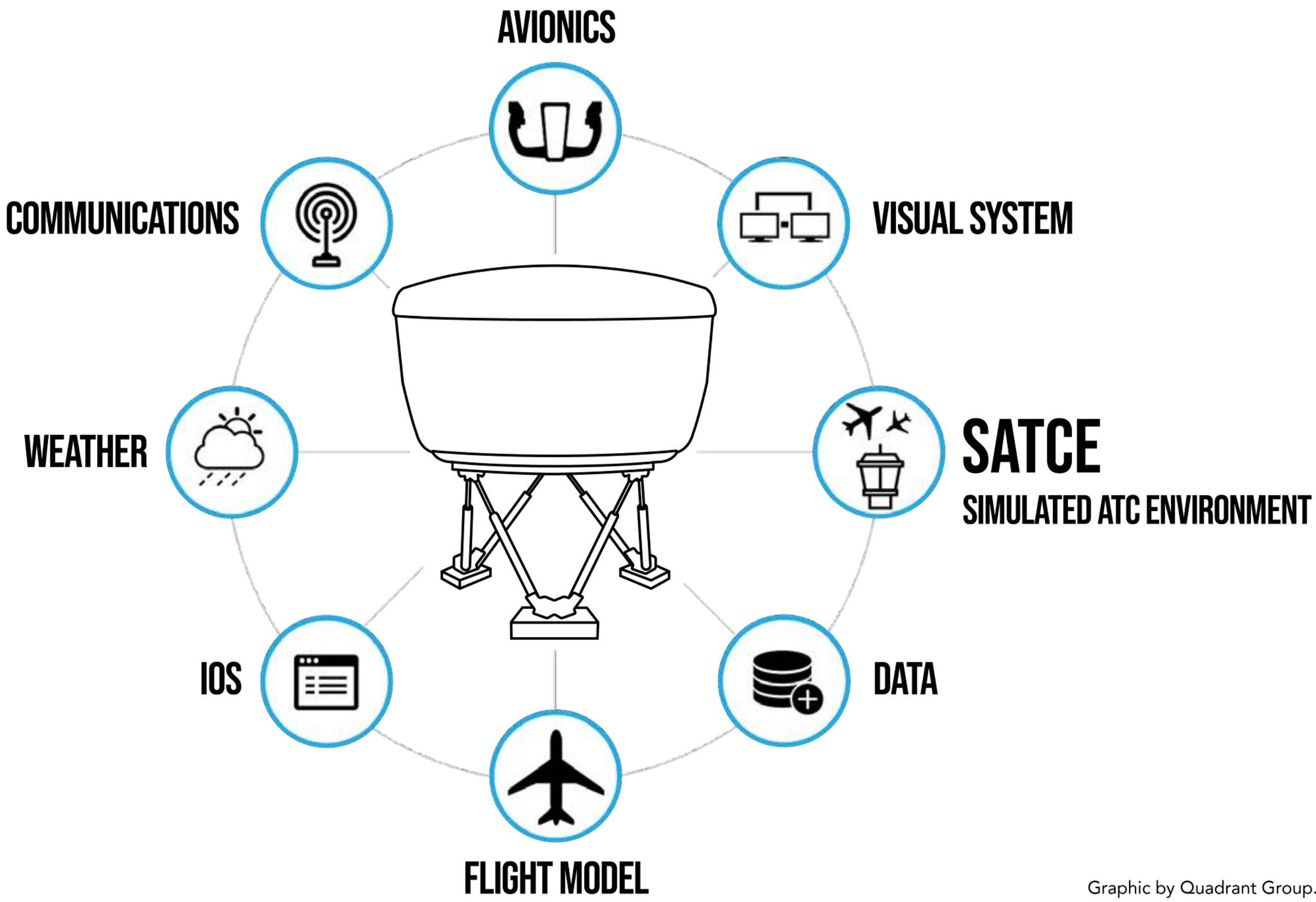
Can we afford it?

Q: Is SATCE an affordable and sustainable investment for flight training?

> **Short answer:** When considering the cost-benefit analysis, investing in SATCE appears favorable compared to other major simulator subsystems. Once adopted at scale, SATCE has the potential to deliver very high training value for relatively modest costs, along with associated operational efficiency, cost savings and benefits to flight safety.

SATCE is predominantly software- and data-driven. Synthetic entities like ATC and traffic are generated through software drawing on diverse information sources such as airspace procedures and aircraft performance data. As a result, SATCE has the potential to augment most (if not all) flight training devices and platforms, regardless of aircraft type or aviation sector.

Integrating SATCE into a training device primarily involves incorporating software, data and connectivity between SATCE and other key simulator systems such as the host, visual, communications, IOS, and cockpit avionics.



Graphic by Quadrant Group.

SATCE is not merely an additional feature, but rather a comprehensive subsystem within the FSTD itself. Integration can take place 'in factory' onto new devices or 'in the field' onto legacy simulators as an update. Factory integration is likely to prove most cost-effective due to economies of scale, streamlined integration, and cost efficiencies.

Unlike other FSTD systems, SATCE requires only minimal hardware and has minor third party licensing requirements, both of which help to reduce the relative cost.

Regular maintenance of the data used by SATCE is essential, especially for training that requires up-to-date airport models, ATC procedures, and airspace data. Ongoing maintenance should be factored into the overall lifetime costs, just as it is for similar subsystems that require regular data updates.

ARINC Specification 439B contains industry guidance on SATCE systems regarding data and integration (Chapter 9), in addition to sections covering installation, documentation, maintenance, updates and upgrades (Chapter 10).

When compared to incremental enhancements in existing simulator systems, such as a visual system upgrade, SATCE has the potential to deliver a higher return on investment in terms of training value, operational efficiencies, cost savings and enhancements in flight safety.

Once SATCE becomes established and widely implemented, along with management of the data that it depends on, economies of scale and sustainable ongoing costs are likely to make this training technology an attractive investment.

> ***"Instead of asking if we can afford SATCE, a more appropriate question might be whether we can afford to exclude it."***
> *- Jeremy Goodman, SATCE subject matter expert*

Where ground maneuvers are trained in the simulator in busy traffic conditions, SATCE may help reduce the number and severity of ground collisions, such as aircraft wing tips contacting other aircraft or objects. Certain maneuvers, such as long push-backs, and known airport taxiway and parking 'hot spots' could be included in training. Where operational cost-savings are demonstrated, further savings could also be realized in lower insurance premiums.

Looking ahead

The FAA has selected SATCE, along with VR, as an immersive technology they wish to evaluate. Research into SATCE has started as part of a 3 year program, planned to be funded in fiscal year 2023, and led by the FAA's System Safety Section, located at the William J. Hughes Technical Center (WJHTC) in Atlantic City, NJ, U.S.A[43].

This activity is intended to focus on air carrier pilot training, investigating the 'effectiveness of these technologies compared to traditional training methods and what the appropriate certification requirements should be'.

As part of this research, the FAA will be collaborating with industry to develop use cases and metrics for evaluating SATCE to produce research outputs in the form of data or publications that will aid in further developing standards and guidance for the use of SATCE in pilot training.

The FAA is leading by example, and the output from their collaborative research is likely to add value to the entire global aviation community.

[43] FAA, Government Request for Information (RFI), 'Immersive Flight Simulation Cooperative Research and Development Agreement', 14 December 2022.

> ***"Why are we ignoring this key element of the operating environment? We have developed sophisticated visual models, motion cueing, weather etc. as though the ATC and traffic environment present little additional complexity to crews."***
> *- Michael Varney, experienced pilot, instructor and industry leader*

In Summary

In the first few months of 2023, several serious high-profile civil aviation incidents, including near-misses, occurred in the United States, resulting in a sharp increase in media coverage and commentary. Concerns have stimulated a renewed focus on runway and terminal area operations. Threats to flights from communications issues as well as controller and pilot errors evident in recent U.S. incidents are also prevalent worldwide. In many regions, air-ground communications are fast-paced and highly-pressured, especially during peak periods at international and national hub airports. However, these threats remain poorly replicated in training using current flight simulator technology, which remains a widely recognized shortcoming.

Post-pandemic recovery and expected continued growth of aviation worldwide will drive the need for pilots that can operate within increasingly busy and complex air traffic systems. In addition, an aging workforce is leading to a decline in experience, measured in flying hours, of active pilots. Growing pilot shortages are driving change in the traditional career progression that young cadets entering the market may expect. Bolstering flight safety and pilot resilience is only possible if incoming cadets receive effective and relevant training and the proficiencies of existing pilots are maintained.

Simulated Air Traffic Control Environment (SATCE) is an AI-based immersive training technology that simulates ATC and other traffic currently missing in the majority of flight simulators. The scope and technical specifications for SATCE have already been defined by industry, and it is currently in use by early adopters yielding promising results.

SATCE generates an operational environment simulation that adds most value during scenario-based flight training where line operations are flown, such as during Line Oriented Flight Training (LOFT). However, current practice and simulator limitations, which includes ATC role-play by the instructor with little or no moving traffic, does not deliver the operational complexity needed to realize the full potential of scenario-based flight training. Arguably, SATCE adds most value to scenarios that involve busy operations on or near runways, such as runway maneuvers, runway incursion avoidance, aborted take-off and go-around training - all of which are the same high risk flight stages exposed by recent incidents.

Several independently developed SATCE systems have been fielded and are in use, having been built using elements of AI. Cognitive computing and AI-based training technologies, including SATCE, offer powerful new tools that enhance flight training and provide comprehensive training data benefitting trainees, instructors and training providers. As investment in AI continues to grow exponentially, further development will allow for more complex scenarios, increased realism and immersion delivered by SATCE, which will deliver increasingly more effective training over time.

The paradigm shift in flight training from an outcome and check-based testing approach towards an evidence- and competency-based training philosophy is the single largest industry driver that necessitates wide scale adoption of SATCE. This shift has resulted in more training emphasis and time devoted to scenario-based real-time flight simulation, requiring an operationally realistic environment within which pilots can exercise and build core competencies. As a result, SATCE plays a crucial role in the development and continued evolution of modern training approaches, including Evidence-based Training (EBT) and the Advanced Qualification Program (AQP).

SATCE is expected to deliver benefits to the burgeoning Advanced Air Mobility (AAM) sector, including overcoming some of the limitations of remote instructor operating stations, delivering realistic traffic and communication simulation in complex airspaces, and providing trainees necessary exposure to new procedures. Beyond training, SATCE is a valuable tool to support vehicle manufacturers and operators obtaining necessary regulatory approvals before introducing commercial services.

Historically, the flight training and simulation industry has been hesitant to embrace change not mandated by regulations or driven by flight safety, often settling for ‘good enough’ solutions. This has been the case for an important aspect of flight simulation - the operational environment - where communications, ATC and traffic have fallen behind the high fidelity simulation of other areas such as the aircraft, visual scene and motion.

Taking proactive measures is crucial instead of waiting for accidents to drive regulatory changes. This paper proposes a pathway involving both industry and regulatory agencies for the widespread incorporation of SATCE into flight training, including its regulatory requirement in flight crew licensing and training programs.

Once implemented at scale, SATCE has the potential to offer highly valuable training at reasonable costs, while also bringing operational efficiencies and cost-savings. The FAA's recent initiation of a collaborative research program to evaluate the effectiveness of SATCE is an encouraging step forward on the path toward long-overdue improvements in simulation, which will enhance pilot training and ultimately help to bolster flight safety and resilience.

Acknowledgements

This paper initially began as a brief article prompted by recent aviation incidents, proposing the wide implementation of SATCE in flight training to enhance aviation safety. As individuals joined in and offered their contributions, the article developed into a comprehensive collaborative paper laying out the rationale for SATCE. If it were not for time and other constraints, it could have easily grown further to incorporate insights from more specialists and organizations, encompassing an even wider scope. From our recent experience, there appears to be no lack of enthusiastic support for this technology from the 'grass roots' of the industry, especially those experienced and concerned with delivering high quality training using the best available technologies with the goal of ultimately supporting safer skies.

The authors wish to thank the following contributors, including those not explicitly listed below, that gave their time and expert input on this paper:

- Larry McDonald, Senior Technical Specialist, Flight Simulation Systems, FAA
- Cpt. Michael Langer, Airline Pilot, Managing Partner CactusPartners
- John Tobin, Industry Consultant, Airline Pilot
- Cpt. John Frearson, Civil Aviation Safety Authority (CASA), Australia
- Cpt. John Bent, PROJECT X
- Nick Papadopoli, Aviation Consultant
- Gary Pearson, CEO Verbyx inc and AI Strategy Consultant
- Henry Emery, Latitude Aviation English Services
- Gary Pallett, Industry Consultant, Digital Aviation
- Stefan Sobol, Flight Simulator Engineering Consultant
- Cpt. Kyle Johnston, Training & Compliance Manager, Atlantic Flight Training Academy, Ireland
- Barry Gaines, Partner, SIM OPS
- Mark Dransfield, Industry and Regulatory Consultant, SIM OPS

Cpt. Michael Varney is the CEO of Salient. Michael has been instrumental in the development of Evidence-based Training since its inception. He has an extensive background as a pilot, instructor, examiner, regulator and manager working in many sectors of the aviation industry including flight simulation. Being a keen advocate for technologies that have the potential to increase realism and better reflect real-world complexity in flight simulation, Michael wholeheartedly supports the adoption of SATCE.

Dr. Jeremy Goodman, an industry consultant and technical product developer, played a valuable role in drafting and collaborating on this paper. We extend our gratitude to Quadrant Group for sponsoring his contributions. Over the past decade, Jeremy has actively supported the development of Quadrant's SATCE solution, Quadrant INTERACT™, and has been a strong advocate for the adoption of SATCE. For those who are not familiar with SATCE, online videos showcasing INTERACT in fully crewed full flight simulators and other training devices can be accessed at: https://vimeo.com/quadrantinteract

Appendix

Recent U.S. Incidents

U.S. runway safety incidents

On January 12 2023, a ground vehicle caused a runway incursion at Baltimore / Washington International airport, crossing a runway without ATC authorization, and was closely missed by a B737 on takeoff using the same runway. A day later, on 13 January, at JFK International Airport, New York, a B777 crossed a runway also without ATC clearance, causing another incursion and a B737 to abort its take-off roll.

On January 23, a runway incursion occurred in Hawaii at Daniel K. Inouye International Airport when a B777 crossed a runway at the same time as a landing Cessna 208B. On February 4, a landing B767 and a departing B737 were involved in a runway incursion with overflight that resulted in a loss of separation at Austin-Bergstrom International Airport in Austin, Texas. On 16 February at Sarasota / Bradenton International Airport, Florida, an A321 was cleared for take off at the same time a B737 was cleared for landing on the same runway. The B737 flight crew self-initiated a go-around resulting in a loss of separation.

On February 22, another runway incursion and loss of separation event occurred, this time at Burbank Bob Hope Airport in California, when a landing CRJ-900 was forced to go around while an ERJ-175 was departing from the same runway. On February 27, a Learjet took off from Boston-Logan International Airport, Massachusetts, reportedly without ATC clearance, while an Embraer ERJ 190 was preparing to land on an intersecting runway. The ERJ took evasive action and performed a go-around as the Learjet crossed the intersection.

Most recently, on 7 March, an Embraer ERJ-175 crossed a runway in use by a departing A319 having received take-off clearance from ATC at Ronald Reagan Washington National Airport in Virginia. ATC instructed the A319 to cancel take-off clearance and the flight crew rejected their take-off roll at low speed.

More details on each of the above incidents are expected to become available as investigations progress by U.S. Government agencies. Preliminary reports from the NTSB, FAA reports, and other information available online from reputable news and aviation safety organizations are listed in the footnotes[44].

---

[44] Further information on U.S. incidents Jan-March 2023. Note - where incident reports from the NTSB or FAA have been unavailable at the time of writing, reputable other online sources have been provided:

1. Incident 07 March DCA - see Aviation Herald Article: https://avherald.com/h?article=5067c7a6
2. Incident 27 Feb 2023 BOS - see flightradar24 Article: https://www.flightradar24.com/blog/faa-investigating-close-call-in-boston/
3. Incident 22 Feb 2023 BUR - see flightradar24 Article: https://www.flightradar24.com/blog/ntsb-investigating-loss-of-separation-and-runway-incursion-in-burbank/
4. Incident 16 Feb 2023 SRQ - see Preliminary Report (NTSB): https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/106768/pdf

Other Recent Incidents

We have included two examples from many worldwide that highlight risks from air traffic controller errors - one serious incident from France last year and the other from the UK.

France

The Bureau d'Enquêtes et d'Analyses (BEA), the French air safety investigation authority, have released a preliminary report from an ongoing investigation into a serious incident that occurred on 23 May 2022 close to Paris Charles de Gaulle airport (CDG)[45]. A scheduled commercial transport flight from Stockholm, Sweden, was conducting an approach to CDG which resulted in a near controlled flight into terrain (CFIT), without visual references to the runway, at a minimum height of 6 feet.

Thankfully, there was no loss of life, injury or damage, however, this serious incident highlights the importance of air-ground communications, and the potential risks associated with communication errors when they occur.

The flight crew of the Airbus A320 were conducting an RNP (LNAV/VNAV) approach to runway 27R at CDG. An incorrect altimeter setting (QNH) was provided by a controller (1011 instead of 1001), resulting in the approach being flown below the glide path. The ground-based Minimum Safe Altitude Warning (MSAW) alarm was triggered prompting ATC to query the crew, however, an on-board terrain warning (TAWS) was never recorded. The crew aborted the approach at a very low height above the ground before the runway.

The second approach was also conducted below the glide path and the MSAW alarm was again triggered. After acquiring visual contact with the runway, the crew corrected the path and landed without further incident.

During this event, an incorrect QNH was twice provided by a controller to the flight crew, and each time the crew read back the incorrect QNH provided. The controller also provided the incorrect QHN to another flight, and the other flight crew did not read back the QNH given, but read back the valid QNH at the time, without this being noticed by the controller.

---

5. Incident 04 Feb 2023 AUS - see flightradar24 Article: https://www.flightradar24.com/blog/ntsb-faa-investigating-fedex-southwest-close-call-in-austin/
6. Incident 23 January 2023 HNL - see Preliminary Report (NTSB): https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/106632/pdf
7. Incident 13 January 2023 JFK - see Preliminary Report (NTSB): https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/106577/pd
8. Incident 12 January 2023 BWI - see FAA Runway Safety Office - Runway Incursions (RWS) https://www.asias.faa.gov/apex/f?p=100:28

[45] BEA 'Serious incident to the Airbus A320 registered 9H-EMU operated by AirHub on 23/05/2022 near Paris-Charles de Gaulle AD'

Q: How would SATCE in simulator flight training support pilot skills and resilience, that would in turn help prevent similar incidents where ATC errors have eroded safety?

> **Answer:** Michael Langer, an experienced long-haul Captain and aviation consultant, comments on current simulator training: "*It's important that pilots train to scrutinize every ATC clearance, as demonstrated by the incident in May 2022 close to CDG. However, in the current setting, with an instructor only role-playing one controller and no other radio traffic on the frequency, trainees regularly detect those intentional mistakes injected by the instructor with ease.*".
>
> A SATCE-generated synthetic radio environment could incorporate ATC threats and errors, including erroneous pressure settings, into real-time training scenarios. Crews in training would not so readily detect the injection of an intentional threat or error given a busy realistic radio environment, especially with multiple users on frequency. Other complexities including mixed local and international accents, non-standard phraseology and non-ICAO languages could also be introduced on frequency to add realism where this would support the training.

UK

On 13 August 2018, a landing Boeing B737 approaching runway 06 at Edinburgh airport in the UK closed to within 875m of a departing Airbus A320. The incident is detailed in a report published by the UK Air Accidents Investigation Branch (AAIB)[46].

A combination of factors, including a number of small delays to the departure of the A320 and a higher than normal approach speed of the B737, led to the loss of separation before controllers became aware of the closeness of the two aircraft. The trainee controller lacked the experience to quickly resolve the situation and the supervising on-the-job Training Instructor judged it safer to let the B737 land than to initiate a go-around in proximity to the departing A320.

A SATCE system used in ground-based flight training could emulate a wide range of air traffic controller errors, including those from the example incidents above. The technology could also be used to simulate controller communication errors to other aircraft and ground traffic, which is impossible to do using current practices and simulator technology.

Evidence-based and highly realistic scenarios using SATCE would help flight crews to recognize and mitigate threats in a safe training environment, which will build their confidence, competence and resilience should they reoccur in real world operations.

[46] UK AAIB investigation, Loss of separation, Runway 06 at Edinburgh Airport, 13 August 2018.