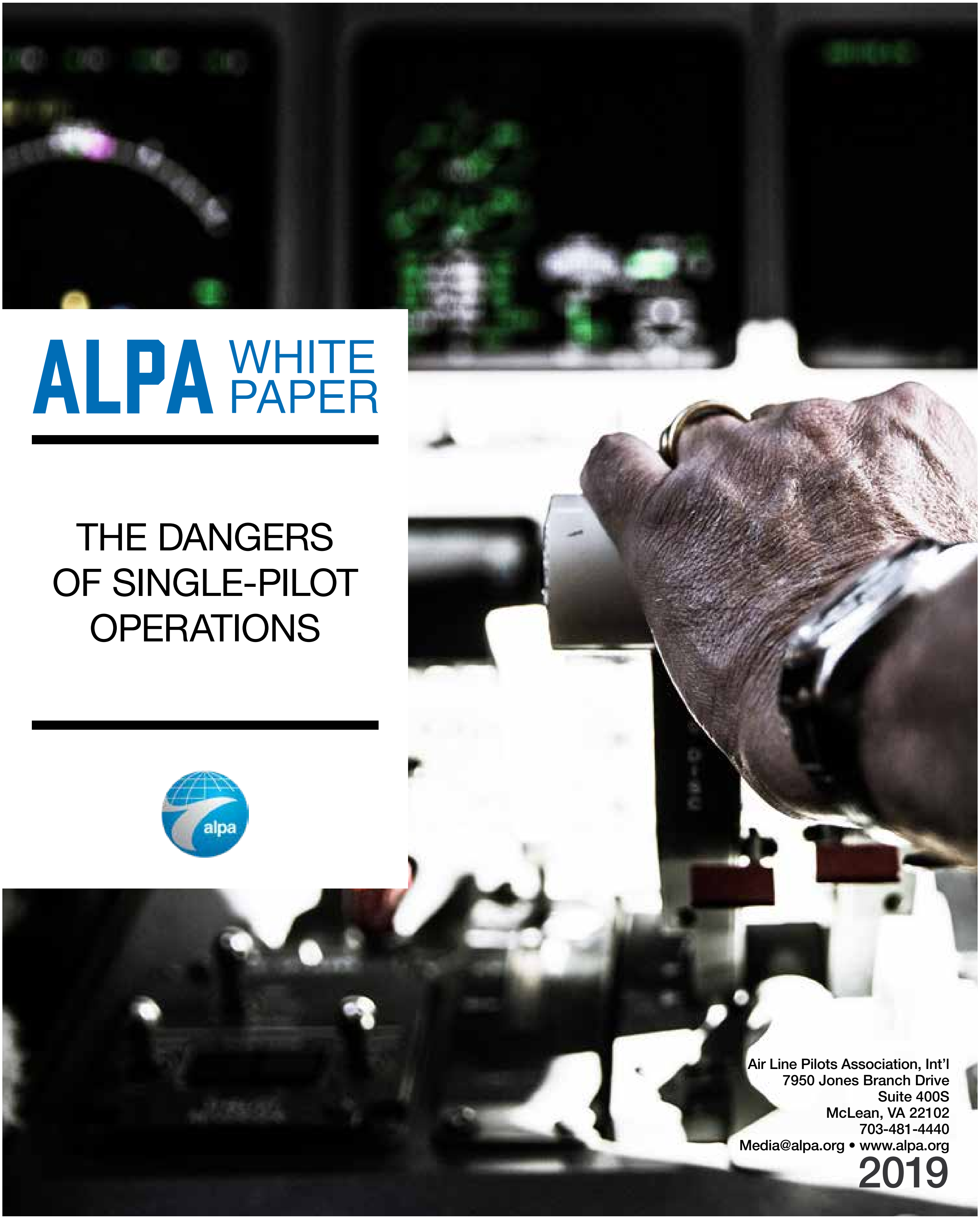

ALPA WHITE PAPER

THE DANGERS OF SINGLE-PILOT OPERATIONS

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EXECUTIVE SUMMARY

Commercial aviation is the world's safest mode of transportation, with a record that continues to improve even as the enterprise steadily grows. The public has many factors to thank for this, but at the top of the list are the highly trained pilots who fly the aircraft through increasingly crowded skies, 24 hours a day, in all types of weather. Yet some entities have begun to advocate for reducing the flight crew present in large aircraft, possibly down to even a single pilot. Those promoting single-pilot operations argue that reducing crew size will lead to cost savings. However, the current body of evidence and experience, including more than a decade of study by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA), shows that the safety risks and challenges associated with single-pilot operations far outweigh its potential benefits.

NECESSITY OF MULTIPLE PILOTS

U.S. law and FAA rules require at least two qualified pilots in the cockpit at all times during flights of large passenger and transport aircraft, with larger crews mandated for long-haul flights. At any given time, one pilot (the "pilot flying") typically is actively flying the aircraft, while the other (the "pilot monitoring") is responsible for monitoring the instrumentation and the flying pilot, checklist management, and communicating with air traffic control. While the modern cockpit features many automated systems, the pilot flying is always actively engaged in flying the aircraft; automation is a tool at his or her disposal.

WORKLOAD SHARING

In standard two-pilot operations, the tasks are shared, which is especially important during the work-intensive taxi, takeoff, and landing phases of flight. Single-pilot operations employ only the pilot flying, who must assume some share of the pilot monitoring's functions, while other tasks are offloaded to computers and ground-based pilots. The result, inevitably, is a significantly increased workload for the pilot flying. Moreover, studies show a clear inverse relationship between pilot workload and safety, particularly during off-nominal conditions. Flight path performance was also better during two-crew operations than reduced or single-crew operations.

COCKPIT COORDINATION

Two pilots seated side by side in the cockpit are able to closely coordinate their actions via constant communications, including nonverbal cues such as head nods and other gestures that indicate a message has been heard or a task is being performed. The pilot monitoring also plays an important role monitoring the pilot flying, watching out for errors or declines in cognitive ability. Should the pilot flying become incapacitated for health reasons during a flight, the pilot monitoring can quickly take control of the aircraft.

ADAPTING TO CHANGING CONDITIONS

Pilots mitigate safety and operational risk on a frequent basis by adapting to changes in circumstances including direction from air traffic control, weather, equipment malfunctions, airport congestion, and flight diversions. This ability to adapt to a dynamic environment is critical: According to FAA data, only one out of every 10 flights conforms to the plan originally entered into an aircraft's flight-management system. Single-pilot operations and reduced-crew operations would compromise that layer of safety, posing an unacceptable risk.

SINGLE-PILOT AIRLINE OPERATIONS: A RISK NOT WORTH TAKING

The risks associated with reduced-crew and single-pilot operations are well documented. Most prominently, these risks stem from the increased workload for the remaining pilot, the elimination of a critical layer of monitoring and operating redundancy in the cockpit, and the inability of a single pilot to handle many emergency situations.

REDUCED COORDINATION

Having pilots seated side by side in the cockpit facilitates the close coordination that is essential to smooth and safe flight operations, especially under off-nominal circumstances. NASA simulations indicate that if the pilots are not co-located, this coordination suffers due to the loss of nonverbal communications. These studies found instances of confusion increase when pilots are not co-located, and that replacing nonverbal cues with verbal communications adds an impractical number of tasks to the pilot's workload.

OVERRELIANCE ON AUTOMATION

Excessive reliance on automated systems can negatively impact pilot performance. Autonomous systems can lead to complacency in the cockpit, as pilots become less vigilant in their monitoring. Autonomous systems can also degrade pilot situational awareness by masking changes in aircraft system health and performance, as well as eroding pilot skills, as many of these can fall into disuse. When unexpected events requiring human intervention occur, pilots who have been using autopilot for an extended period of time can have difficulty transitioning back to active mode.

HANDLING EMERGENCIES

There are numerous documented incidents in which two or more pilots were necessary to avert disaster following major in-flight equipment malfunctions. These include the 2009 incident in which a US Airways pilot ditched into the Hudson River after a bird strike caused a dual-engine failure shortly after takeoff, and the 2018 incident where a Southwest Airlines flight suffered a catastrophic engine failure and debris shattered a passenger window in the cabin. A 2017 NASA/FAA study concluded that single-pilot operations pose an unacceptable safety risk in an emergency situation. The paper also said a pilot incapacitation incident during single-pilot operations could be catastrophic.

PUBLIC POLICY AND OPINION ON SINGLE-PILOT OPERATIONS

U.S. federal aviation regulations governing commercial aviation are clear: At least two pilots must be present in the cockpit of large passenger or cargo transport aircraft. Further legislation requires the presence of additional flight crew to maintain pilot alertness on long-haul flights and to achieve the necessary functionality and safety required of aircraft designs to obtain certification for operation. FAA regulation also reinforces the guarantee of safety via human pilots by prohibiting the use of UAS to transport passengers or cargo for compensation.

Polling data indicate that the public disapproves of reduced-crew or single-pilot operations. In one poll conducted by the Air Line Pilots Association, Int'l, 80 percent of respondents agreed that at least two pilots working together in the cockpit are best equipped to handle flight emergencies, while 96 percent said federal aviation research dollars should be directed at projects other than those aimed at eliminating pilots from the cockpit. The latter preference was confirmed in a similar poll conducted by the market and social research firm Ipsos.

CYBERSECURITY IN THE COCKPIT

The enhanced air-to-ground communications and automation capabilities necessary to implement reduced-crew or single-pilot operations could leave aircraft vulnerable to new forms of tampering or attack. Hackers might, for example, jam signals being used to remotely operate an aircraft, or even commandeer a flight via cyberattack. Signal encryption is the best defense against such attacks; however, encryption introduces signal delays, often lasting for seconds, which could make it difficult to operate an aircraft remotely in an emergency. Moreover, countries have different laws governing the use of encryption technology, and some have banned it altogether.

THE ECONOMIC CASE

Reducing the size of cockpit crews would save airlines and air transport operators money on salaries, benefits, and other expenses, but some, if not most, of those savings would be offset by costs associated with reduced-crew and single-pilot operations. These costs include: outfitting or retrofitting aircraft with the necessary automation, sensor, and communications systems; ground infrastructure costs; salaries and benefits for remote ground-based pilots who would be needed to support single-pilot operations; and certification costs.

INCREASED WORKLOAD

NASA studies have shown that without a pilot monitoring in the cockpit, the pilot flying would face a substantially higher workload, especially under off-nominal flight circumstances. Numerous NASA simulations have demonstrated this phenomenon, along with an associated rise in task shedding and pilot errors. Studies also show that ground-based assistance does not offset the increased workload.

OBSTACLES TO SINGLE-PILOT OPERATIONS

Significant advances in automation and other technologies in recent years have led some in the aviation industry to suggest that reduced-crew or single-pilot operations could save money without compromising safety. In fact, automation, communications, and sensor technologies are decades away from being able to provide the same level of safety as a second pilot in the cockpit. In addition, efforts to implement single-pilot operations would also need to overcome regulatory constraints, cybersecurity concerns, and economic drawbacks.

TECHNOLOGICAL HURDLES

While automation and other technologies have advanced considerably over the years, they have not reached the point of enabling single-pilot operations without compromising safety. To truly replace the second pilot in the cockpit, machines will need to replicate the sensing, assessing, reacting, adapting, and interacting capabilities of a human in a complex and dynamic environment. This level of automation is decades away from becoming reality. Current automation technology is capable of handling specific, limited tasks, but even these systems are prone to errors, which, if undetected, can be compounded over time. Moreover, current technology is incapable of remotely detecting subtle indicators of health complications in a human pilot that could be an indicator of impending incapacitation.

HIGHER-PRIORITY FEDERAL INVESTMENTS AS COMPARED TO REDUCED-CREW AND SINGLE-PILOT OPERATIONS

Reduced-crew and single-pilot operations rank low on the priority list for U.S. federal investment in aviation research and technology. The FAA is currently occupied with the sweeping modernization of the nation's air traffic management system, while NASA is investigating a number of aeronautics technologies that will serve the general public as well as the aviation industry.

UPGRADING THE NATIONAL AIRSPACE SYSTEM (NAS)

The FAA, with help from NASA, is in the midst of a $20 billion-plus modernization of the NAS via multiple programs known collectively as the Next Generation Air Transportation System (NextGen). The overhaul is necessary to ensure safe and efficient operations in the increasingly congested NAS, which is seeing steady growth in commercial aviation plus the entry of new vehicles, including UAS, suborbital space and reentry vehicles, and air taxis. Many of the foundational elements of NextGen are already in place, but the overhaul is not expected to be fully realized until 2025. Pursuing reductions in the size of cockpit crews at this time would be an unnecessary distraction and drain on resources from the pressing task of upgrading the NAS.

ALTERNATIVE RESEARCH AVENUES

Funding research into reduced-crew and single-pilot operations would divert scarce resources from other, more widely beneficial areas of aviation research. NASA's Aeronautics Research Mission Directorate (ARMD) is currently engaged in research that benefits not only the airlines and air transport operators but also the public at large. The research typically supports one of the following goals: enhanced safety, reduced fuel consumption and overall environmental impact, reduced travel times, and increased efficiency in the NAS. Specific projects being pursued by ARMD include: new batteries that would enable all-electric aircraft propulsion, reduced-noise supersonic travel, and hybrid wing-body aircraft designs that use far less fuel than current aircraft. Fuel now represents a substantial portion of airline costs, so reduction in fuel consumption would go straight to the companies' bottom lines.

SECTION 1: NECESSITY OF MULTIPLE PILOTS

The commercial aviation system is the safest transportation system in the world, with a record that continues to improve even amid skyrocketing demand for passenger travel and cargo transport.[1] At the heart of this system are the pilots whose training, skill, and experience have prepared them to handle almost any situation, be it system malfunction, inclement weather, or air-traffic overload. Consequently, U.S. federal aviation regulations have long required onboard crews of at least two qualified pilots on airline flights carrying either passengers or cargo, with larger crews for long-haul flights.

Significant advances in weather monitoring, automation, navigation, surveillance, communications, and information-processing technologies have no doubt been a factor in the impressive safety record of commercial aviation. These advances have reached a point that some commercial airlines and cargo transport operators now argue that cockpit crew sizes can be reduced, in some cases to a single pilot, without compromising safety for either onboard passengers or uninvolved third parties. However, the current body of evidence and experience, including more than a decade of study by NASA and the FAA, strongly argue otherwise.

These studies collectively indicate that despite the dramatic technological advances since the rules were established, a cockpit crew of at least two pilots remains necessary to maintain the current high level of safety and flight deck security. Even under nominal circumstances, a single pilot would face a significantly higher workload than when the tasks are shared, a situation that can lead to shedding tasks and introducing mistakes. This risk is particularly high during the high-workload takeoff, approach, and landing phases of flight, as well as under off-nominal circumstances, such as poor weather conditions or equipment malfunctions. Moreover, no existing technology can eliminate or account for the possibility of pilot incapacitation during flight due to health or other issues. A second pilot is necessary to take the controls of the aircraft under those circumstances. Two human pilots are also better able to adapt to changing circumstances during flight, which is crucial in case of abnormal and emergency events. The shortcomings of remote pilot assistance further reinforce the necessity of having multiple pilots in the cockpit, including the loss of nonverbal communication, possibility of communication outages, and security risks.

THE BENEFITS OF MULTIPLE PILOTS

SPREADING WORKLOAD

Pilots are actively in control of every airline aircraft from departure to arrival gate regardless if they are carrying passengers or cargo. The notion that computers do most of the flying in modern commercial aircraft, even during takeoff and landing, is false. During normal two-pilot operations, one pilot is responsible for flying the airplane. This person is known as the "pilot flying." The other pilot is responsible for monitoring the pilot flying's actions, the flight path of the aircraft, the aircraft and systems states as well as support functions including communications with air traffic control, and ensuring checklist completion. The pilot in this role is referred to as the "pilot monitoring." The pilot flying and pilot monitoring duties typically alternate between the two pilots. Single-pilot operations employ only the pilot flying, who must assume some share of the pilot monitoring's functions, while other tasks are offloaded to computers and ground-based pilots. The result, inevitably, is a significantly increased workload for the pilot flying, which would reduce the current levels of safety of airline operations.

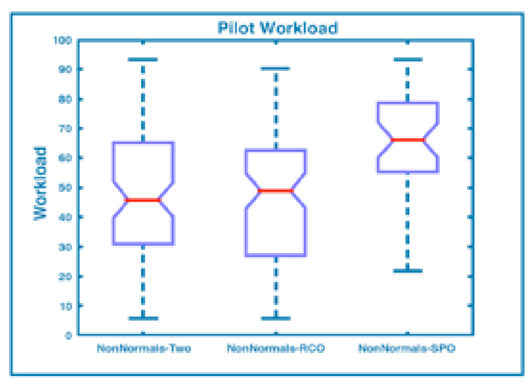

Figure 1. The increased workload experienced under single-pilot operations
Image credit: NASA, 2017, *An Assessment of Reduced Crew and Single Pilot Operations in Commercial Transport Aircraft Operation*

Data from a series of pilot-in-the-loop simulations conducted by NASA and the FAA and presented in September 2017 (Figure 1) indicate a clear inverse relationship between pilot workload and safety:

1 Report on the Operational Use of Flight Path Management Systems, p. 1

"When the pilot workload exceeded certain limits, the pilots would shed tasks and in doing so, errors in execution or omission would occur."[2]

Under off-nominal conditions, such as unexpected changes in weather, minor losses of pressure, or uncoordinated interactions with another aircraft, the study found the workload was significantly higher for a single pilot in the cockpit than for two.[3]

Moreover, flight path performance was better during two-crew operations than reduced or single-crew operations:

"Two pilots provided for a pilot monitoring. Two-crew operations provided four hands, four eyes, and two brains to monitor and work the problem[s]. Two pilots provided for workload sharing, especially in the rudder trim runaway non-normal where the physical workload to control the vehicle was significant. Two pilots provided a larger wealth of experience from which to draw from such as adapting to unique flying techniques [using asymmetric thrust to help balance fuel load or rudder trim], knowing nearby available, suitable, but underused airports [Grand Junction, CO], or understanding secondary or compounding failure effects that are not checklist items [loss of generators will cause pressurization effects]."[4]

Checklist usage, meanwhile, was more consistent and accurate during standard two-crew operations than with reduced-crew or single-pilot operations. Checklist usage was limited in reduced-crew operations—defined in this study as having only one pilot active during the cruise phase of flight—because the start of a checklist often was delayed until the resting pilot resumed flying duties.

MEDICAL CONTINGENCIES

The two-pilot minimum provides a critical layer of redundancy in the cockpit in the event that one pilot becomes incapacitated or impaired for medical reasons during flight. Should incapacitation happen during single-pilot operations, a remote pilot would be responsible for flying and landing the aircraft safely. This approach is unacceptably risky because a remote pilot lacks the full situational awareness of an onboard, alert pilot.

Although incidences of pilot incapacitation in flight are statistically rare, the sheer volume of airline aviation activity worldwide is such that they occur with some frequency. When they have occurred on airline aircraft, the one remaining pilot was fortunate enough be able to manage an emergency descent and landing. However, when looking at these events in a future state where single-pilot airline operations are standard, it highlights an elevated risk. A 2014 NASA paper, citing a study conducted by the FAA Aeromedical Institute, reported 39 recorded incidents of pilot medical incapacitation in-flight during the six-year period from 1993 to 1998.[5] The frequency of these events could increase in the future as a result of an aging pilot population and the likelihood of becoming incapacitated in flight increases with pilot age.[6] Moreover, commercial aviation activity is expected to continue growing along with the world economy over at least the next two decades.[7] Single-pilot operations are unable to mitigate this growing concern.

ADAPTING TO CHANGING CONDITIONS

Pilots mitigate safety and operational risk on a frequent basis by adapting to changes in circumstances including direction from air traffic control, weather, system malfunctions, airport congestion, and flight diversions. This ability to adapt to a dynamic environment is critical: According to FAA data, only one out of every 10 flights conforms to the plan originally entered into an aircraft's flight management system.[8]

Only one in 10 flights conforms to its original flight plan

Yet, pilot error is frequently cited as a causal factor in aviation incidents and accidents, giving rise to the idea that human pilots constitute a weak link in terms of safety. The corollary is that minimizing or perhaps even eliminating the human in the cockpit would improve safety. However, this thesis is fundamentally flawed, largely because it relies on a one-sided data set: instances in which accidents or incidents have occurred. No comprehensive review of the number of accidents and incidents that are avoided due to pilot actions has been done.

2 An Assessment of Reduced Crew and Single Pilot Operations in Commercial Transport Aircraft Operations, p. 6
3 Ibid., p. 7
4 Ibid., p. 6
5 Conceptual Framework for Single Pilot Operations, p. 3
6 Aging and the General Aviation Pilot, p. 11
7 FAA Aerospace Forecast, Fiscal Years 2018–2038, p. 1
8 Report on the Operational Use of Flight Path Management Systems, p. 29

However, there are many examples of incidents in which quick thinking and actions by multiple pilots in the cockpit have averted disaster. Single-pilot operations and, to a lesser extent, reduced-crew operations, would compromise that layer of safety, posing an unacceptable risk. This heightened risk is present even if the possibility of pilot incapacitation is discounted.

THE SHORTCOMINGS OF REMOTE PILOT ASSISTANCE

Remote pilot assistance, whereby pilots on the ground can assist onboard pilots and take control of the aircraft if necessary, has been offered in answer to the excess workload and incapacitation issues inherent in single-pilot operations. However, other issues including the loss of nonverbal communications in the cockpit, the potential for communications outages between the cockpit and air traffic control, and flight deck security make reliance on ground-based pilots problematic.

REDUCTION OR LOSS OF NONVERBAL COMMUNICATIONS

People in everyday life rely on nonverbal communications and cues: head nods, facial expressions, and physical actions that confirm a task is being performed or a message was heard. These cues are especially important in the cockpit, where pilots are constantly engaged in a multitude of tasks. In remotely assisted single-pilot operations, this important communications avenue is all but lost. Pilots have clearly expressed that they prefer face-to-face communications over radio communications.[9] In addition to pilot preference, there are objective reasons to preserve this form of pilot interaction.

A lack of nonverbal communications can cause confusion about roles and responsibilities in any given moment during a flight. NASA has conducted simulations in which two pilots were put through different off-nominal flight scenarios under two different conditions: one in which the pilots were co-located in a room, the other in which they were in separate rooms but able to communicate by microphone. The study found that far more incidents of confusion about roles and responsibilities occurred when the pilots were separated than when they were together (Figure 2). These incidents arose primarily over what the other pilot was doing at any given moment, misinterpretation of landing approach procedures, and the location of briefing material.[10] Although physical cues could be replaced by verbal communications via radio, this approach could add an impractical number of tasks to the pilot's to-do list.[11]

Confusions	Separate	Together
What is the other pilot doing?	14	0
Where is info on the approach plates?	8	3
Where is info in briefing material?	6	0
Other	24	15
Total	52	18

Figure 2. Confusion arises when two pilots do not share a cockpit
Image credit: San Jose University/NASA, 2014, *Toward Single Pilot Operations: The Impact of the Loss of Non-Verbal Communication on the Flight Deck*

GROUND-BASED PILOT CONFUSION

If the eventual goal is to realize a reduction of the pilot workforce, each remote ground pilot would need to be assigned multiple flights to monitor at any given time. During nominal operations, this is a reasonable expectation, since pilots in the cockpit are expected to be aware of the positions and vectors of other aircraft besides their own as needed during flight. However, when off-nominal conditions emerge it has been found that remote ground pilots can have difficulty compartmentalizing the state of each flight.[12] This leads to the pilot confusing information about flights and making decisions based on erroneous information. In order to mitigate this risk, remote ground pilots may only be able to handle a single flight, thus limiting the cost savings that may be realized by eliminating a pilot in the cockpit.

COMMUNICATIONS OUTAGES

Secure, foolproof voice and data communications between the ground (the remote pilot and air traffic control) and cockpit are absolutely required for remote pilot assistance, which in turn is a likely necessity for single-pilot operations. During 2018 alone, multiple instances of lost communications with aircraft occurred—typically during handoff from one air traffic controller to

9 Toward Single Pilot Operations: The Impact of the Loss of Non-Verbal Communication on the Flight Deck, p. 1
10 Ibid., p. 5
11 A Validated Task Analysis of the Single Pilot Operations Concept, p. 17
12 Pilot Situational Awareness and Its Implications for Single Pilot Operations, p. 3024

another—that were deemed serious enough to scramble fighter jets to investigate the affected aircraft.[13] During single-pilot operations, if the onboard pilot were to become incapacitated and communications with the ground were lost, the results could be catastrophic. Even without pilot incapacitation, risk to the aircraft and passengers is increased since the single pilot would have to assume navigation duties to make up for lost external information sources.[14]

SECURITY RISK

Reducing the personnel in the cockpit to a single pilot not only decreases the physical security of

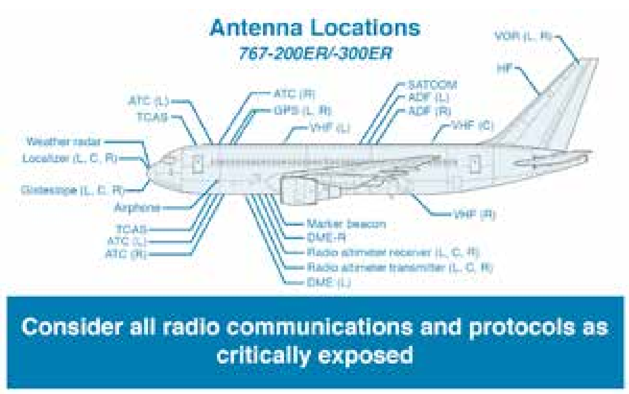

Figure 3. An aircraft contains many targetable data systems
Image credit: Dr. Stefan Frei, 2015, *Cyber Threats in Aviation*

the cockpit, but the cybersecurity of it as well. The communications capabilities required to control aircraft remotely from the ground could introduce new vulnerabilities in the system, since more aircraft functions would need to be open to remote operation (example, Figure 3). A hostile actor could exploit these vulnerabilities to tamper with or even commandeer a flight. There may be precedent for such an event in the world of unmanned aircraft systems: a 2011 incident in which Iran captured a U.S. drone flying over its airspace. Iran claims to have commandeered the drone by exploiting a weakness in its communications link.[15] Although U.S. officials said the drone malfunctioned, the incident underscores the need for secure, encrypted communications links between the cockpit and a remote pilot. Encryption is problematic for at least two reasons. First, in the case of international flights, countries have different laws governing—and in some cases prohibiting—the use of encryption in their airspace. Second, encryption introduces signal-transmission delays, or latency, lasting up to a couple of seconds. These delays could pose control challenges for a remote pilot.[16]

Transportation security regulations require the captain to serve as the inflight security coordinator. In that role, the captain is responsible for directing the actions of other crewmembers for both routine security issues (e.g., disruptive passengers) and crisis situations (e.g., attacks against the cockpit, suspected IED). The captain relies on the first officer particularly to help fly the aircraft and assist with all other duties associated with security events, which may include extensive communications and coordination with flight attendants during a large segment of a flight.

SUMMARY: NECESSITY OF MULTIPLE PILOTS

- The two pilots in the cockpit have different roles:
  - One flies, and one monitors
  - Those roles can be alternated or exchanged
  - Under many conditions, the undivided attention of both pilots is needed
- Multiple NASA and FAA studies have noted the dangers of further reducing flight crew complement
- Neither a ground pilot nor an autonomous system can compensate for an incapacitated pilot
- Remote operation would open new cyber vulnerabilities in aircraft
- Pilot flexibility is essential—only one in 10 flights conforms to the original flight plan
- Ground-based pilots and autonomous systems are poor substitutes for a second pilot on the flight deck
  - Neither can communicate as well as a second pilot
  - Ground-based pilots must split attention, and may get cut off
  - Autonomous systems are not capable enough analytically or physically

13 The Aviation Herald, http://www.avherald.com/h?search_term=loss+of+communiction&opt=0&dosearch=1&search.x=0&search.y=0
14 https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140008907.pdf p. 142
15 The New York Times, Dec. 7, 2011, https://www.nytimes.com/2011/12/08/world/middleeast/drone-crash-in-iran-reveals-secret-us-surveillance-bid.html
16 Cyber Safety and Security for Reduced Crew Operations (RCO), p. 9–10

SECTION 2: SINGLE-PILOT AIRLINE OPERATIONS: A RISK NOT WORTH TAKING

Safety and security are the top priorities for the airline industry and aviation as a whole: Without them, there would be no aviation industry. To maintain and improve on our high level of safety, U.S. federal aviation regulations have required a minimum number of qualified pilots to be active and engaged in the cockpit at all times during airline flights carrying either passengers or cargo. For most flights, this safe minimum is two; the number increases for long-haul flights where fatigue may become an issue.

The multiple pilots are necessary to share the considerable workload that flying airliners entails, monitoring the health and actions of the pilot flying the aircraft, the flight path of the aircraft, and the system states, as well as assuming the control if the pilot flying becomes incapacitated for any reason. Eliminating this critical layer of redundancy would inevitably reduce flight safety, a fact that is well documented both in technical research and pilot experience. Broadly, the reduced safety stems from the increased workload and stress that single-pilot operations would impose on the remaining pilot, particularly during takeoff and landing or under off-nominal circumstances. Off-nominal circumstances include adverse weather conditions, equipment malfunctions, and flight-path diversions—events that pilots routinely encounter and are best equipped to address.

Under reduced-crew or single-pilot operations, a combination of autonomous systems and ground-based pilots with the ability to control the aircraft would be expected to partially offset the extra workload. However, numerous studies by NASA and others indicate that these proposed solutions do not provide the same safety margin as having a second qualified pilot in the cockpit. In addition to increasing workload, reduced or single-pilot operations negatively impact communication and pilot performance. They also do not defend against pilot incapacitation. Moreover, there are many examples of incidents where two pilots in the cockpit were needed to recover from equipment malfunctions that otherwise would have likely resulted in disaster.

SINGLE-PILOT OPERATIONS INCREASE WORKLOAD FOR THE REMAINING PILOT

Having two pilots in the cockpit is necessary to handle the tasks involved in flying an airline's aircraft. A wealth of objective evidence shows that single-pilot operations significantly increase pilot workload, to the point that safety is compromised due to an accompanying increase in mistakes and task shedding. A September 2017 NASA paper on the effects of single-pilot operations illustrates this danger to safety. The paper describes a NASA/FAA experiment involving 36 pilots who flew seven flight scenarios—only one of which was nominal—under two-crew, single-pilot, and reduced-crew conditions.[17] A Boeing 737-800 flight simulator was used for the experiment. The experiment found that pilot workload increased significantly under single-pilot operations in the off-nominal scenarios, which ranged from relatively benign hydraulic leaks to more serious issues such as dual generator failures (Figure 4). The experiment organizers found a direct correlation between the increased workload and the incidence of pilot errors, with a resulting decrease in overall safety.

One proposed solution to offset this increased workload is the use of ground-based pilots. However, a NASA task analysis published in 2015 shows that such assistance does not sufficiently offset the workload increase encountered under single-pilot operations. This task analysis found that under off-nominal conditions, such as a flight diversion, the number of tasks for an onboard pilot assisted by ground-based pilots increased by as much as 24 percent in comparison to the amount normally handled by the captain during standard-two pilot operations.[18] Moreover, to make financial sense as a replacement for standard two-pilot operations, ground operators (pilots) would have to be responsible for multiple aircraft at any given time. However, according to a NASA experiment that examined this approach, pilots can have difficulty compartmentalizing issues faced by these different aircraft.[19] Assistance or intervention by a ground pilot also would be complicated by communications transmission delays introduced by the necessary signal encryption. Without such encryption, these signals would be at risk of tampering by unauthorized actors.[20]

Detailed Actions Required - Taskwork and Teamwork

Full Automation (FA1)

Temporal Function	Pilot	Automation
Control Vertical Profile	Modify CDU Pages Lower Airspeed-Late Descent Confirm Target Altitude Confirm Target Speed	Manage Waypoint Progress
Control Waypoints	Modify CDU Pages Monitor Waypoint Progress Confirm Active Waypoint Monitor Dist Active Waypoint	Calculate Dist Current Waypoint Evaluate Flight Phase Manage Waypoint Progress Direct to Waypoint
Control Communication with ATC	Respond Handoff Confirm Data Communication	Receive Altitude Clearance Receive ILS Clearance Receive Waypoint Clearance
Control Heading	Monitor Heading Trends	Update Lateral Control
Control Heading	Monitor Altitude Monitor Vertical Deviation	Adjust Speed Control Update Pitch Control Evaluate Vertical Mode Evaluate VNAV Mode Transition Evaluate Alt Restriction Mode Altitude Reminder
Control Airspeed	Monitor Descent Airspeed	Update Thrust Control Calculate Speed Deviation
Control Aircraft Configuration	Deploy Flap Deploy Gear Deploy Speed Brake Retract Speed Brake Confirm Config Change	
Control Aircraft Information	Verify TOD Location Verify Crossing Restriction	
Control Operating Procedures	Perform Approach Briefing Perform Approach Checklist Perform Landing Checklist	
Control Flight Deck Components	Turn Off Altitude Alert Respond to Drag Required	

MCP (FA4)

Temporal Function	Pilot	Automation
Control Vertical Profile	Monitor Altitude Lower Airspeed-Late Descent	
Control Waypoints	Manage Waypoint Progress Direct to Waypoint	Calculate Dist Current Waypoint Evaluate Flight Phase
Control Communication with ATC	Receive Altitude Clearance Receive ILS Clearance Receive Waypoint Clearance Respond Handoff Request Clearance	
Control Heading	Dial Heading Selector Push Heading Selector Monitor Heading Trends	Update Lateral Control
Control Heading	Dial Altitude Selector Dial VS Selector Push Alt Hold Switch Push FLCH Switch Push Vertical NAV Switch Push Vertical Speed Switch Monitor Green Arc	Update Pitch Control Evaluate Vertical Mode Evaluate Alt Restriction Mode Altitude Reminder
Control Airspeed	Dial Speed Selector Push Speed Switch Monitor Descent Airspeed	Update Thrust Control Calculate Speed Deviation
Control Aircraft Configuration	Deploy Flap Deploy Gear Deploy Speed Brake Retract Speed Brake Confirm Config Change	
Control Aircraft Information	Verify TOD Location Verify Crossing Restriction	
Control Operating Procedures	Perform Approach Briefing Perform Approach Checklist Perform Landing Checklist	
Control Flight Deck Components	Turn Off Altitude Alert Respond to Drag Required	

Figure 4. Tasks in red must be assumed by the human pilot if a human co-pilot is removed from the cockpit
Image credit: NASA, 2013, *Single-Pilot Operations Technical Interchange Meeting: Proceedings and Findings*

17 An Assessment of Reduced Crew and Single Pilot Operations in Commercial Transport Aircraft Operations, p. 6
18 A Validated Task Analysis of the Single Pilot Operations Concept, p. 16
19 Pilot Situation Awareness and Its Implications for Single Pilot Operations: Analysis of a Human-in-the-Loop Study, p. 3024
20 Cyber Safety and Security for Reduced Crew Operations (RCO), p. 8–10

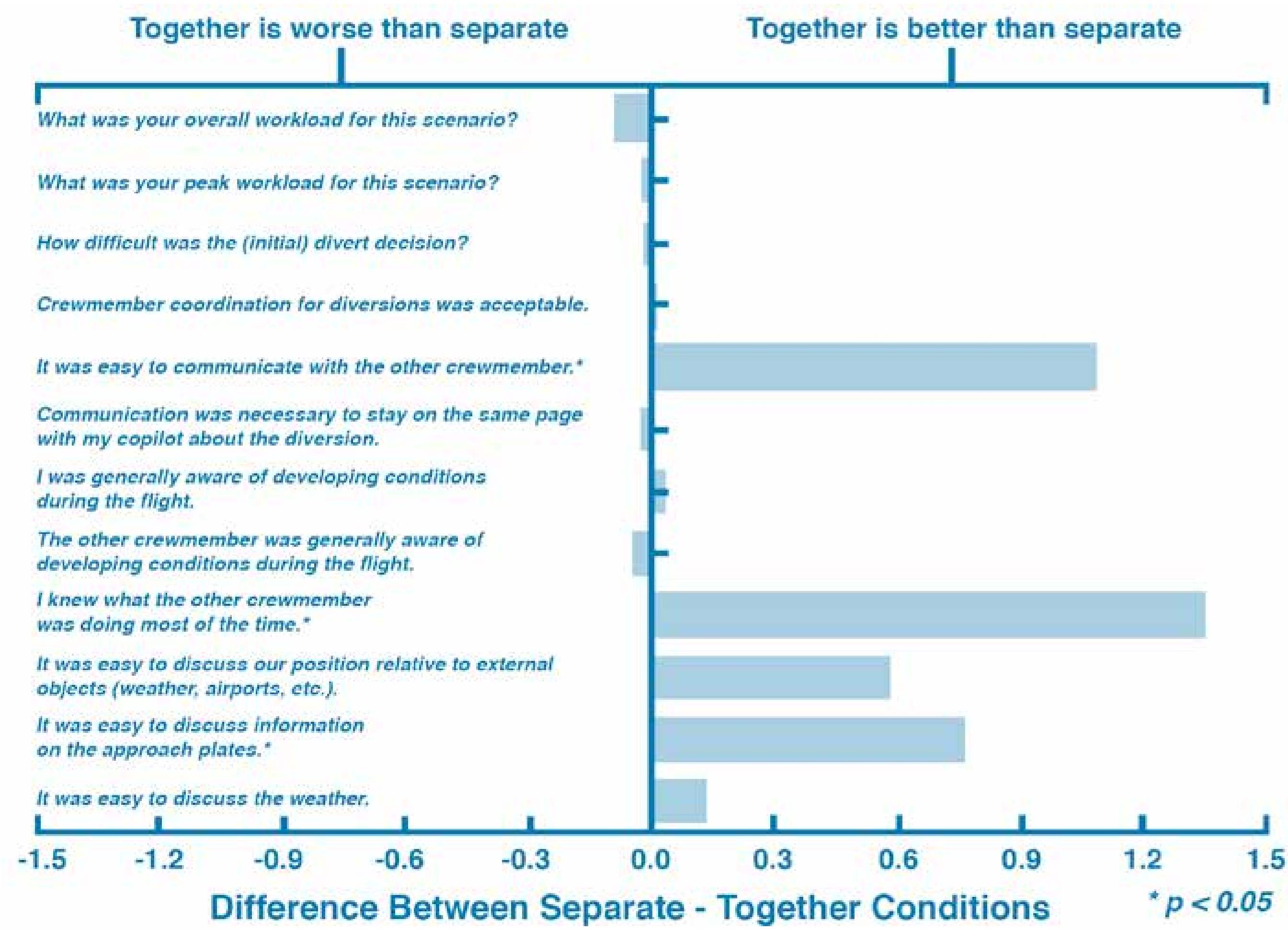

Figure 5. Pilots assess how they felt impeded by separation
Image credit: San Jose University/NASA, 2014, *Toward Single Pilot Operations: The Impact of the Loss of Non-Verbal Communication of the Flight Deck*

REMOTE INTERACTION IMPEDES COMMUNICATION

One significant benefit of the current two-pilot requirement is the close coordination enabled by co-location. Pilots expressed a preference for co-location in a 2014 NASA study (Figure 5). In the study, 20 pilots (10 two-pilot crews) flew six simulated flights that involved a flight-path diversion. The pilots flew under two conditions: one in which the pilots were situated side by side and the other where they were kept in separate rooms. While these pilots were able to perform their required tasks under both conditions, they expressed a clear preference for co-location. Co-location facilitates nonverbal communications—physical cues that indicate that a task is being performed or message has been received, to name two examples. Without co-location, the researchers observed a much higher incidence of pilot confusion, primarily over the other pilot's actions and approach procedures. Moreover, in a post-simulation questionnaire, a majority of the participating pilots rated their overall workload as higher while separated.[21] In the absence of the physical cues naturally present in two-pilot operations, all communications between the pilot flying the aircraft and a supporting ground-based pilot would have to be performed verbally, adding an impractical number of additional tasks.[22]

RELIANCE ON AUTOMATED SYSTEMS AFFECTS PILOT PERFORMANCE

Increased reliance on automation technologies, existing or new, is a cornerstone of reduced-crew and single-pilot operations. While this technology has undoubtedly contributed to the current safety levels of commercial aviation, it is far from being able to replace the second pilot in the cockpit without impacting safety.

Robotic and autonomous systems are still prone to failure,[23] which increases pilot workload.

21 Toward Single Pilot Operations: The Impact of the Loss of Non-Verbal Communication on the Flight Deck , p. 6
22 A Validated Task Analysis of the Single Pilot Operations Concept, p. 17
23 Failures in robotics and intelligent systems, p. 2

According to a 2012 NASA-led study on automation risks, when an error is made by an autonomous system, the pilot task load increases due to the work necessary to clear the erroneous action from the system. As autonomous systems grow more complex, as they inevitably will, the probability of errors will increase, possibly to the point of negating any benefits they might otherwise provide:

"At this time, the prospect of adding significant autonomous decision-making on a piloted aircraft is viewed with some degree of concern for the ability of the system to add value without adding risk."[24]

Moreover, extensive reliance on automated systems can negatively impact pilot performance. The 2012 NASA study, using interviews with experts from industry, government, and academia, found a number of pilot performance issues associated with increased reliance on autonomous systems for decision-making. Autonomous systems that are highly—but not 100 percent—reliable can lead to complacency in the cockpit, as pilots become less vigilant in their monitoring. Autonomous systems also can degrade pilot situational awareness by masking changes in aircraft system health and performance. These changes can build up over time and lead to pilot decisions based on incomplete or inaccurate information.[25] Reliance on autonomous systems also can erode pilot skills, as many of these can fall into disuse.[26] The FAA has in fact encouraged airlines to develop procedures to ensure that pilots maintain their operating skills during training and flight operations. More generally, when unexpected events requiring human intervention occur, pilots who have been using autopilot for an extended period of time can have difficulty transitioning back to active mode.[27]

SINGLE-PILOT OPERATIONS DO NOT ADDRESS PILOT INCAPACITATION

Two pilots in the cockpit is the only reliable defense against the possibility that one becomes incapacitated during flight. Onboard pilots can become incapacitated for a variety of reasons, including health issues such as heart attack or even food poisoning. Though the chances of a pilot becoming incapacitated or impaired during flight are statistically low, the sheer volume of commercial air traffic globally translates into multiple incidents each year. In standard two-pilot operations, a key responsibility of the pilot not flying—the pilot monitoring—is to monitor the physical condition of the pilot who is actually flying the aircraft. The pilot monitoring also is on the lookout for errors or declines in cognitive capability on the part of the pilot flying.

In single-pilot operations, this critical redundancy layer is lost. The ability to reliably monitor pilot health using automated systems will require significant advances in technology.[28] Moreover, a ground-based pilot who may be juggling multiple aircraft at any given time simply cannot respond as quickly to a situation in which the onboard pilot becomes incapacitated as would a co-located pilot. Moreover, while it is assumed that a ground-based pilot will take control of the aircraft if the onboard pilot becomes incapacitated, this pilot would then become unavailable for other aircraft that may need assistance, were they assigned to attempt to support multiple flights.

TWO PILOTS NEEDED FOR FLIGHT DECK SECURITY

The flight deck of an aircraft is the focal point of all aviation security measures, both on the ground and in the air. The safe operation of the aircraft is determined by the pilots at the controls, so the many various layers of security in today's system are intended to first and foremost protect them and their work environment. In addition to the external security measures protecting the flight deck, the captain and first officer also perform duties to protect it, which by extension protects their passengers and the entire crew.

The captain serves by regulation as the inflight security coordinator and they are assisted in the performance of that role by the first officer and cabin crew. The TSA's antihijacking program relies on the two pilots working together and with the cabin crew in passenger aircraft to counter the various levels and types of threats which may arise. During an actual security event, one pilot will focus on flying the aircraft while the other addresses the threat (e.g., flight deck intruder, suspected onboard improvised explosive device, disruptive passenger, armed passenger, etc.), along with the cabin crew as appropriate. Another aspect of flight deck security is the need for pilots to leave the flight deck for physiological reasons, which in the case of a single-pilot operation would leave no one at the controls for an extended period and make the flight deck much more susceptible to a hijacking threat.

24 A Briefing on Metrics and Risks for Autonomous Decision-Making in Aerospace Applications, p. 10–12
25 Ibid.
26 Ibid.
27 Dealing with Unexpected Events on the Flight Deck: A Conceptual Model of Startle and Surprise, p. 1
28 Conceptual Framework for Single Pilot Operations, p. 6–7

US Airways 1549 ditched in Hudson River, NY
Image credit: Greg Lam Pak Ng, 2009, Flickr: Plane crash into Hudson River

TWO PILOTS ARE BEST DEFENSE DURING CRISIS

Pilot skill, experience, and professionalism rank at the top of the list of reasons commercial aviation is the world's safest mode of transportation. Having two pilots in the cockpit at all times ensures that when rare mistakes do occur, they are quickly identified and corrected. Pilots routinely adapt to changing circumstances during flight, including machine or equipment failures that can increase the danger of an accident.[29] Although statistics are not kept on accidents or incidents averted by pilot action, many recorded incidents of aviation emergencies illustrate where this has been the case. Notably, in each of the following examples, a crew of at least two pilots was necessary to avert disaster:

- In July 1989, a United Airlines DC-10 aircraft bound from Denver to Chicago diverted to Sioux City, Iowa, due to an engine failure that resulted in a loss of hydraulics and flight controls. The controls were so heavy that it required two pilots to land the aircraft in a manner that saved the majority of the passengers—not counting a pilot flying as a passenger who came in from the cabin to work the throttles. Investigators subsequently commended the flight crew's performance for greatly exceeding expectations.[30]
- In January 2009, a US Airways flight bound from New York to Charlotte, N.C., ditched into the Hudson River shortly following takeoff after a bird strike caused a dual engine failure. Because the event occurred at such a low altitude, it required two onboard pilots working in close coordination to bring the aircraft down safely in the river. According to the National Transportation Safety Board, the captain's decision to ditch in the river rather than try to reach an airport improved the chances of a survivable outcome. Moreover, the crew's decision to activate the aircraft's auxiliary power unit early during the emergency, which was not in accordance with checklists, ensured the availability of electrical power and was essential to the outcome. All 155 people onboard the aircraft were rescued.[31]
- In April 2018, a Southwest Airlines flight bound from New York to Dallas had to be diverted to Philadelphia after a high-altitude engine explosion. Debris from the engine shattered a window in the cabin, and the resulting decompression pulled a passenger partially outside the aircraft. Despite difficulty handling the aircraft, the crew was able to land safely (the passenger seated next to the shattered window did not survive), all while communicating with the cabin and air traffic control, and performing the required checklists.[32] In an interview following the incident, Tammie Jo Shults, the captain of the aircraft, described the coordination with the first officer in safely landing the aircraft: "We kind of just split the cockpit and I did flying and some of the outside talking and he took care of everything else."[33]
- In August 2001, an Air Transat flight bound from Halifax, Nova Scotia, to Lisbon, Portugal, lost both engines during descent due to a fuel leak. The captain and first officer successfully brought the plane in for an engine-out glide landing despite nighttime conditions, limited instrumentation, and severely degraded aircraft handling capabilities. A single pilot would have been unable to assess the situation while calculating glide-performance data.[34]

29 Ibid., p. 1
30 ALPA research
31 Ibid.
32 Ibid.
33 Forbes, May 11, 2018 https://www.forbes.com/sites/tedreed/2018/05/11/study-of-single-pilot-cargo-aircraft-is-silly-and-southwest-incident-proves-it-pilot-leader-says/#7f8417ca4412ALPA research
34 ALPA research

In all of these examples, the co-location of the pilots and their ability to adapt to the circumstances were key to averting disaster. Single-pilot operations would eliminate or diminish these flight-saving factors.

Moreover, a 2017 NASA/FAA study on single-pilot and reduced-crew operations further indicated that single-pilot operations are not acceptable in an emergency because of increased pilot workload:

"The pilots could overcome the circumstances presented, but rated the workload, safety, and acceptability as being unacceptable in an emergency condition. There were notable flight performance decrements during [single-pilot operations] compared to two-crew operations that suggest unacceptable reduced safety margins."[35]

In addition, as described in earlier sections the report also noted that in reduced-crew or single-pilot operations, instances of pilot incapacitation or impairment could be "catastrophic." The study concluded that entirely new automation and autopilot technologies would need to be introduced to address these and other issues associated with reduced-crew or single-pilot operations.

SUMMARY: SINGLE-PILOT AIRLINE OPERATIONS: A RISK NOT WORTH TAKING

- During takeoff, landing, and crises, the cockpit workload is too much for one pilot to handle
    - During normal operations, a remote operator can only support a single pilot
    - Even so, capability and communication are limited, meaning more work for the pilot flying
    - Otherwise, removing a pilot overloads the remaining pilot and limits them in a crisis
- Remote pilots may have difficulty compartmentalizing the state of each flight monitored
- Autonomous systems can have perfect awareness of an aircraft and still fail to communicate a problem or solution
- The national airspace is designed with two pilots and their capabilities in mind
    - Multiple pilots allow for cross-checking and noticing errors made by the other pilot or flight systems
    - Multiple pilots greatly improve coordination between flight and cabin crew
    - Multiple pilots make for a more secure flight deck

35 An Assessment of Reduced Crew and Single Pilot Operations in Commercial Transport Aircraft Operations, p. 12

SECTION 3: PUBLIC POLICY AND OPINION ON SINGLE-PILOT OPERATIONS

Single-pilot operations must meet the requirements and priorities of aviation policy before it can be implemented into aircraft. In the past, aviation policy has accommodated the transition from three- to two-person crew. This transition required the two-person crew to demonstrate the same safety levels as a three-person crew.[36] However, single-pilot operations are unable to meet the safety levels of a two-person crew; transitioning from three pilots to two reduced redundancy, while transitioning from two to one eliminates it. Standing public policy and opinions on aviation safety affirm that the current environment is unfavorable for single-pilot operations.

The FAA and the Federal Aviation Regulations (FARs) exist to oversee and govern safety measures, which exist to guarantee safety, which is the top priority for aviation. Although single-pilot operations may present potential economic benefits, single-pilot flying presents safety risks. Therefore, single-pilot operations do not align with the priorities of the FAA or federal regulations or FARs. Moreover, the FARs stipulate the need for a minimum of two pilots in the cockpit throughout. The need for two pilots is expressed in regulations relating to division of labor, vehicle design standards, duty limitations, and computer and on-demand operations.

Public opinion is also opposed to single-pilot operations. Polling data show that Americans feel uncomfortable with automated flying, even with less expensive airfare. The public also believes that the government should not put taxpayer money toward automating aircraft. Instead, the public ranks security, Air Traffic Control improvement, fuel efficiency, and faster air travel as higher priorities. Therefore, in considering the will of the people, legislation changes will likely address investments in these areas above single-pilot operations.

CURRENT REGULATION DOES NOT SUPPORT SINGLE-PILOT OPERATIONS

Current federal aviation regulations do not support the development and implementation of single-pilot operations. Air operators or aircraft must demonstrate adherence to the highest standards of safety to be certified to fly. The International Civil Aviation Organization (ICAO) considers safety to be "at the core of [its] fundamental Objectives."[37] The ICAO's Safety Management Manual defines aviation safety as "the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management."[38] Safety must be present at every step involved in the aviation process, from aircraft design to personnel licensing.

Expert reviews uphold that the acceptable risk level for aircraft certified under 14 CFR Part 121 (rules for scheduled operations) is zero.[39] Therefore, given the inherent risks of single-pilot operations, it would be prohibitively difficult for a commercial aircraft with only a single pilot to meet federal regulations for safety. Moreover, multiple sections of 14 CFR stipulate the need for two-pilot operations, including those related to division of labor, vehicle design standards, duty limitations, and computer and on-demand operations.

DIVISION OF LABOR ON THE FLIGHT DECK

Part 121 sets forth the rules for scheduled air carriers, whether regional or major airlines. Two sections under Part 121 specifically prescribe at least two pilots under many particular circumstances. For example, Part 121.385 prescribes the requirements for composition of flight crew in commercial operations and refers to the acceptable workload for one pilot.[40] In this ruling, one pilot is not deemed sufficient to fulfill the requirements for completing multiple tasks in the cockpit.[41] Instead, two pilots would be necessary to satisfy safety levels.[42] This section also states the minimum pilot crew for scheduled air carriers is two pilots, and the airline must designate one pilot as pilot-in-command and the other as second-in-command.[43]

Further, Part 121.543 references two-pilot operations in regard to flightcrew members at controls.[44] This ruling describes the proper qualifications of the second-in-command pilot acting as pilot-in-command when the original pilot-in-command is taking a rest period. Moreover, Section 543 lists the presence of another pilot as one of the conditions under which the pilot-in-command can leave the cockpit.[45]

36 Wilson, Jennifer, et.al., "Understanding Single Pilot Operations (SPO) Certification Requirements," Research Integration Incorporated, 2013.
37 "Safety," International Civil Aviation Organization, https://www.icao.int/safety/Pages/default.aspx
38 International Civil Aviation Organization, Document Doc 9859: Safety Management Manual. 3ed, 2013.
39 Understanding Single Pilot Operations (SPO) p.494
40 14 CFR Part 121.385.
41 Ibid.
42 Ibid.
43 Ibid.
44 14 CFR Part 121.543.
45 Ibid.

AIRCRAFT DESIGN STANDARDS

The regulations show that aircraft design standards currently require the presence of two pilots. 14 CFR Part 25 contains aircraft airworthiness standards for transport category aircraft. Part 25 references the need for multiple crewmembers, particularly in Sections 777 and 1357. The language in Part 25.777 denotes the presence of multiple crewmembers when it mentions that "the controls must be located and arranged, with respect to the pilots' seats, so that there is full and unrestricted movement of each control without interference from the cockpit structure . . . "[46] Meanwhile, Part 25.1457 provides requirements for cockpit voice recorders.[47] The section requires the installation of a cockpit-mounted microphone, located in the best position for recording voice communications originating at the first and second pilot stations.[48]

DUTY LIMITATIONS AND REST REQUIREMENTS

Part 117 prescribes flight and duty limitations and rest requirements for all flightcrew members and certificate holders conducting passenger operations.[49] Part 117.17 specifies flight duty periods for augmented flight crew. An augmented flight crew has more crewmembers than the minimum number normally required, allowing crewmembers to rotate. This ability to rotate allows crew to take necessary rest periods during some long-haul commercial flights. Single-pilot operations would eliminate augmented crew and the pilot's ability to rest during flights—which could potentially lead to incapacitation and flight risks. Reduced-crew operations would similarly compromise the minimum flight crew identified for safe long-haul operations.

COMMUTER AND ON-DEMAND OPERATIONS

Part 135 prescribes the rules for commuter and on-demand operations.[50] Because the operations certified under Part 135 are on-demand and scheduled charter flights, this part does not always require two pilots in the cockpit. However, some Part 135 operators still operate with two pilots in the cockpit in order to ensure passenger safety. The requirements depend on the size of the aircraft and number of people on board. The requirements also depend on whether the flight would be operated under instrument flight rules (IFR) or visual flight rules (VFR). Under IFR, the pilot must rely on instruments alone to make safe judgments, which necessitates a high level of situational awareness. The pilot must also have a balanced workload to prevent disrupting communications with Air Traffic Control. Consequently, the use of single-pilot operations—which studies have shown increases workload—for IFR would require extensive demonstration of safety to comply with regulation. Proper adaptability of automated systems when dealing with spatial disorientation, weather conditions, workload, and the overall level of precision needed for instrument flying would all have to be substantially verified.[51]

THE FEDERAL AVIATION ADMINISTRATION'S POLICIES DISCOURAGE SINGLE-PILOT OPERATIONS

FAA guidance material illuminates its wariness to support single-pilot operations. FAA Advisory Circular 25.1523 offers guidance for complying with the requirements of 14 CFR 25.1523, which pertains to airworthiness certification requirements for minimum flight crew on transport category airplanes.[52] In it, the FAA offers clear considerations about the risks involved in the certification of single-pilot operations. 14 CFR 25.1523 states that the minimum flight crew must be established so that it is sufficient for safe operation, considering the workload of individual crewmembers and accessibility and ease of operation of necessary controls by the appropriate crewmember.[53] While the language does not ban certification of single-piloted transport category airplanes, in the Advisory Circular the FAA does mention that the agency has been reluctant to approve single-pilot operations.[54]

Pilot incapacitation is one reason for this reluctance. Data available up to the signing of AC 25.1523 exposed a number of pilot incapacitations and fatalities relative to Part 135 and 121 operations.[55] In the Advisory Circular, the FAA explains that there were 32 occurrences of pilot incapacitation in Part 135 operations resulting in 32 fatalities, all of which the National Transportation Safety Board (NTSB) attributed to single-pilot operations.[56] Meanwhile, under Part 121 operations—which require two pilots in the cockpit—incidences of incapacitation never led to a single fatality. The FAA makes this observation, stating, "relative to Part 121 operations over the same time period, there were 51 pilot incapacitation occurrences which resulted in a normal recovery of the aircraft by the other pilot."[57]

46 14 CFR Part 25.777.
47 14 CFR Part 25.1457.
48 Ibid.
49 14 CFR Part 117.1.
50 14 CFR Part 135.
51 Wilson, Jennifer, et.al., Supra note 13.
52 Federal Aviation Administration, Advisory Circular 25.1523. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25_1523-1.pdf
53 14 CFR Part 25.1523.
54 Ibid.
55 Federal Aviation Administration, Supra note 4.
56 Ibid.
57 Ibid.

More recent data reveals a similar situation. Reports from the Australian Transport Safety Bureau revealed that from 2010 to 2015 there were 23 pilot incapacitation occurrences per year on average, 75 percent of them happening in high-capacity air transport operations.[58] The reports further revealed that with multipilot crews, incapacitation had minimal effect on the flight.[59] Meanwhile, with single-pilot general aviation operations, incapacitation often meant return to the departure aerodrome or even collision with terrain.[60]

In addition to concerns about pilot incapacitation, the FAA also explicitly opposes the use of UAS for carrying passengers. Order 8130.34D on Airworthiness Certification of Unmanned Aircraft Systems and Optionally Piloted Aircraft provides a sample operating limitations for UAS form. In this form, the FAA prohibits the operation of UAS to carry persons or property for compensation or hire. The prohibition is applicable to all flights in unmanned aircraft in the NAS. This prohibition further indicates the FAA's apprehension regarding the use of remote piloting for commercial aircraft.

PUBLIC OPINION OPPOSES SINGLE-PILOT OPERATIONS

Public opinion must be taken into consideration when creating or changing legislation, since, ultimately, legislation should be an expression of the will of the people. Currently, the public is far from convinced that single pilot-operations should happen at all. Moreover, the public is not in favor of taxpayer money being spent on studies that support the economic development of airlines. Polling results show that other segments of air travel are currently far more important. Polls also show that studies in support of automation should be conducted by private institutions interested in technology maturity for automated flights. The public considers air travel the safest means of transportation, which is in part made possible by having two pilots in commercial airplanes.

Surveys reveal that the public is not supportive of government funding going toward studies on automation. An overwhelming 75 percent of Americans believe that the airlines should be the ones paying for single-pilot research, rather than the government. Instead, Americans believe that taxpayer money should be invested in improving other segments or processes in aviation (Figure 6). Sixty-one percent of Americans believe that security, namely screening processes, is the most important area of improvement to focus on. The second most

58 Ibid.
59 Ibid.
60 Ibid.

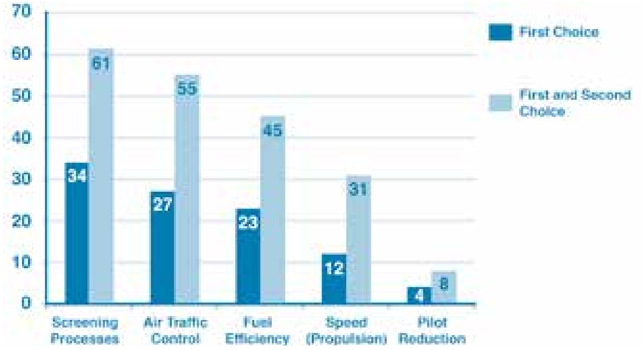

Figure 6. Public opinion on where the government should prioritize investment. Source: Ipsos

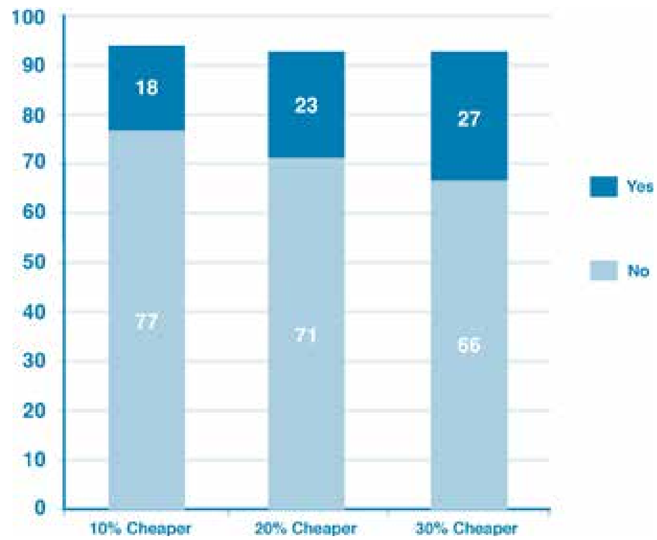

Figure 7. Percent of those polled who replied to the question "Would you fly on a pilotless plane if the airfare was 10, 20, 30% cheaper?" Source: Ipsos

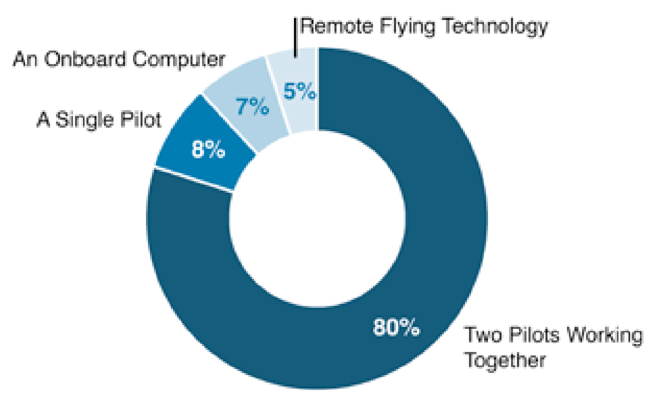

Figure 8. Public opinion on the best defense against emergency in flight. Source: Ipsos

important area is Air Traffic Control, followed by fuel efficiency and faster air travel. In contrast, only 8 percent of those polled believe that the government should invest in technologies that would eventually lead to reduction of the number of pilots in the cockpit.

The survey also found that 85 percent of Americans would be uncomfortable on a flight without a pilot. In addition, polling shows that the public is not willing to fly with an airline whose planes were automated even if the airfare was less expensive. Sixty-six percent of Americans would not fly on a pilotless airplane, even if the airfare was 30 percent cheaper (Figure 7).

An overwhelming number of Americans believe that two pilots in the cockpit is the best option when faced with urgent problems during flight (Figure 8). This opinion aligns with expert opinion regarding the safety advantages of having two pilots in the cockpit. Sharing duties, such as running checklists, is one example of how safety is enhanced by not flying alone.[61] Distractions can cause a pilot to lose his or her place, but with two pilots, a more effective response system can be employed.[62] With two pilots on board the aircraft, one person can identify the checklist task to be performed, while the other person performs the task.[63] In addition, studies have concluded that a single pilot communicating with a remote pilot during emergencies would entail an enormous workload for one pilot.[64]

SUMMARY: PUBLIC POLICY AND OPINION ON SINGLE-PILOT OPERATIONS

- Current law is written with the understanding that it requires at least two pilots to fly a large plane safely
    - Aircraft design requires two pilots
    - Long-haul flights may require more flight crews, rotating to keep two active, alert pilots flying
    - The FAA forbids autonomous aircraft from flying passengers or cargo for compensation
- Changing policy in a way that compromises aviation safety will be avoided
- Over three-quarters oppose legislation to fund research in single-pilot operations
- The public does not believe that autonomous flying is currently safe or worth investing in
    - 96 percent polled prioritized other aviation R&D over single-pilot operations
    - 80 percent believe that two pilots are the best flight crew in an emergency

61 Burnside, Joseph E., "The Two-Pilot Problem," Aviation Safety Magazine, February 2018. http://www.aviationsafetymagazine.com/issues/38_2/features/The-Two-Pilot-Problem_11459-1.html.
62 Ibid.
63 Ibid.
64 Gore, Brian F. and Wolter, Cynthia A., "A Validated Task Analysis of the Single Pilot Operations Concept," 2015.

SECTION 4: OBSTACLES TO SINGLE-PILOT OPERATIONS

At first glance, it is easy for technology and autonomy advocates to seemingly prove that the infrastructure and climate for single-pilot operations appear to be already in place. However, in reality, many obstacles must be overcome for single-pilot operations to be implemented. First, further technology development is needed. While some labor under the misconception that the technology necessary to implement reduced-crew and single-pilot operations is already available,[65] in fact significant advances in automation, communications, and sensor technologies will be required to make the transition without compromising safety. Some of these technologies are expected to be ready within the next 10 years or so, but others, including high-level artificial intelligence, are decades away.

Meanwhile, the FAA is occupied by a far more pressing priority: modernizing the enormously complex U.S. NAS to accommodate anticipated increases in commercial airline traffic as well as the introduction of new vehicles, including unpiloted aircraft systems. This is part of a global trend; ICAO is working to create new international guidance for aviation operations. Driving this new guidance, which incorporates new technologies and improved practices, is the goal of increasing the speed and efficiency of airline operations globally without compromising safety.

Reduced-crew and single-pilot operations also introduce new cybersecurity concerns that would need to be addressed. Polling data also indicate that the flying public is not comfortable with the idea of single-pilot operations.[66] Finally, the economic case for reduced-crew and single-pilot operations is not as clear-cut as it first appears. While reducing the number of pilots in the cockpit might result in some reduction in salaries, benefits, and other expenses, that conclusion is not foregone. At a minimum, these savings would be significantly offset by the costs associated with the implementation of reduced-crew operations and ensuring the appropriate staffing and compensation of ground-based pilots. Shortcomings in the economic case could weaken the incentive to pursue reduced or single-pilot operations.

TECHNOLOGICAL HURDLES REMAIN

Automation technology has advanced significantly over the years and is an important tool pilots employ to keep flying safe. Under the NextGen program, the FAA and NASA are working on a number of new automation technologies (Figure 9), many of which are expected to come online within the next 10 years. This class of new technologies includes the Automated Emergency Descent System, which automatically lowers an aircraft's altitude in the event of a cabin depressurization;[67] Automatic Dependent Surveillance-Broadcast, which automatically broadcasts an aircraft's position, altitude, and other navigation information every second;[68] and En Route Automation Modernization, which covers areas such as radar flight data processing, communications support, and the transition from ground- to satellite-based surveillance.[69] Other capabilities, including the ability to ingest, analyze, and integrate the multitude of data streams coming into the cockpit to produce actionable information for pilots and auto-pilot systems alike, are expected to be available in the next five to 10 years.[70]

While considered necessary for reduced-crew or single-pilot operations, these emerging capabilities will not, by themselves, preserve the level of safety provided by two pilots in the cockpit. Numerous major technological hurdles must be cleared before reduced-crew and single-pilot operations could be adopted without adversely impacting airline safety. Artificial general intelligence and machine-pilot interaction and monitoring in particular are two challenges that must be addressed to achieve the levels of safety provided by two human pilots. Moreover, even if these technology challenges were overcome, increased dependency on automation may negatively impact pilot performance and trust. Such a negative user experience and perception could stymie technology communication, presenting an obstacle to technology development.

ARTIFICIAL GENERAL INTELLIGENCE

Perhaps the biggest technological hurdle to safe reduced-crew and single-pilot operations is an advanced form of artificial intelligence called artificial general intelligence, or AGI. Unlike existing or emerging forms of artificial intelligence that can handle specialized individual tasks, AGI, as envisioned, will effectively replicate human judgment across a broad spectrum of sensing, analytical, decision-making, and implementation functions (Figure 10). Such a capability might someday safely replicate the redundancy in the cockpit provided by the second pilot. However,

65 Flying solo—How far are we down the path towards pilotless planes?, p. 3. https://neo.ubs.com/shared/d1ssGmLAVeEB/
66 ALPA polling data
67 https://www.airbus.com/newsroom/news/en/2018/03/airbus-developed-a350-xwb-safety-feature-enables-automated-emerg.html
68 https://www.ainonline.com/sites/default/files/pdf/2015-01-avionics-nextgen.pdf
69 https://nextgen.erau.edu/research/
70 http://aviationweek.com/awin/connectivity-human-factors-drive-next-gen-cockpit

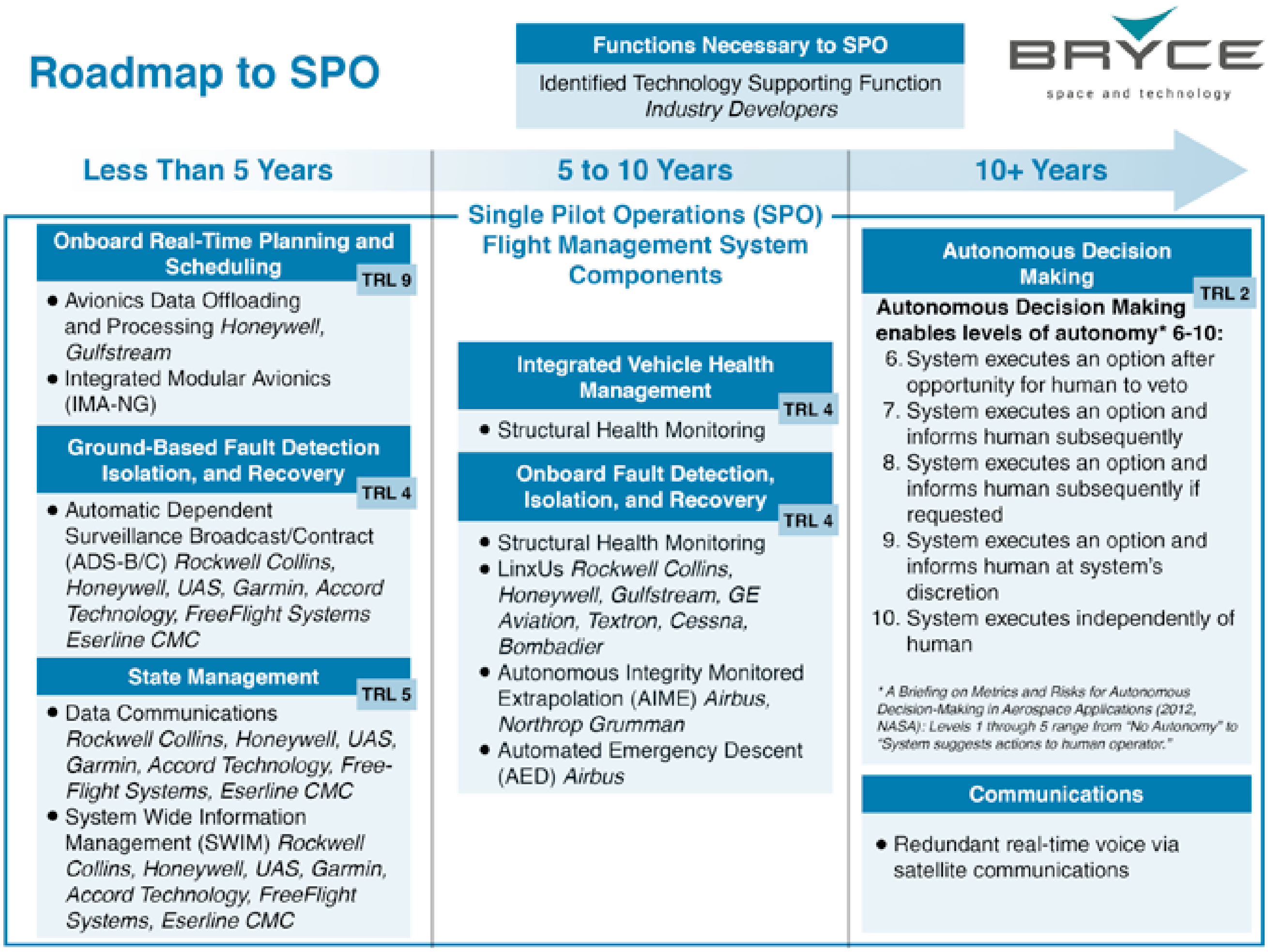

Figure 9. A road map of the technologies necessary to develop single-pilot operation
Image credit: Bryce Space and Technology

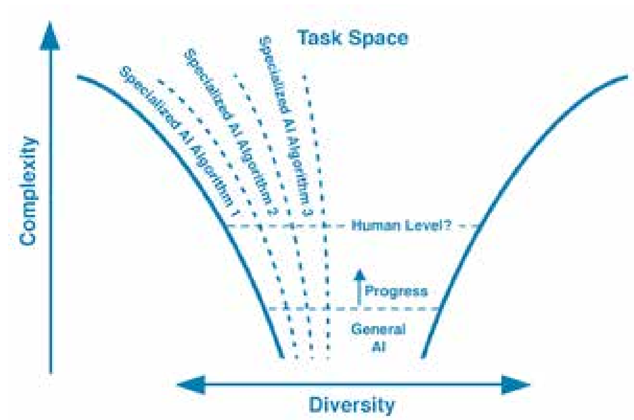

Figure 10. A depiction of the difference between narrow/specific AI and general AI
Image credit: Arthur Franz, 2015, *Toward tractable universal induction through recursive program learning*

this technology is still a theoretical construct. One prominent expert in the field says true AGI is at least two decades away.[71]

MACHINE–PILOT INTERACTION AND MONITORING

Short of being able to act, sense, and react like a human pilot, artificial intelligence will have to perform at least two key functions to enable single-pilot operations, according to a 2014 NASA paper. These two functions are interaction and task exchange with the human pilot (captain) and monitoring of the health and cognition of the captain.[72]

Interaction includes tasks such as the machine informing the captain what it is doing, confirming important parameters such as altitude settings, and recalling information and instructions provided by air traffic control. Interaction is complicated by the fact that different tasks might be better suited to the captain than the machine—and vice versa—at any given time. The ability to reallocate tasks between the two, especially during off-nominal circumstances, is needed. If

71 Forbes, https://www.forbes.com/sites/forbestechcouncil/2018/06/18/artificial-general-intelligence-breakthroughs-to-watch-out-for-in-2018/#6d9555586f83
72 Conceptual framework for single pilot operations, p. 6–7. https://www.aviationsystemsdivision.arc.nasa.gov/publications/2014/HCIAero2014_Bilimoria.pdf

the captain becomes overloaded with tasks, he or she must be able to offload to automation with full confidence. If the machine must offload for similar reasons, it must be able to provide a reason and other situational awareness information ahead of time. This complex interaction is well beyond the capability of current technology.

The ability to remotely monitor pilot health and cognition is also required if ground controllers are to be given responsibility for taking over an aircraft whose captain has become incapacitated during flight. The systems needed to do this also must catch mistakes made by the captain as an onboard first officer would. While some aspects of a pilot's condition can be monitored by automation, the 2014 NASA paper stated that it is unlikely the technology will advance to the required level in the time frame that some envision for single-pilot operations.

Another NASA paper published in September 2017 said that while many incapacitating conditions have easily detectable indicators, gauging a pilot's mental state is a far more challenging proposition:

"Detection of the pilot state is a non-trivial problem for which no 100% reliable solution currently exists. While death can be reliably detected, conditions that impair a pilot's judgment [e.g. hypoxia] can be more difficult to detect. Determination of pilot impairment will likely require the development of new onboard automation to assess pilot state, but also joint assessment and confirmation from the ground operators based on their interactions with the onboard pilot."[73]

Computers and machines have indeed come a long way over the last 50 years, but the ability to closely read, interact with, and appropriately swap roles with humans in a highly dynamic environment is still well beyond them. This is the stuff of science fiction, not the state of current technology.

PILOT EXPERIENCE AND PERCEPTION

In addition to whether the level of automation required for single-pilot operations is technologically feasible, concerns remain about relying on such technology. Increased dependency on automation in aviation may not be advisable:

"A key requirement for [single-pilot operations] implementation is advanced automation that provides onboard support functions at a level well beyond what is currently available in modern commercial aircraft. While it may be tempting to simply automate as many of the current pilot functions as possible, distancing the captain from the flight/mission could erode situation awareness [SA] and cognitive readiness."[74]

In other words, over-dependence on automation could take the pilot out of the loop, placing the aircraft at risk in case of emergency or other changing circumstances.

Securing pilot trust is another obstacle. Robotic systems are prone to failures that can undermine user trust in these systems, eroding their usefulness and benefits. Further factors, such as obscured communications and an unequal degree of dependence between the human and the machine impede trust further. While trust is necessary for humans to take advantage of autonomy, putting trust in unreliable autonomy, particularly in an aviation context, is dangerous.[75] Furthermore, a lack of trust and perceived safety could inhibit pilot acceptance of automated systems, which presents a barrier to their development.

UPGRADING THE NAS IS A PRESSING PRIORITY

Currently, the FAA manages roughly 43,000 airline passenger flights per day, delays to which cost more than $26 billion annually to the U.S. economy.[76] Approximately half of these delays are attributable to issues with the NAS.[77] To address these issues, the FAA, with support from NASA, is in the midst of a long-delayed, massive NAS modernization effort. NextGen features dramatic improvements in satellite-based aircraft tracking

73 Enhanced Ground Support: Lessons from Work on Reduced Crew Operations, p. 7
74 Conceptual framework for single pilot operations, p. 6–7
75 A briefing on metrics and risks for autonomous decision-making in aerospace applications, p. 8

76 FAA's Air Traffic By The Numbers, June 2019
77 Airlines for America, "U.S. Airline Industry Review: Allocating Capital to Benefit Customers and Investors, p. 60 http://airlines.org/wp-content/uploads/2017/03/A4A-Industry-Review-8.pdf

and surveillance, navigation, automation, air traffic flow management, communications, information management, and weather monitoring. The FAA describes NextGen, whose major elements are supposed to be in place by 2025, as one of the most ambitious infrastructure projects in history,[78] with an estimated cost in the tens of billions of dollars.

New entrants in the NAS are heightening the need for this upgrade. In addition to the projected growth in traditional aviation—including transport, passenger, and general aviation—the NextGen program must address new vehicles and services that are entering U.S. airspace. UAS and commercial space and reentry vehicles are already active, while electric vertical takeoff and landing vehicles for urban passenger transport are believed to be on the horizon.[79] This increase in vehicles impacts safety: In 2016 alone two near misses involving airliners and drones were officially recorded, both involving Air France flights making their descent.[80] In 2017 there were two documented collisions between drones and aircraft occupied by people in North America.

In addition to the safety issues, these new entrants are likely to exacerbate the delays and costs driven by the overstressed NAS. In a paper describing its efforts to accommodate the new entrants, NASA offered a hint of the NAS transformation that needs to take place:

"To address these challenges, the National Airspace System needs to undergo a transformation to a more scalable, flexible, user-focused system that addresses safety and security requirements and resiliency for current and new users."[81]

Clearly, updating the NAS is a necessary and urgent endeavor for both safety and economic reasons. This urgency has compelled both FAA and NASA to commit their time and resources to this effort, thereby reducing their ability to pursue a nonessential undertaking such as reduced-crew or single-pilot operations.

Upgrading air traffic management in the United States through NextGen is a national effort within a worldwide plan led by the ICAO. ICAO's Global Air Navigation Plan (GANP) addresses international objectives regarding the management of rapid traffic growth. The GANP sets forth a strategic methodology which leverages existing technologies and prepares for future developments, based on state and industry objectives.[82] The GANP in turn characterizes aviation system block upgrades, designed to be used by the regions, subregions, and ICAO member states when they wish to adopt individual modules of the comprehensive airspace plan. There are multiple modules, which are grouped within the major themes of greener airports, globally interoperable systems and data, optimum capacity and flexible flights, and efficient flight paths.[83]

ICAO's concern related to air traffic management comes from the fact that "global air traffic has doubled in size once every 15 years since 1977 and will continue to do so."[84] In alignment with the GANP, air navigation improvement programs are being undertaken not only by the United States through NextGen, but by multiple other ICAO member states. Some of the most notable examples are the SESAR in Europe; CARATS in Japan; and SIRIUS in Brazil.[85]

CYBERSECURITY ISSUES PRESENT ADDITIONAL CHALLENGES

Reduced-crew and single-pilot operations introduce a cybersecurity issue due to the requirement that ground-based pilots be able to assume control of the aircraft in the case of pilot incapacitation or other emergency. Because hostile actors have attacked radio communications to aircraft in the past, the possibility of exploiting weaknesses in communications links to disrupt or even commandeer aircraft in flight must be addressed (Figure 11). In order to prevent reduced-crew operations from opening up powerful new avenues of cyberattack on aircraft, obstructive countermeasures must be taken.

The only viable way to address this threat is to encrypt communications between the aircraft and ground. Two factors complicate encryption. First, countries often have restrictions on the

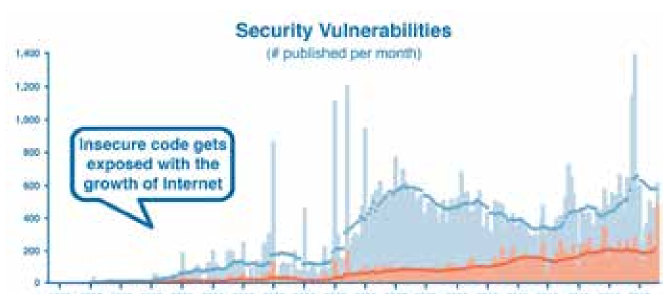

Figure 11. The challenge of maintain a secure cyberspace
Image credit: Dr. Stefan Frei, 2015, *Cyber Threats in Aviation*

78 FAA, https://www.faa.gov/nextgen/what_is_nextgen/
79 Overview of NASA's Air Traffic Management eXploration (ATM-X) Project, p. 1
80 ALPA data
81 Overview of NASA's Air Traffic Management eXploration (ATM-X) Project, p. 1

82 2016-2030 Global Air Navigation Plan. Fifth Edition. 2016
83 ATM: A Vision of the Future. 2012
84 ICAO Global Air Navigation Plan. Document 9750-AN/963. Fifth Edition - 2016.
85 2016–2030 Global Air Navigation Plan. Fifth Edition. 2016

use of encryption in their airspace, with some barring it entirely. Second, encryption introduces transmission delays that can last for seconds, which could prove problematic in an emergency when real-time responses are critical.[86]

PUBLIC OPPOSITION PRESENTS POLITICAL BARRIER

Polling data indicate that Americans are not comfortable with reduced or single-pilot operations. According to an Air Line Pilots Association, Int'l poll, 80 percent of Americans believe that two pilots in the cockpit is the best way to troubleshoot issues and respond to unforeseen events. Moreover, 96 percent of respondents see investments to enable reduced-crew or single-pilot operations as less important than other aviation-related investments (Figure 12).[87] The unpopularity of reduced or single-crew operations presents a political barrier, as policymakers will hesitate to make regulation changes that the public deems unsound.

A DEFICIENT ECONOMIC CASE MAY WEAKEN INCENTIVE

The primary reason behind the push by airlines and air transport operators to reduce cockpit crew sizes is simple: fewer pilots means lower payroll expenses. According to an analysis performed by the Air Line Pilots Association and Bryce Space and Technology Group, single-pilot operations could save U.S. airlines and air transport companies some $8.3 billion per year in salaries, personnel expenses, and benefits. This total represents 5 percent

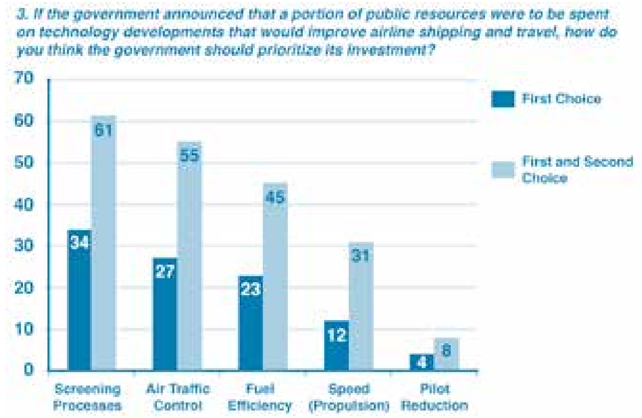

Figure 12. Reducing pilots in the cockpit is undesirable to the public
Source: Ipsos.

of the $168 billion in nonfuel annual expenses incurred by these companies.[88]

However, this estimate does not take into account the considerable costs of implementing reduced-crew and single-pilot operations, which would have to be borne by the companies and, to some extent, the U.S. taxpayer. These include the cost of outfitting or retrofitting aircraft fleets with the necessary automation systems and sensors, the required ground infrastructure, the salaries for additional ground-based pilots to support the airborne pilots in the cockpit, and the costs of certifying the new systems. When these costs are factored into the equation, the economic case for reduced-crew and single-pilot operations becomes less compelling, especially since pilot costs are not the majority of operating expenses for the major airlines (Figure 13). Without an

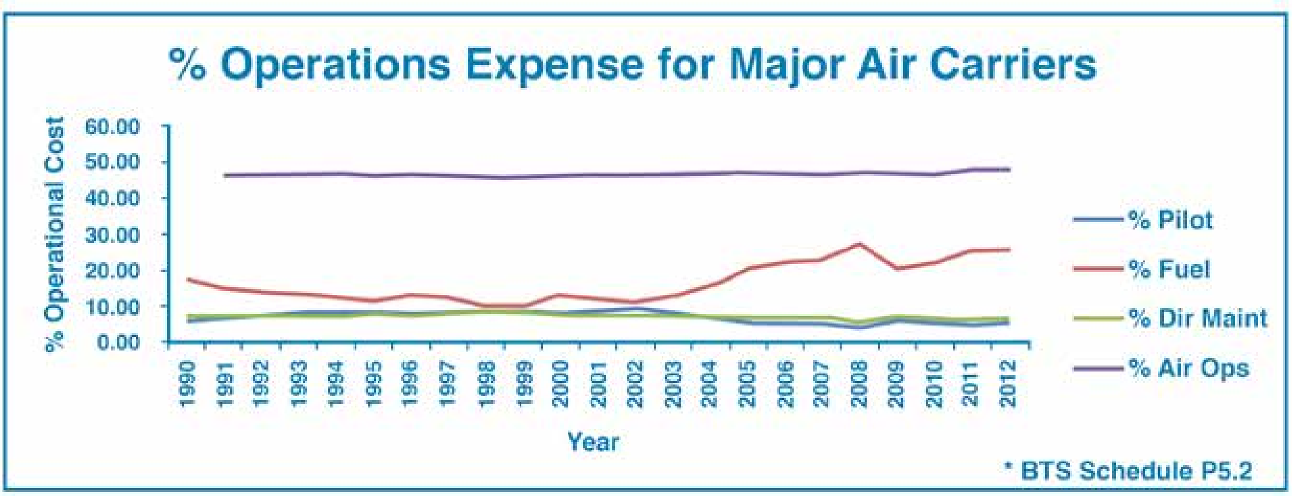

Figure 13. Pilots are a minor cost faced by airlines
Image credit: MITRE, 2014, *Design of a Single Pilot Cockpit for Airline Operations*

86 Cyber Safety and Security for Reduced Crew Operations (RCO), p. 8–10
87 ALPA polling data
88 ALPA and Bryce Space and Technology research and analysis

airtight economic case, the incentive to pursue reduced or single-pilot operations weakens and potentially even stalls.

It is worth noting that the potential labor cost savings are based solely on the costs incurred in the cockpit. There would be a need for ground-based pilots to support the pilots in the cockpit. While there has been significant speculation about the potential efficiencies of ground-based pilots, the Air Line Pilots Association has not found any documentation that definitively concludes that a ground-based pilot could safely support multiple aircraft. By relocating a pilot that is currently in the cockpit to the ground, then the only cost savings would come from reduced travel costs (estimated at about $700 million per year or less than 0.5 percent of total nonfuel expenses).

SUMMARY: OBSTACLES TO SINGLE-PILOT OPERATIONS

- Current technology can't compensate for removing a pilot from the cockpit
  - The greatest challenge is autonomous decision-making
  - Specialized artificial intelligence is well-developed, but it can only respond to specific cases
  - General artificial intelligence capable of judgement is still theoretical, and may be decades away
- The current data infrastructure is not designed to support the traffic needed for autonomous or remote operation
- New systems must be developed to let a pilot replacement interact with cabin crew and passengers
- Unless single-pilot operations are universal, an early adopter would lose business from safety-conscious customers
- The benefits to single-pilot operations are economic, but the savings are small and the costs are significant
  - Removing one of the flight crew would only cut about 4 percent of the total cost of a passenger flight
  - This would compete against the costs to develop new technology, new infrastructure, and new training as well as testing and certifying to safety standards, and ground-based pilots.

SECTION 5: HIGHER-PRIORITY FEDERAL INVESTMENTS AS COMPARED TO REDUCED-CREW AND SINGLE-PILOT OPERATIONS

Commercial aviation tends to grow with the economy. The FAA projects revenue passenger miles, a benchmark for aviation growth, to grow by 2.4 percent per year through 2037, with higher growth internationally.[89] Given this growth, efforts are constantly under way to optimize efficiency, safety, and cost. Some promote investment in reduced-crew or single-pilot operations to reduce the cost of flying and also improve efficiency and safety. However, other pursuits are both more pressing and yield greater economical and societal benefits. In discussions with Congress, FAA, NASA, and numerous stakeholders in the aviation community, they expressed their highest priorities for improving aviation. NASA was noted as saying:

". . . the aviation community's highest priorities for research lie in safety, highly efficient aircraft, the evolution of the Next Generation Air Transportation System [NextGen], UAS access to the National Airspace System [NAS]. More recently, community focus on on-demand aviation systems has increased as UAS have shown the potential for more profound changes to the aviation system."[90]

As the stakeholders stated, addressing congestion of and access to the U.S. NAS is a top priority. The NAS is heavily stressed by surging demand for air transportation services and the entry of new vehicles into the airspace, such as UAS. In response, the FAA and NASA are in the midst of a multibillion-dollar overhaul of the nation's air traffic management system aimed at increasing efficiency, safety, capacity, predictability, and resiliency. The effort, NextGen, is both leveraging and driving technological advances in automation, data processing, communications, surveillance, navigation, and other areas.

In addition to that endeavor, NASA is investing in technologies with the potential to make aircraft smarter, safer, more fuel efficient, faster, and quieter. These activities will make commercial aviation more profitable while reducing its environmental footprint in the years ahead. Given the urgency of NextGen, coupled with future investment opportunities that offer tangible economic and societal benefits, spending aimed at reducing the number of pilots in the cockpit of commercial aircraft should rank near the bottom of the U.S. government's priority list.

EFFORTS TO REBUILD THE NAS

The need to rebuild the NAS cannot be overstated: Currently, the FAA manages roughly 44,000 flights per day, delays to which cost more than $28 billion annually to the U.S. economy.[91] Half of these delays are attributable to the NAS.[92] These numbers will only increase over time: The International Air Transportation Association, for example, has estimated that the number of air passengers worldwide will double between now and 2034, to 7 billion.[93] New entrant operators are exacerbating these issues, with the introduction of UAS and commercial space and reentry vehicles.

THE NEXTGEN PROGRAM

To address the challenges facing the NAS, the FAA and NASA are leading the NextGen program. NextGen is expected to cost more than $20 billion and to be in place by 2025.[94] The FAA has already deployed much of the foundational infrastructure for NextGen. The infrastructure components include the Traffic Flow Management System, Time Based Flow Management, and En Route Automation Modernization, all focused on efficient air traffic routing and data handling. The En Route Automation Modernization program is among several efforts that support the transition from a ground- to a satellite-based air traffic management system, which will improve the resiliency of the NAS.

On top of that foundational layer, the FAA is implementing Automatic Dependent Surveillance-Broadcast, System Wide Information Management, and Performance Based Navigation. These technologies will enable more precise and flexible aircraft route planning, saving both time and fuel. Next on the agenda are the NAS Voice System, the NextGen Weather Processor, and Common Support Services-Weather, which are expected to be in place starting in 2020. These systems will enhance NAS efficiency by showing where aircraft will be at critical moments in flight, as opposed to where they are at any given moment.[95]

During the years 2020–2025, the FAA expects to focus on realizing and consolidating the benefits of the NextGen infrastructure. Establishing the infrastructure will require upgrades to the aircraft

89 FAA Aerospace Forecast, Fiscal Years 2018–2038, p. 56
90 NASA Aeronautics: Strategic Implementation Plan, 2017 Update, p. 21
91 FAA's Air Traffic By The Numbers, June 2019
92 Airlines for America, "U.S. Airline Industry Review: Allocating Capital to Benefit Customers and Investors, p. 60 http://airlines.org/wp-content/uploads/2017/03/A4A-Industry-Review.pdf
93 International Air Transport Association, "Total Passengers Set to Double to 7 Billion by 2034," Press Release No. 55. 26 November 2015
94 FAA, https://www.faa.gov/nextgen/faqs/
95 FAA, https://www.faa.gov/nextgen/where_we_are_now/

The goal of System Wide Information Management as depicted by FAA

that utilize the NAS. While many of these initial NextGen capabilities are considered enabling for reduced-crew and single-pilot operations, the FAA currently has no major plans or research programs aimed at that outcome.[96]

ACCOMMODATING NEW ENTRANTS TO THE NAS

Both the FAA and NASA have dedicated efforts to accommodating the new entrants into the NAS. Given the emergence of UAS applications in recent years, integrating civilian UAS into the NAS is a particular priority. The FAA has a road map for this effort, which envisions UAS flying side by side with piloted aircraft using many of the same air traffic management systems and procedures.[97] While initial rules and procedures governing small UAS operations in the NAS are already in place, a more detailed regulatory framework is still in progress. FAA hopes to have this framework in place by 2020.

Meanwhile, NASA's Air Traffic Management–eXploration (ATM-X) program is focused on accommodating the introduction of new vehicles including UAS, commercial space and reentry vehicles, and air taxis. UAS and commercial space/reentry vehicles are operating today, while a number of major aerospace companies are exploring air taxis—vertical takeoff and landing craft providing unscheduled, or on-demand, services.[98] The ATM-X program is also pursuing technologies that will allow traditional large commercial aircraft to fly user-preferred routes—with a focus on the congested northeast corridor—more predictably, saving time and fuel.[99,100] In addition to addressing immediate and near-term issues facing the NAS, this effort also benefits traditional commercial air operators.

TECHNOLOGY DEVELOPMENT MEETING AVIATION PRIORITIES

NASA's Aeronautics Research Mission Directorate (ARMD) invests in commercially promising technologies that are beyond the financial horizon of the private sector, with an emphasis on those offering societal benefits, including safety assurance and environmental protection. NASA is investigating a number of new technologies that promise high future payoffs for aviation stakeholders, including airliners and air transport operators, passengers, and the general public. These efforts are, broadly speaking, aimed at making air travel faster, safer, and more enjoyable while reducing its cost and environmental impact.

ARMD PRIORITIES

NASA ARMD's priorities are captured in "NASA Aeronautics: Strategic Implementation Plan, 2017 Update," which is the latest iteration of what the agency characterizes as a living document. As outlined in the plan, investment priorities are influenced by three "mega drivers": global growth in demand for high-speed mobility, affordability and sustainability, and technology convergence. NASA's response to these drivers is organized into six strategic thrusts in aeronautical research:

A sampling of UAS demonstrators
Image credit: U.S. Navy

96 Bryce research
97 Integration of civil unmanned aircraft systems (UAS) in the National Airspace System (NAS) roadmap, p. 4.
98 Barrons, https://www.barrons.com/articles/air-taxis-could-be-the-next-big-thing-in-aviation-1532105388
99 NASA, https://www.nasa.gov/aeroresearch/programs/aosp/atm-x/atm-x-project-description
100 Overview of NASA's Air Traffic Management-eXploration (ATM-X) project, p. 4

NASA Aeronautics Strategic Implementation Plan logo

safe and efficient growth in global operations, innovation in commercial supersonic aircraft, ultra-efficient commercial vehicles, transition to alternative thrust and energy, real-time system-wide safety assurance, and assured autonomy for aviation transformation.[101]

Although the automation thrust is relevant to reduced-crew and single-pilot operations, it is not connected to those applications in the strategic plan. NASA's near-term efforts—2015 to 2025—are focused on limited, or bounded, and "predominately human supervised," autonomy, with applications to small-scale systems, including UAS. Research for the mid-term (2025–2035) and far term (beyond 2035) is geared toward increasingly larger-scale, adaptive autonomy, complemented by advanced sensors and networks. The road maps do not mention the potential for autonomous systems to replace humans in the cockpit. In fact, the terms "reduced-crew operations" and "single-pilot operations" are nowhere to be found in ARMD's strategic planning document.

LONGER-TERM, HIGH-PAYOFF RESEARCH

NASA has a number of specific long-term research and development efforts under way that could lead to safer, more fuel efficient, faster, quieter, and more environmentally friendly aircraft. Fuel efficiency is a great example of how NASA's research could lead to substantial economic gains for the aviation industry. Fuel accounted for only 10 percent of airlines' costs in 1995, but that percentage jumped to 30 by 2011, according to NASA. Although jet fuel prices have declined substantially since the 2011–2013 peak, they are expected to continue rising over the long term, impacting the affordability of air transportation and the sustainability of current commercial aviation operating models.[102] Consequently, research and development to improve fuel efficiency is deeply needed—research that NASA is providing, as described below.

The following are just some of the NASA research and development efforts with greater potential payoff than reduced-crew or single-pilot operations:

- NASA's X-59 Quiet Supersonic Technology experimental aircraft, which will fly faster than the speed of sound but without the accompanying sonic boom, potentially opening a new market for supersonic travel over land.
- Hybrid wing-body aircraft, which have the potential to dramatically reduce fuel costs for large cargo aircraft. This technology could lead to aircraft that are 70 percent more fuel efficient than the Boeing-built C-17 Globemaster military cargo transport.
- Air-breathing lithium-ion batteries that theoretically could offer the highest energy storage capacity of any battery technology. These batteries could pave the way for the development of electrically powered aircraft.
- The X-57 all-electric aircraft, whose ultimate goal is a five-fold reduction in energy consumption during the high-speed cruise phase of flight compared to traditional propulsion.
- NASA's Ultra-High Bypass Advanced Nacelle Technologies Flight Demonstration, a cooperative effort with an industry team led by jet engine maker Pratt & Whitney to design, develop, and demonstrate engine technologies that improve aerodynamic performance while reducing weight and noise.
- Truss-braced wings that have the potential to provide an 8 percent savings in fuel burn over aircraft with nonbraced wings.
- Single-aisle turbo-electric aircraft with aft boundary layer propulsion, an innovative propulsion concept compatible with current airliner configurations that will save fuel over current jet engine technology.

101 NASA Aeronautics: Strategic Implementation Plan, 2017 Update, p. 5
102 Ibid., p. 19

Research that could lead to safer, more efficient aviation operations is not limited to NASA and the FAA. The U.S. Air Force Research Laboratory, for example, has joined NASA in funding hybrid wing-body research projects and also is working on advanced structural health monitoring and healing systems. A number of initiatives are also under way in Europe, including the Remote Tower Service project, an effort by Saab and the Swedish Civil Aviation Administration to allow air traffic control information to be provided by unmanned towers.

Some of these and other efforts are many years away from fruition, but all respond directly to the stated needs of the aviation industry and government assessments of the public good. In recent polling data, the public also expressed a clear preference for spending government dollars on the types of technologies described above versus those that would help eliminate pilots from the cockpit.[103] Moreover, funding for aeronautics research is scarce relative to the growth in aviation volume and complexity currently taking place—a growth expected to accelerate over time. Therefore, now is not the time to expend resources on reducing the size of cockpit crews, which already ensure safety and will continue to do so in the years ahead.

X-47B hybrid wing-body prototype
Image credit: www.nasa.gov

Artist's rendering of X-57
Image credit: NASA Aeronautics: Strategic Implementation Plan, 2017

SUMMARY: HIGHER-PRIORITY FEDERAL INVESTMENTS AS COMPARED TO REDUCED-CREW AND SINGLE-PILOT OPERATIONS

- Current FAA and NASA priorities place other key investments over research into reduced crew
  - Integration of new vehicles such as drones and air taxis into the national airspace is key
  - New data management infrastructure will support pilot and ATC operations
  - NextGen overhaul of national airspace is a major and overdue undertaking, and implementing reduced crew would disrupt it
- Proposed legislation that mandates investment in studies to enable reduced crew risks delaying NextGen implementation
- New data infrastructure and information support systems may enable new crew configurations in the future, when the technology is ready
- Government agencies and commercial aviation are also investing in technologies with greater potential benefits
  - Quieter supersonic vehicles could cut down on travel time
  - New wing and body designs will cut down on fuel consumption, saving more than cutting a pilot
  - New intelligent support systems will give pilots and crew more tools to ensure safe flights

103 Ipsos poll conducted July 19–24, 2018, on behalf of the Air Line Pilots Association, Int'l

SUMMARY AND CONCLUSION

The commercial aviation system owes its stellar safety record to the highly trained pilots who fly the aircraft on a daily basis. Having two pilots in the cockpit at all times provides for a shared workload, which is important in the best of circumstances, and indispensable during emergencies. The second pilot in the cockpit also provides critical insurance against the very real possibility that the primary pilot becomes incapacitated for any reason during a flight. Moreover, that second pilot plays an important role monitoring the actions and the conditions of the primary pilot, also known as the pilot flying. It is primarily for these reasons that FAA regulations have long required that at least two fully qualified pilots be present in the cockpit of large passenger and cargo transport aircraft.

Advances in several key technologies, most notably automation, have doubtlessly contributed to aviation safety and eased pilot workload. However, significant advances will be required in automation and other technologies for airline and air transport operators to reduce the number of pilots in the cockpit without compromising safety. Until automation technology can provide the same level of situational awareness, communication, and judgment as humans, two pilots in the cockpit remain a necessity for achieving maximum safety.

THE NECESSITY FOR A SECOND PILOT IN THE COCKPIT

Having at least two pilots in the cockpit is essential to keep up with the workload on the flight deck in off-nominal conditions. Two pilots are also the only real defense today against the possibility of pilot incapacitation during flight. Assistance from remote pilots on the ground has been offered as a solution to these challenges, but studies have consistently shown that pilots communicate and coordinate better when they are co-located in the cockpit. Co-located pilots rely heavily on nonverbal modes of communication, such as head nods and other physical gestures and actions that indicate a message has been received or an issue is being addressed.

In addition, implementing reduced-crew or single-pilot operations would require assured communications between the cockpit and the ground regardless of aircraft location—a capability we do not currently have. In 2018 alone, there were multiple instances of lost communications between the air and the ground. These outages were deemed serious enough to scramble fighter jets. Moreover, the level of communication between the cockpit and ground required for single-pilot operations would open new avenues of attack for those seeking to disrupt or even commandeer flights for whatever purpose.

TECHNOLOGY READINESS

Substantial advances in automation technology have contributed to making flying safer while easing pilot workload. However, technology is not yet advanced enough to replace pilots in the cockpit. Automation technology is capable of performing specific, defined tasks, but it cannot sense, assess, act, interact, and adapt in complex situations the way human beings can. Automated and robotic systems are also prone to failure, which can make it difficult for human pilots to trust the technology.

PUBLIC OPPOSITION TO SINGLE-PILOT OPERATIONS

Polling data indicate that the public is not ready to accept single-pilot operations. In one poll by the Air Line Pilots Association, Int'l, 80 percent of respondents said having two pilots in the cockpit at all times is the best way to deal with an emergency during flight. In addition, 96 percent of respondents said the U.S. government should prioritize other aviation investments above eliminating pilots from the cockpit.

This low public opinion has direct impacts on industry leaders: Doug Parker, chief executive of American Airlines, has stated that American is not pursuing reduced-crew operations because "the comfort [pilots] provide is not something that most customers are going to want to forgo." Qantas Airlines Chief Executive Alan Joyce agrees that it is too early to increase the automation of the cockpit. FedEx's vice president of Safety, Bobbi Wells, also supports the idea that automation can complement the current flight crew but not replace individual members: "We've done an excellent job in aviation with automation that allows us to be more powerful as people. But I don't think we've done enough on the human being side. No matter what happens with aviation, we are not going to engineer human beings out of aviation."

INVESTMENT ALTERNATIVES

Support for investing in reduced-crew or single-pilot operations rests on the argument that airlines

and air transport companies could save on pilot salaries, benefits, and other expenses. However, any such savings would be offset by other costs associated with reduced-crew and single-pilot operations. These costs include salaries and benefits for ground-based pilots who would be responsible for monitoring multiple flights and assist during emergencies; outfitting/retrofitting aircraft cockpits with the necessary automation, communications and other systems; ground infrastructure upgrades; and aircraft certification.

Moreover, more pressing investment priorities exist—namely, rebuilding the U.S. air traffic management system. The FAA, with NASA's help, is currently pursuing this effort through NextGen. The $20 billion-plus program is required to address continuing growth in commercial aviation—both in the U.S. and globally—and the entry of new vehicles into the U.S. NAS. Given the scope of this endeavor, the FAA does not have resources to spare on a nonessential and complicated undertaking such as introducing single-pilot operations.

In addition, NASA's Aeronautics Research Mission Directorate (ARMD) presents investment alternatives that carry greater societal and economic benefits than single-pilot operations. ARMD is investigating a number of different technologies that have the potential to make aircraft faster and more fuel efficient while reducing their environmental impact. These technologies include supersonic passenger aircraft without the sonic boom that makes travel over land problematic, advanced battery cells that could enable electric propulsion, and new engine and wing-body aircraft designs that could dramatically reduce fuel consumption. As taxpayer-funded investments, these technologies are better suited than those required to enable single-pilot operations because the beneficiaries include the flying and nonflying public, as opposed to just the airlines and air transport operators. Moreover, given fuel's increasingly high percentage of overall airline costs—fuel costs in aviation rose from 10 percent to 30 percent from 1995 to 2011—many of these investments would profit these operators.

CONCLUSION

The number one priority in commercial aviation is and always will be safety. Any measures or changes designed to improve the efficiency and economy of the current system must be accomplished without compromising safety. The best guarantor of safety is having at least two fully qualified professional pilots in the cockpit. Investing in reduced-crew operations would displace other potential investments that would benefit all aviation stakeholders—including the airlines and air transport companies—and compromise safety. Even in the modern technological age, there is no safe substitute for having at least two human pilots in the cockpit of large passenger and cargo transport aircraft.