Oregon State University
College of Engineering

Improving Pilot-Controller Communication Through the Use of Artificial Intelligence for Real-Time Radio Analysis

May 2022

Design Challenge: Runway Safety/Runway Incursions/Runway Excursions

Challenge K: Enhancing airfield safety through application of emerging technologies.

Participants:

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Executive Summary

Radio communication has been a central part of aviation since the first air-to-ground communication system was installed in 1917 (Army Center of Military History, 2006). The technology behind these communications has remained largely unchanged since the early days of aviation, but with an ever-increasing number of flights and more complex airspace than ever before, radio communications are only becoming more and more crucial to flight safety.

Unfortunately, radios — especially when busy with traffic — have a tendency to exacerbate natural communication barriers between humans. A combination of noisy environments, radio static and preoccupancy with other tasks can result in crucial information being omitted or misunderstood during transmissions.

We propose a new software utility that listens to and analyzes radio transmissions in real-time, raising an alert for air traffic controllers if miscommunication is detected. Using modern artificial intelligence, the software is capable of detecting communication issues including incomplete readbacks, mistaken call signs and number transpositions. The software is then able to alert controllers of the detected miscommunication, specifying the relevant instructions, numbers or call signs that must be clarified. With this additional information, the controller is able to clarify their communications with pilots before the issue has the opportunity to jeopardize flight safety.

Future advancements could see similar technologies being implemented on the flight deck, allowing pilots to verify communications independently of air traffic controllers. Such an implementation would further increase safety in the National Airspace System (NAS) by reducing the impacts of miscommunication, although additional precautions must be taken to avoid distraction during critical phases of flight.

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Problem Statement and Background

Background on Communications in Aviation

The technology backing radio communication in airplanes and control towers has remained largely unchanged since the early days of aviation. However, with evolving airspace and an ever-increasing number of flights, clear communication between pilots and controllers is only becoming more important. Today, radios are used for nearly all communications between aircraft and controllers, from initial clearances to taxi and takeoff instructions to enroute and landing instructions (FAA, 2021).

Although relied upon heavily for flight safety, radio communications tend to exacerbate natural communication barriers between humans. A combination of noisy environments, radio static, cognitive bias and preoccupancy with other tasks can result in crucial information being missed during transmissions.

Current Miscommunication-Avoidance Strategies

As radios have been at the heart of aviation communication for decades, the years of radio communications have led to numerous strategies being developed to avoid confusion. Controllers are taught to use standardized phraseology and terminology in their transmissions to aircraft, and usually expect a relatively standard response (FAA, 2021). Pilots are required to read back critical instructions given by air traffic controllers, such as takeoff, landing and approach clearances (FAA, 2021). Such readbacks give controllers a chance to catch and correct any information the pilot may have missed. Even when readbacks are not required, controllers may still expect or ask for them when an instruction is deemed highly important, or when deviation may jeopardize flight safety.

Additionally, several state-of-the-art technologies are being developed and implemented to prevent miscommunication between pilots and controllers. Federal Aviation Administration (FAA) Advisory Circular (AC) 90-117 defines a Data Communications system — Data Comm for short — which enables air traffic controllers and pilots to communicate critical information, like flight plans and clearances, over text rather than radio (FAA, 2017). Since 2020, there have averaged “more than 8,500 Data Comm departure clearances every day,” according to the FAA — just over 18% of the 45,000 daily commercial flights in the United States (FAA, 2021). Unfortunately, the Data Comm technology is currently only available at 62 airports in the United States, and is only available using relatively expensive avionics, which are typically not installed in older or general aviation aircraft (FAA, 2021).

Future Miscommunication-Avoidance Strategies

Even as an increasing number of airports and aircraft adopt Data Comm technology, human-to-human radio communications will remain important for time-sensitive and safety-threatening situations. As such, research is being performed to help create systems that enable clearer speech understanding between pilots and air traffic controllers. Several papers have already outlined automatic speech transcription algorithms, achieving character accuracies up to 93.1% on air traffic communications data sets (Badrinath & Balakrishnan, 2021). The benefits to these live transcription systems are numerous: controllers will be able to access real-time records of communications with aircraft in their airspace, compare these records to the instructions and clearances previously given, and quickly determine whether any miscommunication has occurred. However, this technology also has the unfortunate possibility of causing new communication issues when not presented clearly to the user. Incorrect transcriptions could cause controllers to misinterpret speech heard over the radio and act upon false information, in addition to increasing cognitive load. In order to assure flight safety, transcriptions must be presented with very little room for ambiguity, and words or phrases for which the system has low confidence should be clearly marked.

Research and Literature Review

The research and literature review process included a search for relevant accident/incident investigations and Aviation Safety Reporting System (ASRS) reports, as well as interviews of airport operators and experts. Additionally, we conducted a survey of air traffic controllers to gain insight into the frequency and common types of miscommunication in aviation.

Accident and Incident Investigations

Government agencies often report on aviation accidents and incidents to help prevent them from occurring in the future. In the United States, the National Transportation Safety Board (NTSB) is responsible for such investigations, including identifying common risk factors. We selected three investigations from the NTSB, Indonesian National Transportation Safety Committee and Bulgarian Air Traffic Services Authority that cited pilot-controller miscommunication as a key risk factor, and discuss these in detail in this section.

PSA Flight 182 (1978)

On September 25, 1978, PSA Flight 182 — a Boeing 727-214 — collided with a Cessna 172 on final approach at San Diego International Airport (KSAN) (NTSB, 1979). According to the NTSB report, Flight 182 was instructed to “maintain visual separation” by San Diego approach before being handed over to Lindbergh tower at KSAN. Rather than reading back the full “maintain visual separation” instruction, the captain replied “Okay” and contacted Lindbergh tower.

After their initial contact, the tower alerted Flight 182 of the Cessna at “twelve o’clock, one mile.” The captain and first officer struggled to find the plane, telling the controller they “had [the Cessna] a minute ago,” then following up with “I think he’s passed off to our right.” Due to radio static, the controller testified to hearing “passing” rather than “passed,” which would have suggested that the crew had the Cessna in sight. On the flight deck, the crew continued to try to find the plane, with the first officer asking if they were “clear of the Cessna” to which the flight engineer replied “supposed to be.”

Seventeen seconds later, the conflict alert system warned the San Diego approach controller that the Cessna and Flight 182 were dangerously close. The approach controller advised the Cessna of the traffic descending into San Diego, but “the transmission was not acknowledged” and the aircraft collided moments later.

Several key communication issues occurred throughout the two minutes of radio communication:

1. Flight 182 did not read back the “maintain visual separation” instruction, and the approach controller did not require the crew to explicitly acknowledge their additional responsibility. This introduced uncertainty about who was responsible for separation, and may have contributed to Flight 182 losing sight of the Cessna.
2. Radio static caused the controller to hear “I think he’s passing off to our right” rather than “I think he’s passed off to our right.” As Flight 182 failed to inform the controller that they had previously lost sight of the Cessna (a requirement after accepting a “maintain visual separation” clearance), the controller understood the transmission to mean that Flight 182 still had the Cessna in sight, and that the Cessna was currently passing them

on the right. Had the controller heard “passed” instead, or clarified the transmission with the crew, it would have been clear that Flight 182 no longer had the Cessna in sight.

3. The Cessna did not acknowledge the traffic advisory from San Diego approach. It is unknown whether the pilots heard and would have had time to react to and acknowledge the transmission before the collision.

Garuda Indonesia Flight 152 (1997)

Garuda Indonesia Flight 152 was an Airbus A300B4 that departed Soekarno-Hatta International Airport in Jakarta, Indonesia on September 26, 1997 heading to Polonia International Airport in Medan, Indonesia (National Transportation Safety Committee, 1997). The crew was initially cleared to descend down to 3000 ft, and was told to expect an Instrument Landing System (ILS) approach into Polania’s Runway 05. Medan approach then instructed the crew to turn “heading 240 to intercept Runway 05 from the right side.” However, the controller used the wrong call sign for the aircraft, saying “Merpati 152” — an aircraft that the controller had served earlier in the day — instead of “Indonesia 152”. After not receiving a response for nearly 20 seconds, the controller asked Flight 152 if they read the instruction, this time using the correct call sign. Flight 152 responded with “say again,” and the controller repeated his previous instruction, but forgot to mention that they would be intercepting Runway 05 from the right. From there, confusion grew rapidly as the pilots and controller had different understandings of the approach path. The flight crew and controller went back and forth on the directions of turns for several minutes, with the captain instinctually turning left as documented on the approach plate, while the controller asked for right-hand turns. A minute later, Flight 152 collided with terrain, killing all passengers and crew.

Among other factors, including failures of the onboard Ground Proximity Warning System, numerous communication issues were noted in the crash investigation:

1. Potentially the most obvious communication issue was the controller's use of the wrong call sign, and subsequent failure to include relevant details about the approach when asked to repeat (specifically that they were cleared to intercept the localizer from the non-standard right side). This miscommunication set the groundwork for the confusion about turn directions in the approach that followed.
2. During the confusion around the turn directions, the first officer incorrectly read back a heading of 040 instead of the instructed 046. Although not a major error by itself, the erroneous readback suggests a high workload on the flight deck that furthered the communication issues between the pilots and the controller.

Air France Flight 268P (2007)

On April 13, 2007, Air France Flight 268P — an Airbus A320 — entered Runway 27 without clearance at Sofia Airport in Sofia, Bulgaria (Bulgarian Air Traffic Services Authority, 2007). A CRJ200 on a 5.5 nm final approach for the same runway performed a successful go-around, and there was no collision or accident involving either aircraft. The Bulgarian Air Traffic Services Authority investigated the situation as a "serious incident."

The investigation discovered several communication issues between Flight 268P and Sofia tower. After the aircraft arrived at the holding point for Runway 27, Sofia tower asked if the crew was "ready for immediate departure" from Runway 27, and the captain confirmed that they were ready. The tower then notified the crew of landing traffic on a 5 mile final, and instructed them to "keep holding point." Flight 268P read back the landing traffic advisory, but failed to read back the hold short instruction. The controller did not inquire further about the incomplete readback. Several seconds later, Flight 268P taxied onto Runway 27. The controller noticed, and instructed the landing traffic to perform an immediate go-around.

Aviation Safety Reporting System (ASRS) Reports

The ASRS collects confidential, self-reported safety reports from pilots and controllers, and provides a searchable database to help view high-level trends in aviation safety. Searching the database for pilot-controller miscommunication resulted in hundreds of reports over the past five years. Two of the most relevant reports are discussed in this section.

Similar Call Signs in Busy Airspace (ASRS Report 1815668)

This report describes a private pilot and a flight instructor (Aircraft Y) who were performing touch-and-go's at a towered airport with parallel runways (Aviation Safety Reporting System, 2021). On their ninth takeoff from the right-side runway, the tower stated "Aircraft Y, continue upwind, I will call the crosswind." Several moments later the tower instructed Aircraft X, which had departed off the left-side runway, to turn left crosswind. The flight instructor did not hear the aircraft's call sign, but the private pilot believed the tower had said Aircraft Y, and after a short deliberation began a left crosswind turn. Shortly after, the tower instructed Aircraft Y to turn right crosswind and the private pilot responded that they were in the wrong downwind after making the incorrect crosswind turn. The pilot of Aircraft X reported that he had seen Aircraft Y, and that it was a "close one."

Undetected Incorrect Readbacks (ASRS Report 1775013)

This report describes an airline crew who received an instruction to taxi from their gate to the departure runway via "Romeo, Yankee, Uniform, Kilo cross [Runway] Y, to [Runway] XXL" (Aviation Safety Reporting System, 2020). However, the crew misheard the transmission and taxied Romeo to Yankee, crossing Runway Y at Yankee rather than turning on Uniform and crossing at Kilo. After analyzing the situation, it was determined that the crew briefed and read back the incorrect instructions, but the ground controller did not catch the mistake in the readback. The reporter, who was the captain of this flight, added that higher controller workloads during the COVID-19 pandemic could explain the ground controller's failure to catch the readback error.

Air Traffic Controller Survey

To get a better understanding of the needs and concerns of experienced air traffic controllers, we designed a survey to collect data on the perceived amount of miscommunication that occurs on a daily basis. The survey included questions about the controller's experience in the aviation industry as well as the percent of transmissions made in which the controller would describe there to have been at least moderate miscommunication, which was explicitly defined as "instances where you as the controller are left unsure of whether the pilot understood your instructions correctly." Additionally, the survey asked controllers to describe the most common reasons for miscommunication. We then evaluated each response and classified it into one of several categories: incomplete readbacks, mistaken call signs, number transposition, language and accents, expectation bias, blocked transmissions, and communication speed. In total, 38 controllers responded to at least one of the survey's questions.

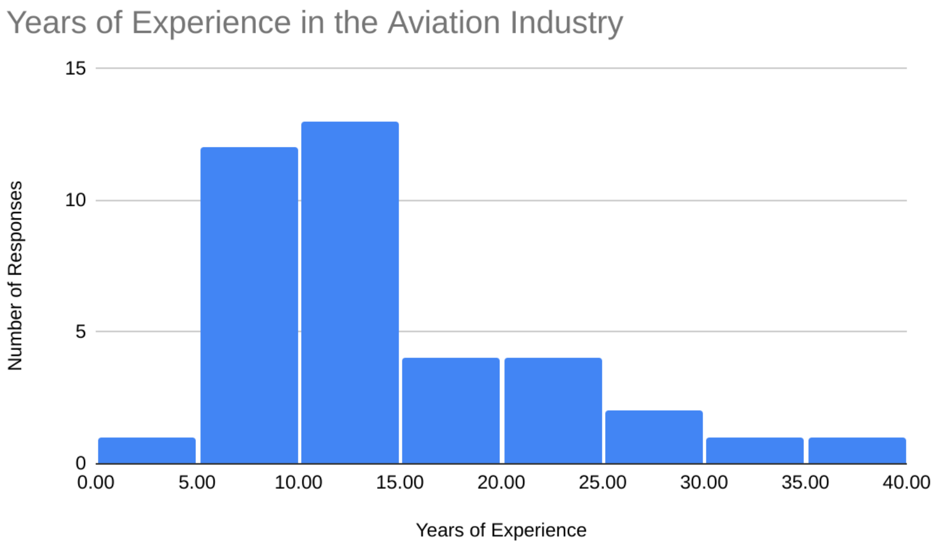


Fig. 1: Respondents' experience in the aviation industry.

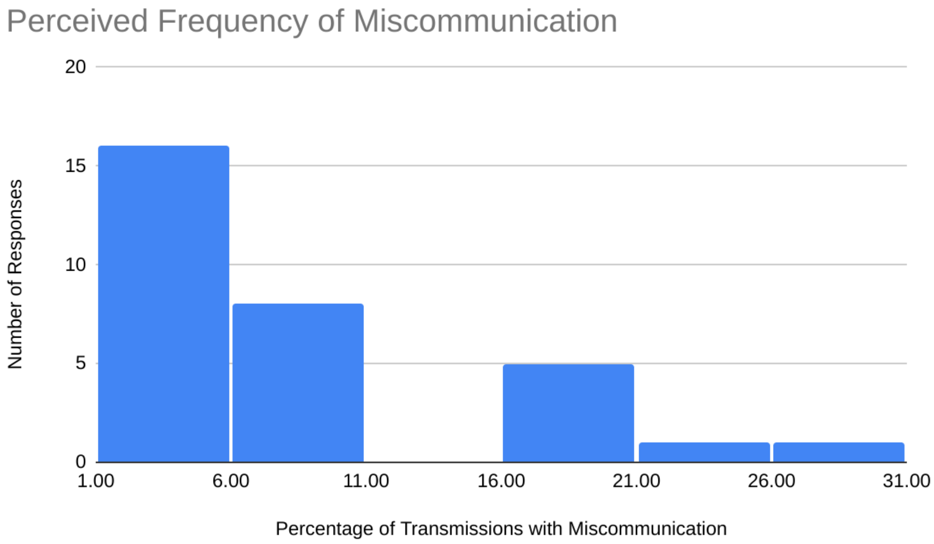


Fig. 2: Respondents' perceived frequency of miscommunication. Mean = 9.5%.

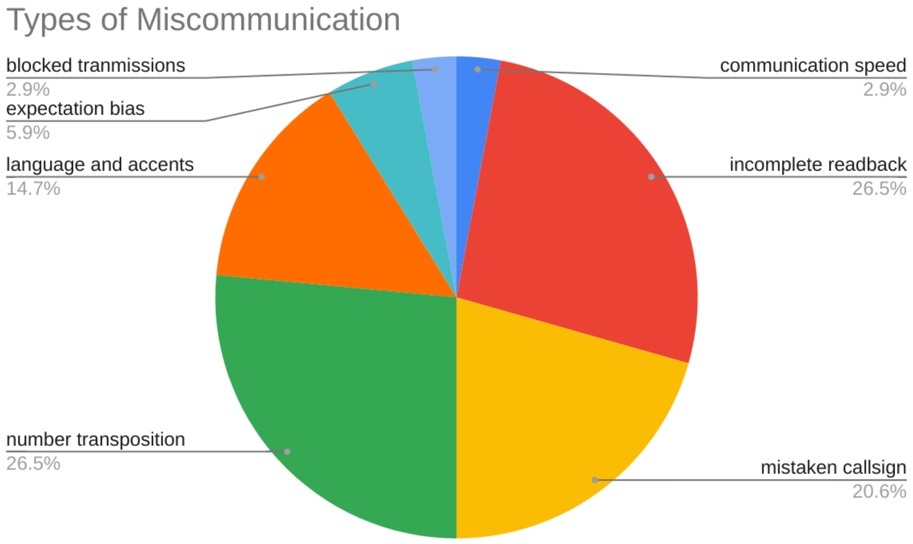


Fig. 3: Most common miscommunication classifications.

After analyzing the data and comments by the respondents, it became clear that the frequency and types of miscommunication depended heavily on several factors:

- Type of controlling facility (tower, TRACON, ARTCC)
- Size of controlling facility and surrounding airspace (Class B, C or D airspace)
- Geographical location of controlling facility
- Amount of flight training in and surrounding the airspace

For example, controllers who reported the most frequent miscommunications and incomplete readbacks were those in busy Class D airspaces with large numbers of student pilots. Controllers at larger airports along the west coast reported that language barriers and unfamiliar accents greatly contributed to miscommunication in their airspace.

We also asked controllers whether they believed “a software that provides accurate live transcriptions of radio calls on your screen” would be beneficial for their situational awareness.

Many controllers were skeptical and said that such a tool would likely be more distracting than it would be helpful, citing potential transcription errors that could lead to more confusion. Others noted that their eyes should almost always be focused on the radar scope, so they would only use transcriptions in rare cases — and even in these cases, it would be easier to simply talk to the pilot. This feedback helped us restructure our design to use simple and automatic alerting mechanisms that more closely align with the needs of controllers.

Interactions with Experts

As part of our research, we interviewed and interacted with several experts within the aviation industry and within fields directly related to the proposal.

Eric Lyn

Eric Lyn is an air traffic controller at San Gabriel Valley Airport (KEMT) in El Monte, California, with over seven years of experience. Outside of his job in the tower, Lyn is also an instrument-rated pilot, meaning he has experience on both sides of the radio. In a phone call interview, Lyn discussed the communication challenges he has faced both as a controller and while acting as the pilot of an aircraft. Many of the most frequent communication issues Lyn has experienced — including incomplete readbacks, mistaken call signs and language barriers — aligned closely with the data gathered in the controller survey.

Lyn also shared three common miscommunication-avoidance strategies controllers use if they suspect a pilot is not understanding their transmission: speaking slower, longer separation between instructions, and less information in each instruction. He noted that automatic miscommunication warnings could greatly supplement emerging technologies like Data Comm, especially if the system has a high rate of accuracy. Additionally, Lyn noted that such a system would be able to be used by nearly all aircraft — including general aviation — that may not be able to add Data Comm technology for weight or cost reasons.

Dr. Christopher Sanchez

Dr. Christopher Sanchez is a professor of human psychology at Oregon State University, where his research focuses on how people interact with technology. Additionally, Dr. Sanchez is currently working with the FAA to create visualization and safety technology for automated drone systems, which operators and air traffic controllers could use to prevent conflicts with existing air traffic. We contacted Dr. Sanchez to learn more about his research and experience building technology for controllers, as well as to receive feedback on the proposed implementation for miscommunication avoidance.

In the interview, Dr. Sanchez provided many valuable insights from his expertise on human-computer interactions. Specifically, he suggested that combining both auditory and visual cues would be the most effective way of alerting the controller to a potential communication issue. The auditory cue would serve as an immediate signal that something had gone wrong and prompt the controller to look at a known part of the screen for further information about the issue. Additionally, Dr. Sanchez noted that such an approach would be less distracting to a user than providing the same information solely via an audio or visual medium, as it would allow the controller to reference the data when they deemed it was safe to do so.

Dr. Sanchez was also able to provide us with psychological background and explanations for some of the common categories of miscommunication. He theorized that incomplete readbacks, mistaken call signs and number transpositions typically stem from a form of expectation bias, where the pilot or controller hears what they are expecting rather than what is actually said. Introducing computer detection algorithms, which are not affected by expectation bias like the human brain, could increase safety by alerting the controllers to incorrect readbacks that may slip by.

Dr. Vincent Remcho

Dr. Vincent Remcho is a commercial pilot and experienced flight instructor in Corvallis, Oregon. Throughout his time as a flight instructor, Dr. Remcho has taught dozens of pilots working on their private, instrument and commercial ratings. We interviewed Dr. Remcho to better understand the pilot's side of aviation communications as well as the common radio mistakes made by student pilots.

According to Dr. Remcho, instrument approaches are by far the most difficult phase of flight to make and process radio calls for experienced and student pilots alike. The increased workload involved with following an instrument approach plate and monitoring the additional instruments opens the door for communication mistakes such as incomplete readbacks or mistaken call signs. Additionally, Dr. Remcho noted that knowing what information needs to be read back can be challenging for new instrument pilots. Fortunately, Dr. Remcho found that controllers were typically very helpful in correcting pilots if mistakes did occur in their readback.

Student pilots working towards their private pilot certificate often struggle most with their initial tower contacts, Dr. Remcho has found. Forgetting to include important information in their initial call often leads to further miscommunication between students and controllers later when there are differing understandings of the aircraft's position and course.

Problem Solving Approach

Our initial approach for reducing miscommunication was to present the controllers with a display showing live radio transcriptions. As controllers and pilots speak on the radio, the transcriptions would appear on the controller's screen. If the controller missed a communication from an aircraft or wanted to confirm a readback, they would be able to reference the screen and read the relevant transmissions. However, through our research, interviews and literature review, we realized our initial design was impractical; controllers want a system that can alert them to potential miscommunication, without having to divert their attention from their radar scopes.

Using the new information we obtained, we formulated three questions to guide our revised problem solving approach:

1. What types of communication issues would the system best be able to detect?
2. For what categories of miscommunication would automatic alerting be most beneficial for the controller?
3. How can the system best alert the controller to the miscommunication, and what information should be included in this alert?

Understanding Radio Transmissions

To be able to detect communication issues, the system must first be able to understand and parse radio transmissions. Fortunately, most radio transmissions follow a relatively similar pattern that is easily parsable by a computer. Controllers' instructions to aircraft always include the target aircraft and an instruction (or multiple instructions), and typically include a specifier such as an altitude, heading or runway.

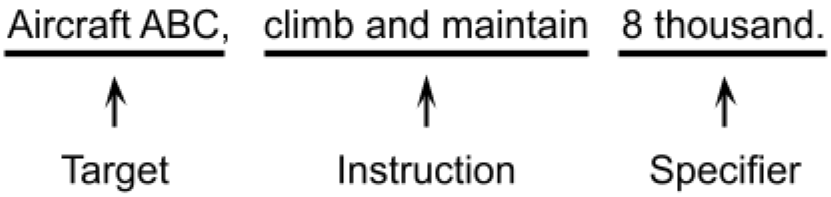


Fig. 4: Typical controller syntax.

After parsing the controller's instruction, the next challenge becomes parsing the pilot's readback. In general, pilot readbacks follow a similar structure as the controller's instruction, but typically do not conform to the same level of consistency, which can be more difficult for a computer to understand. For example, "Climb and maintain 8 thousand, Aircraft ABC" may also be read back as "Up to 8 thousand, Aircraft ABC" or "Climbing to 8 thousand, Aircraft ABC."

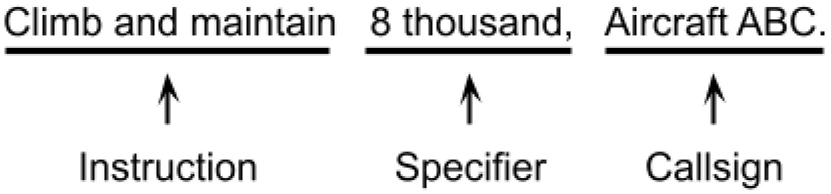


Fig. 5: Typical pilot readback syntax.

To address this issue, the system must hold a database of synonymous instructions such that a pilot reading back "up to 8 thousand" will register as a valid readback for a "climb and maintain 8 thousand" instruction. Table 1 describes common controller instructions and alternative readbacks pilots often use, which we collected from listening to several hours of air traffic control dialogue from multiple major airports (KSEA, KJFK and KPDX).

Instruction	Alternative Pilot Readbacks	Remarks
Climb and maintain [altitude]	Up to [altitude]	
	Climbing to [altitude]	
	[Altitude]	Direction (climb/descend) is not confirmed in readback
	Roger/affirmative	Instruction is acknowledged, but no confirmation of details
Descend [altitude]	Down to [altitude]	
	Descending to [altitude]	
	[Altitude]	Direction (climb/descend) is not confirmed in readback
	Roger/affirmative	Instruction is acknowledged, but no confirmation of details
Turn [direction] heading [heading]	[Direction] to [heading]	
	[Heading]	Direction of turn is not confirmed in readback
	Roger/affirmative	Instruction is acknowledged, but no confirmation of details
Cleared for takeoff [runway]	*None, readback should be verbatim*	
Cleared to land [runway]	*None, readback should be verbatim*	

Table 1: Common Air Traffic Control (ATC) instructions and alternative readbacks by pilots. Green indicates the highest level of clarity, yellow indicates acceptable clarity and red indicates major clarity concerns.

Alternative readbacks also introduce an interesting transcription-related problem: computer transcription algorithms are typically no better than humans at detecting word contexts. In fact, they often make more mistakes than humans when presented with similar-sounding words, such as “to” and “two,” or “for” and “four” (Ghosh, Chingtham & Ghose, 2016). Consider the following scenario, where Airplane ABC is instructed to climb from their initially cleared altitude to 9 thousand feet:

Controller: Airplane ABC, climb and maintain niner thousand.

Pilot: Climb to niner thousand, Airplane ABC.

A controller is likely to easily understand the readback to mean “Climb *to* nine thousand.” However, a computer may interpret and display the pilot’s readback as “Climb *two* nine thousand” and alert the controller of miscommunication. Several new speech recognition systems have been introduced in recent years to combat the effects of homophones in automatic transcriptions, but such systems have not yet been applied to aviation communication datasets, so the impact of improving this issue has not been measured (Ghosh, Chingtham & Ghose, 2016).

Detectable Communication Issues

From our controller survey, we determined that the majority of communication issues fall under three categories: incomplete readbacks, mistaken call signs and number transposition. As such, an initial focus on these three categories would provide the greatest immediate assistance in reducing the impacts of miscommunication in their airspace. As research continues, and as artificial intelligence algorithms become more sophisticated, we expect that additional categories could be reliably detected by the system.

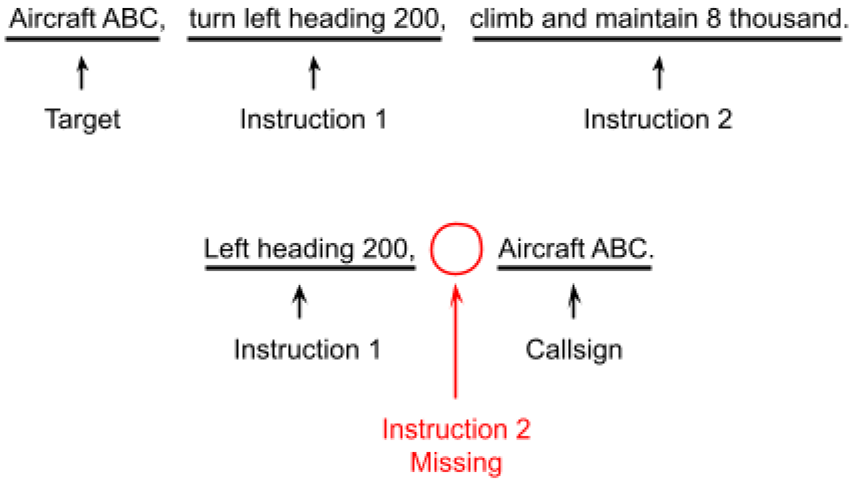


Fig. 6: Example incomplete readback with missing instructions.

Incomplete readbacks can be detected by comparing the controller's transmission to the pilot's readback, as shown in Figure 6. As an initial check, the number of instructions should be the same for both transmissions — if they differ, the readback is not complete. Next, each instruction from the controller's transmission should be checked against the readback — if any instructions differ, such as "descend" instead of "climb," the readback is not complete.

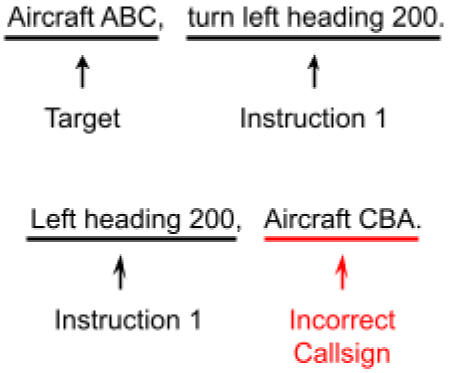


Fig. 7: Example readback with mistaken call sign.

Detecting mistaken call signs is relatively straight-forward. The system will store a list of the controller's instructions in a table, along with a value as to whether each instruction has had a successful readback (including call sign). When the system detects a readback from an aircraft, the instruction and call sign will be checked against the table; if the instruction matches a recent instruction from the controller to that aircraft, the readback will be marked as complete. If the readback does not match an instruction to that aircraft, but rather matches an instruction issued to another aircraft managed by the controller, the system has detected a mistaken call sign and will alert the controller. The system will additionally alert the controller if no call sign is present in the read back.

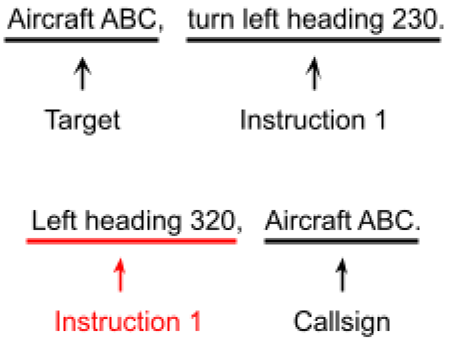


Fig. 8: Example readback with number transposition.

Number transposition occurs when the instructions in a readback are correct, but the specified numbers are interpreted out-of-order. For example, an aircraft that is told to "turn left heading 230" may be read back as "left heading 320." This type of error is especially common during high-workload portions of the flight, such as before takeoff or landing. This issue is so prominent that the FAA released a Safety Alert for Operators (SAFO) for San Francisco

International Airport, as pilots frequently confused “Runway 01L” and “Runway 10L,” which differ in length by over 4000 ft (FAA, 2018).

To automatically detect number transposition, the system must first confirm the validity of the instructions and call signs as described above. If both are valid, the specifiers of the controller’s instruction and the aircraft’s readback can be compared. If the specifiers are not exactly identical, the controller will be alerted to possible number transposition.

Alerting Controllers

The feedback we received from controllers and industry experts suggested that properly alerting the controller was crucial to the success of any miscommunication-detection system. Several alerting options were considered, including auditory, visual and a combination of both.

Eventually we concluded that a combination of auditory and visual alerting mechanisms would be most suitable for this application. As controllers often have their eyes focused on the radar, an auditory cue — such as a short, recognizable beep — would provide more immediate feedback than a system that provides only visual indicators on a secondary screen. However, visual alerts are equally important as they can more easily provide details about the potential miscommunication, such as relevant aircraft and instructions, without impacting the controller’s ability to hear incoming communications over the radio. In this dual-alerting approach, the auditory cue will indicate that potential communication issues have been detected and that the controller should look to their secondary screen for additional details.

Description of Technical Aspects

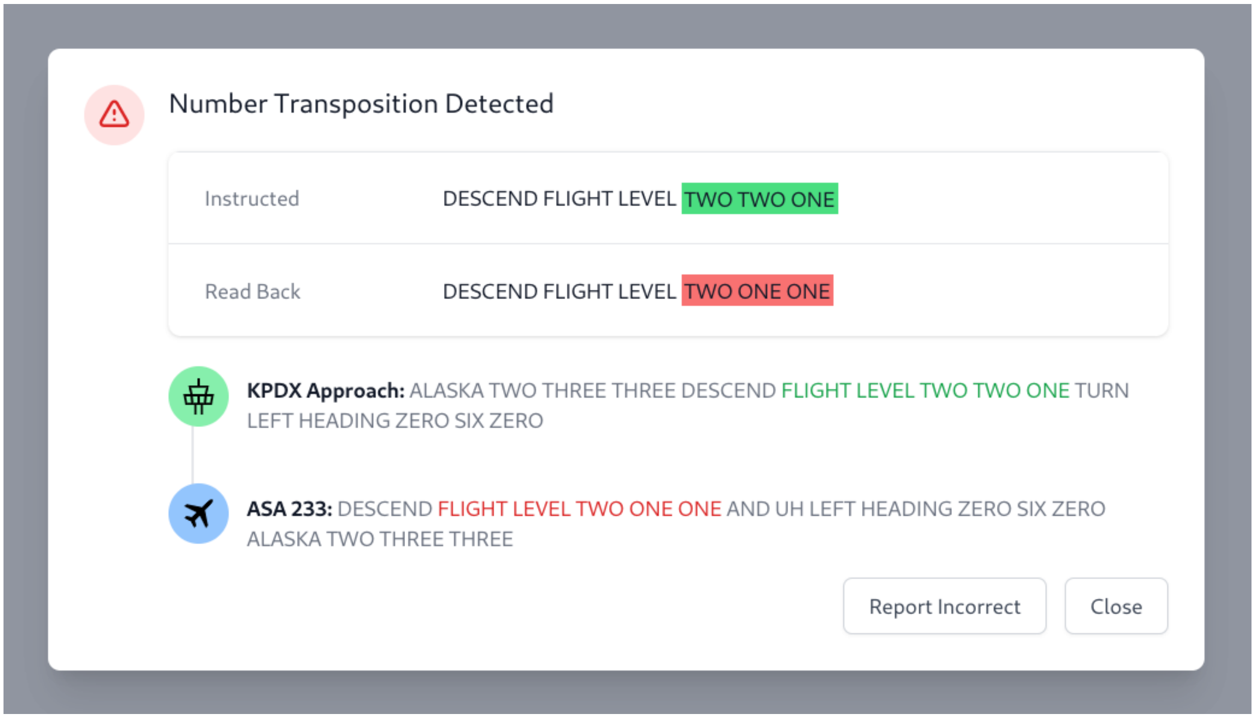
The code for a proof-of-concept detection and alerting system is freely accessible on GitHub at https://github.com/andrewda/acrp-miscommunication-detection. The software is written in TypeScript and Vue.js, using transcribed radio calls from LiveATC.net — a website that provides recordings of ATC communications. As a next step, the software could be combined with speech-to-text algorithms, allowing it to continuously monitor a radio frequency without the need for manual transcription inputs.

Feature Overview

The proposed software utilizes the knowledge acquired from research and literature review, and implements the solutions outlined in our problem solving approach. The software is capable of detecting incomplete readbacks, mistaken call signs and number transpositions in transcribed audio recordings. We designed the codebase to be flexible and modular, enabling new detection algorithms to be easily added as a part of future research.

The detection process begins with textual parsing, transforming the transcribed radio calls into consistent data structures that can be more easily understood by the computer. This parsing system quickly became one of the most challenging components of the program due to the various synonymous readback formats, discussed previously in Table 1. Once parsed into a consistent format, the transmissions are passed to the individual detection algorithms, which each specialize in detecting different forms of miscommunication. The implementations of these algorithms closely align with the descriptions in the “Detectable Communication Issues” section of this report.

Additionally, the software includes audio and visual alerts for detected communication issues, including the type of error, aircraft involved, and relevant radio transmissions. The visual alerts are structured to allow them to be processed by air traffic controllers with minimal effort, ensuring they are not distracted from their primary responsibilities. Figures 9, 10 and 11 display the software's automatically generated alerts for number transpositions, mistaken call signs and missing instructions, respectively. Each alert contains the most critical information at the top, with notable differences highlighted in green and red. Each alert also contains the relevant radio transmissions, with important fragments highlighted.



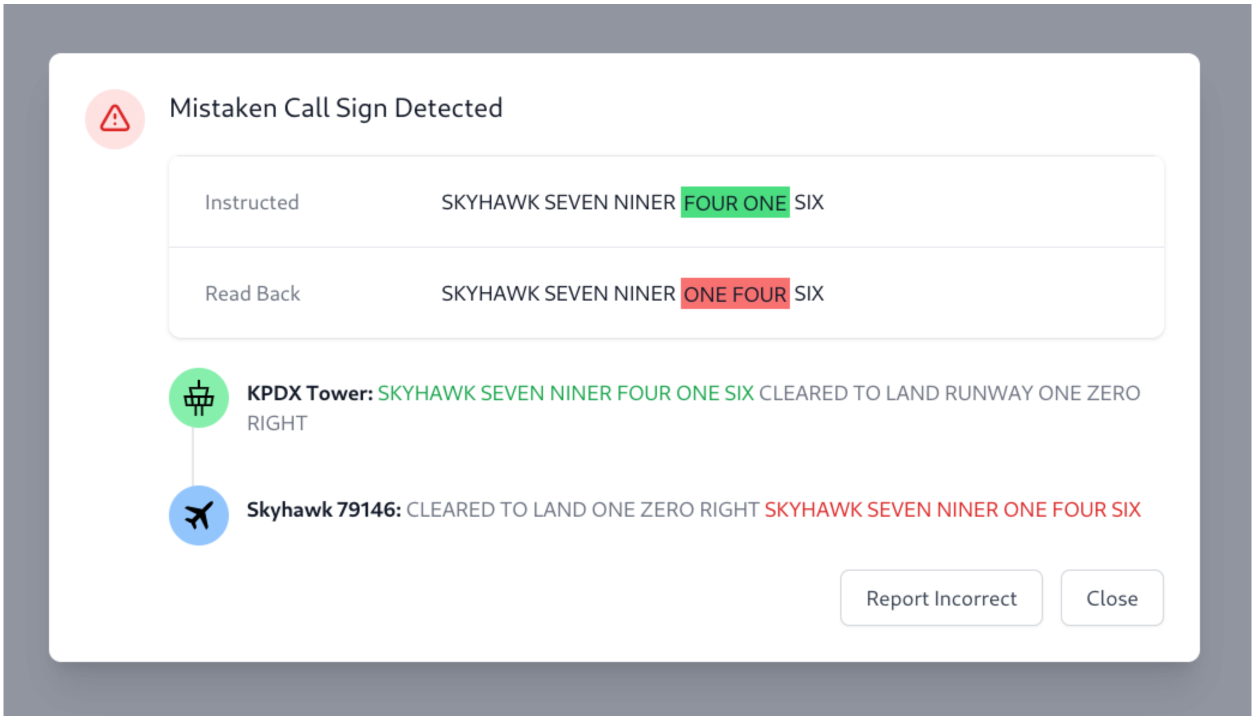
Number Transposition Detected

Instructed	DESCEND FLIGHT LEVEL TWO TWO ONE
Read Back	DESCEND FLIGHT LEVEL TWO ONE ONE

KPDX Approach: ALASKA TWO THREE THREE DESCEND FLIGHT LEVEL TWO TWO ONE TURN LEFT HEADING ZERO SIX ZERO

ASA 233: DESCEND FLIGHT LEVEL TWO ONE ONE AND UH LEFT HEADING ZERO SIX ZERO ALASKA TWO THREE THREE

Fig. 9: Detection and alert of possible number transposition.



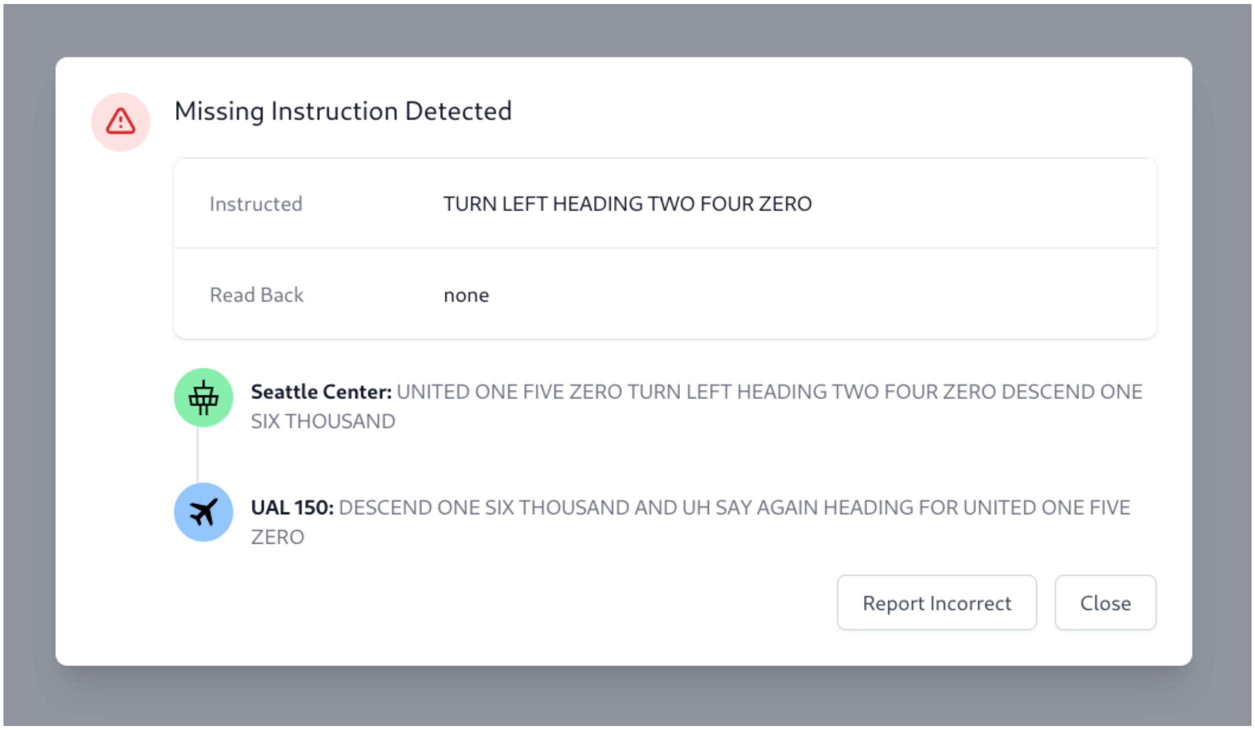
Mistaken Call Sign Detected

Instructed	SKYHAWK SEVEN NINER FOUR ONE SIX
Read Back	SKYHAWK SEVEN NINER ONE FOUR SIX

KPDX Tower: SKYHAWK SEVEN NINER FOUR ONE SIX CLEARED TO LAND RUNWAY ONE ZERO RIGHT

Skyhawk 79146: CLEARED TO LAND ONE ZERO RIGHT SKYHAWK SEVEN NINER ONE FOUR SIX

Fig. 10: Detection and alert of possible mistaken call sign.



Missing Instruction Detected

Instructed	TURN LEFT HEADING TWO FOUR ZERO
Read Back	none

Seattle Center: UNITED ONE FIVE ZERO TURN LEFT HEADING TWO FOUR ZERO DESCEND ONE SIX THOUSAND

UAL 150: DESCEND ONE SIX THOUSAND AND UH SAY AGAIN HEADING FOR UNITED ONE FIVE ZERO

Fig. 11: Detection and alert of possible missing instructions.

Safety Risk Assessment

As with many advancements in technology — and especially in areas relating to artificial intelligence — special attention must be paid to the shortcomings of the technology to ensure safety. Using the Safety Risk Management (SRM) phases defined in AC 150/5200-37, we performed a safety risk assessment of the proposed solution (FAA, 2007). In this section, each of the identified safety concerns is outlined, including likelihood and severity, along with potential risk mitigation strategies.

Incorrect Transcriptions

The proposed solution requires automatic radio transcriptions to be generated behind the scenes. Transcriptions are considered incorrect if the characters understood by the system do not match the words spoken. However, not all words are equally important in aviation radio transmissions; some critical instructions must be understood completely, whereas other words (or utterances) may simply be filler, and their absence would not change the general meaning of the transmission. These words and phrases can be divided into several categories, ordered by their relevance to flight safety:

1. Critical instruction terms (e.g. “cleared”, “hold short”, “climb and maintain”)
2. Call signs
3. Supplementary numbers and specifications (e.g. “runway two three”, “one five thousand feet”, “ILS one seven”)
4. Filler words (e.g. “uh”, “with you”, “good night”)

Incorrect transcriptions of critical instructions are the most likely to jeopardize flight safety. For example, a system that fails to generate an alert for an incorrect readback (false negative) could convince the controller that the pilot read the instruction back correctly and prevent corrective action. False positives, such as when a system incorrectly fails to detect and transcribe a pilot's correct readback, are slightly less severe and will typically only require additional confirmation from the controller. Incorrect transcriptions of supplementary numbers and specifications, such as approach names, landing or departure runways, or altitude assignments, are similar in impact to false positive transcriptions of critical information; both require clarification by the controller but should be easily caught with appropriate training.

Overall, incorrect transcriptions will occur frequently due to a variety of factors, including accents and radio static. However, due to the nature and structure of aviation radio transmissions, we expect critical instructions to be significantly less subject to incorrect transcription. As such, the likelihood of minor safety issues from incorrect transcriptions can be considered frequent, while the likelihood of hazardous issues can be considered remote.

Non-Speech Factors

Speaking with air traffic controllers revealed a layer of communication beyond just the language being used: vocal tone. Controllers use vocal signals like tone of voice, stress and perceived confidence to help make decisions about whether a pilot truly understands the instruction being given. Years of experience and thousands of hours listening to radio transmission give controllers natural insight into these aspects of speech that computers struggle to detect. Although there is emerging research into detecting stress and confidence through speech recordings, such technologies are still a long way from being usable in production applications (Chanda, Fitwe, Deshpande, Schuller, & Patel, 2016).

Without the ability to detect stress or confidence in pilots' tone of voice, the system is somewhat handicapped compared to human listeners. As such, the system may not be able to detect instances of miscommunication where the correct words are used, but the pilot appears unconfident or questioning in their transmission.

Although there will undoubtedly be instances where the system is unable to detect miscommunication through a pilot's tone of voice, the impact of such events will be minimal. Controllers are already trained to take action when they detect that a pilot may be unsure about an instruction, and the addition of this system will not impact controllers' ability to correct these instances (barring complacency and overreliance, which is discussed in detail below).

Complacency and Overreliance

Advancements in automation where humans are still in-the-loop nearly always come at the risk of complacency and overreliance (Parasuraman, Molloy & Singh, 1993). These risks can be extremely hazardous to safety, as it means a controller could miss a communication error they would have otherwise caught simply because the system did not alert them. To overcome this issue, we considered several common methods to lower rates of complacency (Grissinger, 2019):

- Limit interactions between humans and computers: the system should be capable of performing all important tasks in the background, and alert the controller only when necessary.
- Design technology to reduce overreliance: the system should avoid common pitfalls that lead to overreliance, such as providing excessive information to the user.

- Provide comprehensive training: controllers should be thoroughly trained on the system and receive regular refresher training as new features are incorporated into the application.

Although the system is designed to decrease complacency and overreliance through these methods, the risk can never be fully eliminated. As such, controller training should include detailed information about the risks of overreliance on technology. Additionally, manually disabling the system at regular intervals — especially while controllers are becoming familiar with the technology — could help limit complacency, provided the controllers are adequately informed about the process. Implementing these risk mitigation strategies reduces the likelihood of overreliance to a low level and ensures that any instances of overreliance have only a minor impact on safety.

Risk Matrix

To analyze and visualize the overall risks in the proposed system, a risk matrix was created as described in AC 150/5200-37 and the FAA Safety Management System Manual (FAA, 2007). The risk matrix considers both the likelihood and severity of specific risk scenarios, and classifies them as low, medium or high risk level. Risk scenarios determined to have a medium or high risk level should be thoroughly analyzed to mitigate as much risk as practicable.

Severity **Likelihood**	**Minimal 5**	**Minor 4**	**Major 3**	**Hazardous 2**	**Catastrophic 1**
Frequent A	🟩 A5	🟨 A4	🟨 A3	🟥 A2	🟥 A1
Probable B	🟩 B5	🟨 B4	🟨 B3	🟥 B2	🟥 B1
Remote C	🟩 C5	🟩 C4	🟨 C3	🟥 C2	🟥 C1
Very Remote D	🟩 D5	🟩 D4	🟩 D3	🟨 D2	🟥 D1
Improbable E	🟩 E5	🟩 E4	🟩 E3	🟨 E2	🟥 E1

Table 2: Definition of risk likelihood and severity as defined in AC 150/5200-37. Green implies low risk level, yellow implies medium risk level, red implies high risk level (FAA, 2007).

Likelihood	**Expected Occurrence Rate**
Frequent	At least once per week.
Probable	Less than once per week, and at least once per three months.
Remote	Less than once per three months, and at least once per three years.
Very Remote	Less than once per three years, and at least once per 30 years.
Improbable	Less than once per 30 years.

Table 3: Definition of risk likelihoods as defined in the Safety Management System Manual (FAA, 2019).

Risk Scenario	Likelihood	Severity	ID	Risk Level	Potential Mitigation Strategies
False transcription of supplementary information	Frequent	Minor	B4	Medium	Continuous improvements to detection algorithms and comprehensive controller training.
False negative (system did not alert a missed critical instruction)	Remote	Hazardous	C2	High	Continuous improvements to detection algorithms and comprehensive controller training.
False positive (system alerted a correct readback, e.g., due to non-speech factors)	Frequent	Minimal	A5	Low	Impact is minimal; controllers' existing training should be sufficient to detect stress and lack of confidence in readbacks.
Complacency and overreliance	Remote	Minor	C4	Low	Limit interactions between humans and computers, design technology to reduce overreliance, provide comprehensive training.
Total system failure	Very Remote	Hazardous	D2	Medium	System should be easily disableable to prevent system failure from impacting safety.

Table 4: Risk scenarios and corresponding risk levels and mitigation strategies.

Projected Impacts

Benefits and Practicality of Adoption

Throughout this proposal, we have outlined the numerous benefits the proposed software would bring to air traffic controllers and the increased safety it could bring within the NAS. To finalize and bring this design to a production-ready state, the detection and alerting software must be augmented to perform transcriptions using live radio audio. An additional server will likely need to be purchased and installed at each controlling facility where the software is installed to perform the live transcriptions.

Adoption of the software could occur independently at each facility and need not be implemented at all air traffic control facilities simultaneously. Initial small-scale testing at Class D airports with pilot training facilities would make sense given student pilots' increased rate of communication errors. Upon completion of successful testing, the software could be implemented at busier Class D and Class C airports, and finally at Class B airports and ARTCC facilities. Additionally, while we believe this system could be beneficial for all controllers, we recognize that controllers experience varying levels of comfort with automation systems. The system should be capable of being disabled by controllers who find it distracting, and enabled by those who appreciate the additional miscommunication alerts.

Cost/Benefit Analysis

The largest upfront cost required to get this system ready for real-world use is development time. We estimate that a team of five full-time developers could complete this software, including implementing live radio transcriptions, in 6 months. Assuming 40-hour work weeks, the development time will be roughly 5,200 person-hours. According to Indeed (an employment related website), the average FAA software developer salary is $92,074 per year, or roughly $49.40 per hour (Indeed, n.d.). Thus, the total estimated development cost will be roughly $256,880. The software must also be thoroughly tested, which will likely take roughly 200 hours. Using the same developer pay, this testing will incur a one-time cost of $9,880.

Each facility implementing the system would need a rack server to process the transcriptions and radio calls. One of the most common rack servers for similar workloads is the Dell EMC PowerEdge R340, costing roughly $1,463 (Dell, n.d.). Additionally, each facility would need to train controllers to use the new technology, which we estimate would require roughly 8 hours per person. Although the number of controllers varies widely dependending on the facility, we will consider a moderately-sized Class D airport with 10 controllers on staff. According to the Bureau of Labor Statistics, air traffic controllers have a mean hourly wage of $61.50 (Bureau of Labor Statistics, 2021). Thus, training would cost roughly $4,920 per facility. We can also assume there will be 5 hours of system maintenance per month, or 60 hours per year. At the software developer wage of $49.40 per hour, this ongoing cost will be roughly $2,964 per year per facility.

Initial Implementation Costs				
Item	**Rate**	**Quantity**	**Subtotal**	**Remarks**
Software development	$49.40/hr	5200 hr	$256,880	Calculated using average FAA software developer salary, assuming five developers, 40hr work weeks and 6 months of development time.
Software testing	$49.40/hr	200 hr	$9,880	
Subtotal			**$266,760**	

Per-Facility Adoption Costs				
Item	**Rate**	**Quantity**	**Subtotal**	**Remarks**
Dell EMC PowerEdge R340	$1,463/ea	1	$1,463	
Controller training	$61.50/hr	80 hr	$4,920	Assuming training takes 8hr per controller at a facility with 10 controllers.
System maintenance	$49.40/hr	60 hr/yr	$2,964/yr	Recurring yearly cost.
Subtotal			**$9,347**	**First year cost. Subsequent years cost $2,964.**

National Adoption Costs 315 towered airports, 15,000 controllers (Potter, 2014)				
Item	**Rate**	**Quantity**	**Subtotal**	**Remarks**
Dell EMC PowerEdge R340	$1,463/ea	315	$460,845	
Controller training	$61.50/hr	120,000 hr	$7,380,000	Assuming training takes 8hr per controller with 15,000 controllers in the NAS.
System maintenance	$49.40/hr	18,900 hr/yr	$933,660/yr	Recurring yearly cost.
Subtotal			**$8,774,505**	**First year cost. Subsequent years cost $933,660.**

Table 5: Overview of implementation, per-facility and national adoption costs.

From the controller survey conducted and discussed in the "Research and Literature Review" section, we determined that self-reported communication issues requiring clarification occur in approximately 9.5% of radio transmissions. At an air traffic control facility with 240 operations per day and an average of 8 communications per aircraft (numbers gathered while listening to Tower and Ground communications at KEMT) there will be roughly 182 instances of miscommunication. From discussions with industry experts, clarifications require an average of 20 seconds of attention from the controller, including detection, processing and verbal confirmation with the aircraft. As a majority of the controller's attention goes towards processing the miscommunication, the proposed system should be capable of reducing clarification time to 10 seconds, halving the amount of time controllers spend on resolving communication issues. Currently, assuming 20 seconds of attention is needed to handle communication issues, 182 instances of miscommunication would require just over one hour of controller attention per day, or 369 hours of attention per year. However, with the proposed solution and estimated savings of 10 seconds per instance, time spent handling communication issues could be cut by approximately 30 minutes per day, or 184.5 hours per year, freeing controllers to handle additional traffic or manage existing traffic with less overhead. Expanded more broadly to the entire National Airspace System, there are 16,405,000 flights handled by the FAA every year and roughly 131,240,000 communications per year (FAA, 2022). Using the same metric, we expect there to be 12,467,800 instances of miscommunication per year, requiring a cumulative 69,265 hours of controller attention. With the proposed solution, this could be reduced by 34,632 hours per year.

In addition to time savings, the proposed solution can increase safety and decrease the likelihood of accidents and serious incidents. Specifically, from discussions with airport operators, communication issues play a role in approximately 25% of runway incursions. Assuming the proposed system is capable of detecting and helping controllers mitigate these communication issues in 30% of instances, a 7.5% decrease in runway incursions can be expected. In 2016, runway incursions were estimated to cost a total of $200 million in delays and decreased operations, so a 7.5% reduction in runway incursions would equate to $15 million in yearly savings (Safe-Runway GmbH, 2017).

National Adoption Benefits		
Item	**Subtotal**	**Remarks**
Controller time saved	$2,129,868/yr	Based on 34,632 hours saved per year at $61.50/hr.
Decreased runway incursions	$15,000,000/yr	Based on $200 million yearly cost of runway incursions, and a 7.5% reduction in incursions using the proposed solution.
Subtotal	**$17,129,868/yr**	

Table 6: Overview of benefits and cost savings using the proposed solution.

Over 10 years, the proposed solution is expected to cost $18,377,865 ($266,760 implementation cost, $8,774,505 first year cost, $933,660 subsequent year cost). In contrast, the system is expected to save $171,298,680 in controller time and decreased cost of runway incursions. Thus, over a 10-year period, the benefits of the system outweigh the costs by a factor of 9.3. It is worth noting that these estimates do not consider salary increases, inflation or hardware replacements over a long period of time. However, we do not expect these additional costs to have a significant impact when compared with the benefits of the system.

Fulfillment of FAA and ACRP Goals

Although much has changed since the early days of aviation, one constant has been radio communication, which has been a reliable system since AT&T invented the first air-to-ground communication system in 1917 (Army Center of Military History, 2006). Since then, languages have been standardized and communication ranges have increased, but the core technology has remained unchanged: two people talking into microphones.

The FAA's mission is "to provide the safest, most efficient aerospace system in the world," and the ACRP strives to improve aviation with "practical solutions to airport challenges" (FAA, n.d.; Transportation Research Board, n.d.) We believe our proposed solution accomplishes both of these goals. By harnessing modern artificial intelligence, controllers can be informed in real-time about potential miscommunication before it becomes a problem, increasing both efficiency over the radio and overall flight safety. Additionally, we have found this solution to be practical from both a cost and practicality of adoption perspective.

Appendix A

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Appendix B

“Oregon State University is a comprehensive, research intensive public land-grant university. OSU is one of only two land-, sea-, space- and sun-grant universities with such designation in the country. Oregon State programs and faculty are located in every county of the state and investigate the state's greatest challenges. The state of Oregon is OSU’s campus but our mission is to serve the state, the nation and the world. The university works in partnership with the P-12 school system, Oregon community colleges and other colleges and universities to provide access to high-quality educational programs. Strong collaborations with industry and state and federal agencies drive OSU's research enterprise.” (Oregon State University, n.d.)

Appendix C

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Appendix E

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The ACRP Design Competition has certainly been a meaningful learning experience. Through the competition, I have had the opportunity to perform exciting research, talk with industry experts and hone my technical writing skills. In addition, creating the proof-of-concept software allowed me to implement many of the theoretical concepts and design strategies I had learned in classes into a real-world, functioning program.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

Interviewing an air traffic controller was critical for this project, as they are the target audience for the product being designed and would thus be the only ones who could provide me with key information to make it successful. Unfortunately, finding a controller to talk to proved to be more challenging than I had originally anticipated. Initially I planned to schedule a tour of a tower and ask communication-related questions in-person, but after calling four airports in Oregon, I realized the ongoing COVID-19 precautions made this goal impossible. Next I attempted to schedule a phone interview, but was turned away from the first airports I contacted. Eventually I was able to get an interview scheduled, but it too was later canceled on short-notice. Back to square one, Dr. Wagstaff suggested contacting airports outside of Oregon, which is eventually how I found Eric Lyn at San Gabriel Valley Airport (KEMT) in El Monte, California.

3. Describe the process you or your team used for developing your hypothesis.

After first hearing about the ACRP Design Competition, I spent a few weeks brainstorming problems I had faced as a pilot. During this period, I went on an IFR training flight where one of the controllers repeatedly switched two numbers in the call sign. This interaction prompted me to think more about communication in aviation, and how it could be improved to increase safety. I hypothesized that artificial intelligence may be able to play a role in detecting these communication issues.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Participation by airport operators and industry experts was absolutely useful in this project. Each person interviewed contributed new insights, suggestions and anecdotes from their own experiences in industry. Talking with individuals from a wide range of backgrounds helped me keep my research grounded in reality.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

While working on this submission for the ACRP Design Competition, I had the opportunity to improve my research, technical writing and project management skills. These skills are all incredibly valuable in the workforce, and especially while pursuing a technical career in the aviation industry.

Faculty

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

The ACRP competition provided an opportunity for Andrew to go well beyond the kind of assignments and projects involved in a typical college experience. He identified a key issue in aviation safety (miscommunication between pilots and controllers), did extensive research to identify the biggest challenges, and developed a proposed solution along with an assessment of its costs and benefits. To ensure that his design aligned with true needs, he devised and conducted a survey of air traffic controllers to elicit their views on types and prevalence of miscommunication. He supplemented the survey with in-depth interviews of an air traffic controller, flight instructor, and professor of psychology. He also applied his skills in software design and development to create a prototype solution to detect and provide alerts for miscommunications. Overall, the ACRP competition enabled Andrew to combine his knowledge as a pilot with his computer science and research skills to propose a solution of potentially great benefit to the aviation community.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. I will add that in my view, the focus and scope of the project that Andrew (an undergraduate junior) chose was closer to the depth of investigation that I would anticipate coming from a Master's graduate student.

3. What challenges did the students face and overcome?

A major challenge to Andrew's project was the difficulty of gaining access to air traffic controllers. Their on-the-job experience provides a key element for characterizing miscommunication types and frequency. Due to the COVID-19 pandemic, typical opportunities like tours of ATC towers were not an option. Andrew reached out to several facilities to try to arrange individual interviews. In most cases he was told no, and in one case an arranged interview was canceled by the facility at the last minute. His persistence enabled him to obtain the primary source information despite the current restrictions and challenges. A second challenge is that Andrew worked on this design as a solo project. He did not have peers with whom he could share the work that was required, yet the final design is extensive, carefully researched, and compelling.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes. The ACRP competition gives students a chance to investigate real-world challenges of relevance to aviation in depth and with an assessment of real impact. Positioning the investigation within a competition infuses the work with additional motivation.

5. Are there changes to the competition that you would suggest for future years?

One suggestion would be to create an online environment in which participants from different universities could connect. Those with similar interests might lead to further collaboration in the future or help each other build their professional networks.

Appendix F

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