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THESIS

**AUTOMATED VOICE-CONTROLLED TACTICAL AIR
TRAFFIC CONTROL SIMULATION TRAINING**

by

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September 2023

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**AUTOMATED VOICE-CONTROLLED TACTICAL AIR TRAFFIC CONTROL
SIMULATION TRAINING**

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Submitted in partial fulfillment of the
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ABSTRACT

Simulation is a critical component of training tactical air traffic controllers within the Marine Air Command and Control System. The effectiveness of this training is directly related to the abilities of the simulation operators who provide the environment the student air traffic controllers train in. The majority of simulation operators tasked to provide training lack the abilities to provide effective training. This thesis research addresses the gaps in the abilities of simulation operators through leveraging speech recognition and synthetic voice software to automate simulation operator roles. The research was conducted in two phases. First, the development of an automated training prototype to fill the role of a simulation operator. And second, a survey to compare the performance of the developed prototype to the current training methods. The results of the survey show that the prototype is capable of handling routine simulation operator tasks. The prototype was particularly strong at interacting with the simulation software to “fly” simulated entities; however, the prototype struggled to match human performance in handling the complex problem of grammatical variations in air traffic control speech amongst the Marine Air Command and Control agencies.

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List of Acronyms and Abbreviations

API	Application Programming Interface
CAC2S	Common Aviation Command and Control System
DASC	Direct Air Support Center
DIS	Distributed Interactive Simulation
FAA	Federal Aviation Administration
FAST	FLAMES Automated System Trainer
FIRE	FLAMES Interactive Runtime Executable
FLAMES	Flexible Analysis, Modeling, and Exercise System
FLASH	FLAMES Scenario Highlighter
FORGE	FLAMES Operational Requirements Graphical Editor
ICAO	International Civil Aviation Organization
IDE	Integrated Development Environment
MACCS	Marine Air Command and Control System
MAGTF	Marine Air-Ground Task Force
MATCD	Marine Air Traffic Control Detachment
MISTEX	MACCS Integrated Simulation Training Exercise
PDU	Protocol Data Unit
SAPI	Speech Application Programming Interface
TACC	Tactical Air Control Center
TAOC	Tactical Air Operations Center

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CHAPTER 1:

Introduction

Simulations have long been an integral component of Marine Air Command and Control System (MACCS) training. Simulations present the opportunity to train controllers, crews, and control agencies in the absence of live aircraft. This has numerous benefits to include reducing costs required to conduct training, increasing the amount of training repetitions, and enabling the training audience to make mistakes in a safe environment that does not threaten the lives of pilots and aircrew. The current method of conducting MACCS simulation training is highly reliant on simulation operators. The proficiency of these operators directly influences the effectiveness of the training.

Simulation operators, commonly known as pucksters or bug pilots, provide the critical role of interacting with the training audience to fully simulate aircrew actions. Simulation operator responsibilities include responding to student controller voice commands, driving simulated aircraft entities in accordance with those commands, coordinating with the simulation cell leadership to provide synchronized training events, and making tactical decisions as the “pilot” in command of simulated aircraft. Performing as a simulation operator is not an easy task, and a poor operator can degrade the training experience of the controllers, crews, and agencies conducting training.

While there are capable simulation operators, there are generally not enough to completely meet all training requirements. This is particularly true as the level of training rises from individual to the crew or agency level. The higher the level of the training event, the more simulation operators needed, and the more proficient they must be to support the training. The MACCS agencies must provide these simulation operators from the same group of controllers who could be participating in the training. Often controllers who show potential as a simulation operator are continually placed in that role, preventing them from progressing further in their fields.

To provide a good training experience, simulation operators must be proficient in three areas. First, they must be proficient in the crew position they are providing training for. Second, they must be proficient in simulating the mission sets of the aircraft they represent.

And finally, they must be proficient in the use of the simulation software used to conduct the training. A gap in any proficiency can negatively impact the training as described earlier. The focus of this thesis is the development of a prototype simulation trainer, capable of fulfilling the role of a simulation operator conducting training for tactical air traffic control common to the MACCS agencies.

1.1 Problem Statement

There is a manpower shortage of proficient simulation operators for conducting simulation training within the MACCS. This shortage leads to reliance on simulation operators who lack proficiency in their military occupational specialty, the roles they simulate, or the use of their simulation software. The MACCS community does not take advantage of the technical solutions employed in the commercial air traffic control industry to augment training through automated simulation operators. Utilizing these technical solutions will result in reduced numbers of personnel required as pucksters while providing a better and more consistent training experience to the training audience.

1.2 Research Questions

1. What is the feasibility of integrating synthetic voice and speech recognition software into current military simulation systems to automate tactical air traffic control simulation training?
2. How will the use of an automated simulation trainer compare to the current training method of reliance on simulation operators?

1.3 Scope and Limitations

This thesis is focused on the development of a prototype simulation trainer that can be used to fill the role of simulation operators conducting tactical air traffic controller training in the MACCS. The prototype was designed and built to be capable of integrating with current MACCS equipment and software to the greatest extent possible. This prototype is not a direct plug and play with current MACCS equipment; however, it is a step in the right direction of enhancing MACCS simulation training with modern technology.

The first step of this thesis was an investigation of similar work in the air traffic control field. This step was used to identify modern technology solutions available and see the approaches other took to solve this problem. The second step was the development of the prototype itself. This step included the design, programming, and initial testing of the prototype. And lastly, the final step was an evaluation of the prototype compared to the current training method of using simulation operators. This step was necessary to evaluate the utility of the prototype and determine if it was a useful tool or not.

1.4 Benefits of this Study

The benefits of this study are the production of a prototype capable of providing automation in tactical air traffic controller simulation training. This reduces the requirements on MACCS agencies to maintain and train cadres of proficient simulation operators to facilitate training. An automated capability would provide a consistent training environment, independent of simulation operator proficiency levels. Furthermore, an automated trainer would reduce the manning and training costs associated with executing tactical air traffic control simulation training. In addition, air control simulation training occurs within the joint force and this study could provide value to other services or communities automation through voice-controlled simulation.

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CHAPTER 2:

Background and Related Work

To understand the areas of improvement available in military air traffic control simulation training, we must have some knowledge of military air traffic control structure, current training practices, state of the art technologies, and the work conducted in the general area of study. With this knowledge we can compare the current practices and identify areas where new technologies can increase automation in military simulation training. This chapter will review the MACCS to establish a base framework for current military air traffic control system. Next, we will cover current simulation practices within the MACCS. And finally, we will explore the related work conducted in the area of air traffic control simulation training. With these pieces, we will have a good intuition of how military air traffic control simulation training can be improved with automation technologies.

2.1 The Marine Air Command and Control System

This section establishes the baseline for how military air traffic control is currently conducted within the Marine Corps. The MACCS is the system through which the Marine Corps conducts the command and control of aviation assets. The MACCS philosophy of command and control is centralized command and decentralized control [1]. The planning, operations, and employment of the MACCS are covered in [1]. The MACCS functions as a collection of agencies, each serving a specific purpose to enable the Marine Air-Ground Task Force (MAGTF) to conduct the six functions of Marine Aviation. The senior MACCS agency is the Marine Tactical Air Control Center (TACC), who exercises centralized command. The TACC's subordinate agencies are the Direct Air Support Center (DASC), Tactical Air Operations Center (TAOC), and Marine Air Traffic Control Detachments (MATCDs) which provide the decentralized control. The roles and purposes of the MACCS agencies are discussed in detail in the following subsections.

2.1.1 Marine Tactical Air Control Center

The Marine Tactical Air Control Center Handbook describes the TACC as the senior agency of the MACCS [2]. The handbook states that the TACC serves as the centralized command post from which the MAGTF Aviation Combat Element commander exercises command over air operations. The handbook emphasizes the TACC does not directly perform air control, it exerts influence through its subordinate agencies as well as serves as the integration point for the MACCS to the rest of the MAGTF. Additionally, the handbook states the TACC plans, supervises, and executes all air operations within the MAGTF's assigned airspace and it integrates Marine aviation fires into the MAGTF targeting process.

2.1.2 Direct Air Support Center

The Direct Air Support Center Handbook describes the DASC as the "principal MACCS air control agency, responsible for the direction of air operations directly supporting ground forces" [3]. The handbook adds the DASC uses procedural air control to process requests for air support, integrate aviation assets with ground-based fires, and provide safe transit to aircraft within its assigned airspace. The handbook describes a DASC crew as having two controllers responsible for control of aircraft, the Tactical Air Director and Helicopter Director. The handbook further states the Tactical Air Director is responsible for controlling fixed-wing aircraft, and the Helicopter Director is responsible for controlling helicopters and unmanned aerial systems. These controllers provide aircrews their missions, threat information, and deconfliction of aircraft with fires missions.

2.1.3 Tactical Air Operations Center

The Tactical Air Operations Center handbook identifies the TAOC as the primary control agency responsible for airspace surveillance and control of anti-air warfare missions [4]. The handbook adds the TAOC uses its organic sensors to produce a common air picture for the MAGTF and provide positive control of aircraft. As described in the handbook, a TAOC crew has two types of controllers, the Tactical Air Traffic Controller and Air Intercept Controller. The handbook further details the Air Intercept Controller is responsible for controlling all anti-air warfare missions and the air intercepts of airborne targets. The Tactical Air Traffic Controller is responsible for routing of all aircraft assigned to the TAOC that are not under control of the Air Intercept Controller. The Tactical Air Traffic Controller

provides mission information, situational awareness, and traffic deconfliction for all aircraft under their control.

2.1.4 Marine Air Traffic Control Detachment

The Marine Air Traffic Control Detachment handbook describes the MATCDs as the principal terminal control agencies for the MAGTF. The handbook states their mission to “provide all-weather radar, non-radar, and tower air traffic control services to the MAGTF” [5]. The handbook adds that MATCDs operate similarly to the commercial air traffic control system and follow Federal Aviation Administration standards, allowing them to operate within the U.S. National Airspace System controlled by the Federal Aviation Administration (FAA) as well as the airspace systems of International Civil Aviation Organization (ICAO) members. The handbook further details the crew and controllers of the MATCD as follows. A MATCD has controllers in Tower Sections or Radar Sections. Tower Section controllers consist of Local Controllers and Ground Controllers. Local Controllers sequence and separate aircraft in airspace and runways assigned to the air traffic control tower. Ground Controllers issue ground movement clearances to vehicles and aircraft on the airfield. The Radar Section controllers are the Approach Controller, Arrival/Departure Controller, and Final Controller. The Approach Controller is responsible for all instrument flight rules traffic within their assigned airspace and transfers control of aircraft to the Arrival/Departure Controller. The Arrival/Departure Controller provides services to aircraft once received from the approach controller until handing them off to a Local or Final Controller. The Final Controller provides precision approach radar services during reduced visibility periods. In addition to the tower services, the handbook adds, MATCDs provide Marine Air Traffic Control Mobile teams that can provide Local Controller services in austere environments.

2.2 MACCS Simulation Training

The MACCS is a diverse collection of different control agencies with many different training requirements. This section will generalize the different simulation practices used amongst the MACCS agencies to meet their specific training requirements. Simulation is a large part of MACCS agency training. The DASC and TAOC have recently updated the majority of their live controller training requirements to allow them to be carried out in live, virtual,

or constructive environments [6], [7]. The TAOC has additionally implemented simulation development and simulation operator training into its instructor training syllabi.

2.2.1 Unit Level Training

Unit level training (i.e., training that does not incorporate higher level units) is an integral part of MACCS agency training. The majority of unit level training is focused individual crew member training. Every MACCS agency has a training and readiness manual that dictates the training syllabus for all of the agencies' crew positions. These syllabi consist of training events in different skill areas that must be completed in order to attain proficiency in a crew position. These training events range from academic study to performance events. The smaller scale of unit level training makes it easier to conduct on a daily basis, as it does not require large amounts of instructors or resources. MACCS agencies currently use simulation capabilities embedded in their tactical systems to conduct unit level training.

The basic construct of using simulation to conduct individual training relies on simulation operators. Simulation operators are the instructors who develop and execute simulation training. In unit level training, simulation operators are generally experienced controllers who are already proficient in the crew position they will be providing training for. The biggest role these simulation operators play in controller training is that of a pseudo-pilot. As a pseudo-pilot, the simulation operators are responsible for providing the responses and training inputs to the student controllers. A good simulation operator is able to provide appropriate aircraft responses and inputs, use their respective simulation software to "fly" simulated entities, and provide feedback on student performance. Most individual training events are not robust scenarios and simulation operators are able to fill their role and provide respectable training. However, not all individual training events can be completed at the unit level. Some training events require coordination with other MACCS agencies. To accomplish these events through simulation, MACCS agencies conduct MACCS Integrated Simulation Training Exercises (MISTEXs).

2.2.2 MACCS Integrated Simulation Training Exercises

The MISTEX is the MACCS's vehicle to integrate its agencies in a simulated training environment. The primary purpose of a MISTEX is to establish a fully capable MACCS for

supporting future live air operations [2]. They are designed to exercise crew coordination, information flow, and agency integration. While the primary purpose is not individual training, individual training events can still be accomplished by student controllers. However, several factors may limit the effectiveness individual training events in a MISTEX.

Individual controller training in a MISTEX is accomplished in much the same way as in unit level training. A controller student will still interact with a simulation operator performing as a pseudo-pilot. The major differences are that the simulation operator is usually no longer the experienced controller as before and the scenarios are typically much more robust. The scenarios are not only more robust for the student, they are also more robust for the simulation operator. This requires additional tasks to be performed by the simulation operator as they must coordinate with other members of the simulation cell to ensure a consistent simulation is occurring across the MACCS.

During a MISTEX, the MACCS agency crews are manned to their full levels. This often means the experienced controllers who provided simulation operator services at unit level training are now filling senior crew position roles within the agency, and unavailable to be pseudo-pilots. Since the crews are being fully manned, this means that multiple controllers will be training simultaneously and multiple simulation operators will be needed to provide that training. Not only are the experienced simulation operators no longer available, there are now larger manpower requirements for simulation operators. This often leads to units placing whoever is available in the pseudo-pilot role, even if they lack the ability to do the job well. This degrades individual controller training as an inferior pseudo-pilot will not provide appropriate responses and inputs, may not be able to drive simulated entities as directed, as well as may not be able to provide constructive feedback on controller performance.

In addition to degrading individual training, the shortage of pseudo-pilots will degrade the agency training and impact the primary objective of preparing the MACCS to operate as a system. The scenarios in a MISTEX are much larger than unit level training and there are many more simulated aircraft and fire missions to be carried out by the simulation cell. The inferior pseudo-pilots will struggle to control all of the simulated entities assigned to them. They will often lose track of simulated entities they are piloting when voice responses are required at a rapid rate. In addition to losing track of entities, pseudo-pilots may cause inconsistencies in the training environment. For example, an aircraft that was originally

scheduled to transfer from one agency's airspace to another's may be re-tasked to remain in the first agency's airspace. If the pseudo-pilots for the two agencies do not coordinate, it is possible that they may both represent the same aircraft simultaneously to their respective student controllers. This could cause conflicts in the MACCS as the agencies are trying to source aircraft to missions and are unable to determine the agency the aircraft is actually working for because it appears to be responding to both agencies simultaneously. More common inconsistencies come from not maintaining the proper states of the aircraft, such as fuel levels or weapons expended.

2.3 Related Works

With the knowledge of the MACCS and its current simulation training practices covered, we now turn our focus to related work in the area of automation of air traffic control simulation. This section will cover the state-of-the-art technologies, challenges, and opportunities in integrating automation into MACCS simulation training. Each subsection details the works of researchers conducting similar research to this thesis.

2.3.1 Possibilities, Challenges, and the State-of-the-Art of Automatic Speech Recognition in Air Traffic Control

In a journal article for the International Journal of Computer and Information Engineering, Nguyen and Holone [8] present the results of an extensive literature review of modern automatic speech recognition technologies and approaches to applying automatic speech recognition in air traffic control applications. The authors goal is provide a good starting point for researchers in the field to understand the challenges associated with developing automated speech recognition systems in air traffic control applications and understand general criteria for selecting an automated speech recognition technology to use.

To begin, Nguyen and Holone give a general overview of the classification of modern speech recognition technologies. The authors use the definitions in [9] to classify speech recognition systems by three categories, type of speech utterance, type of speaker model, and vocabulary the system can recognize. There are subcategories within each of these categories as described here:

1. **Speech Utterances** – In their article, Radha and Vimala [9] categorized four classes of utterances that define how a speech recognition technology works. The authors define a speech utterance as the smallest unit of speech. An utterance can be as small as the sounds of a word.
 - (a) **Isolated Words** – Isolated word recognizers can only recognize a single word and require gaps of silence surrounding the spoken word.
 - (b) **Connected Words** – Connected word recognizers also need space between utterances, however they can recognize more than a single word at a time.
 - (c) **Continuous Speech** – Continuous speech recognizers can recognize multiple words spoken naturally.
 - (d) **Spontaneous Speech** – Spontaneous speech recognizers are similar to continuous speech recognizers with the added capability of recognizing stutters, mispronunciations, and non-words. [9]
2. **Speaker Models** – Radha and Vimala define the two broad categories of speaker models. This delineation is necessary as all speakers have unique voices and speech patterns. The two categories the authors state in their article are:
 - (a) **Speaker Dependent** – Speaker dependent models are designed for a specific speaker. They are generally more accurate for the particular speaker, but much less accurate for other speakers. These systems are usually easier to develop, cheaper and more accurate, but not as flexible as speaker adaptive or speaker independent systems.
 - (b) **Speaker Independent** – Speaker independent systems are designed for variety of speakers. It recognizes the speech patterns of a large group of people. This system is most difficult to develop, most expensive and offers less accuracy than speaker dependent systems. However, they are more flexible. [9]
3. **Vocabularies** – The final category Radha and Vimala use to categorize speech recognizer systems is vocabulary size. The authors detail the subcategories as follows:
 - (a) **Small vocabulary** – tens of words
 - (b) **Medium vocabulary** – hundreds of words
 - (c) **Large vocabulary** – thousands of words
 - (d) **Very-large vocabulary** – tens of thousands of words
 - (e) **Out-of-Vocabulary** – Mapping a word from the vocabulary into the unknown word [9]

Nguyen and Holone [8] recommend that for air traffic control applications, to include automated simulation applications, researchers should select an automatic speech recognition technology that supports continuous speech recognition, uses an independent speaker model, and is capable of handling a medium vocabulary. The authors recommended speech recognition technology is best suited to meet the five challenges of automatic speech recognition integration in air traffic control applications. The five challenges are call sign detection, poor input signal quality, ambiguous terms, use of non-standard phraseology, and multiple languages [8]. These challenges are also present in military air traffic control communications.

The challenges that most inhibit the integration of speech recognition technology into MACCS simulation capability are call sign detection, ambiguous terms, and non-standard phraseology. Call signs are an important feature of air traffic control communications. They identify who is speaking to whom. Call sign detection can be difficult in military air traffic control because the same flight may be referred to by different variations of the same call sign. For example the call sign “Hawk21” could be transmitted as “Hawk21,” “Hawk,” or “1” depending on the context of the communications. This ambiguity can cause problems when there are multiple flights under different variations of a call sign, such as “Hawk21” and “Hawk31.” Call sign detection is important in simulation because the pseudo-pilot must correctly identify the simulation entity to manipulate by its call sign.

Ambiguous terms are another point of friction military air traffic control speech recognition. One example is that aircraft headings, bearings measured between an aircraft an object, altitudes, and speeds are all expressed three numbers spoken one digit at a time. It can be difficult to differentiate the meaning behind the terms as they are all expressed the same.

Finally, the lack of a non-standard phraseology amongst the MACCS agencies means that an automated speech recognition for MACCS simulation training must recognize the multiple forms of commands given by the various agencies. This challenge goes even deeper than the agency level, as individual controllers each have their preferred style of control. Nguyen and Holone [8] provide an excellent example of this by referencing an analysis of European air traffic controllers speech conformance to ICAO standards, where it was shown that less than 30% of controller utterances conformed to the standard’s recommendations [10].

2.3.2 An Automated Simulation Pilot Capacity to Support Advanced Air Traffic Controller Training

An application of automated speech recognition and synthetic voice technologies in commercial Air Traffic Control training was conducted by Tarakan et al. [11]. The authors detail their research in developing a high-fidelity training prototype for the FAA called the enrouteTrainer. The authors' goal was to provide an overview of the enrouteTrainer and its performance in field tests. The article also covers metrics that can be used to evaluate automated simulation trainer systems.

The enrouteTrainer was designed to meet specific requirements to support training air traffic controllers. Tarakan et al. [11] designed the enrouteTrainer to be able to respond to air traffic controller communications, model the flight of the simulated aircraft entities, and also initiate communications with the controller in relevant situations. In addition to providing the pseudo-pilot functions for training, the enrouteTrainer also collects communications data to aid in the analysis of controller performance. Taraken et al. also state that the enrouteTrainer was not designed to perform to the highest abilities of human pseudo-pilots. The authors' design focused on limiting costs and performing to a high enough level to support the training objectives.

The enrouteTrainer developers selected Nuance ASR 8.5 for speech recognition and RealSpeak Telecom 4.0 for speech synthesis [11]. The Nuance ASR 8.5 was selected for its numerous capabilities to aid in recognizing speech [11]. These abilities include speaker independence, providing a confidence score to transcriptions, the ability to return a specified number of potential recognitions ranked by confidence score, the ability to provide a partial transcription when a full recognition is not possible, ability to include key-value pairs in recognition results to aid in processing, and the ability to accept static and dynamic grammars [11]. The authors configured the Nuance ASR 8.5 to increase its performance in recognizing air traffic control speech. These configurations were providing a specific grammar, specific phonetic model, and settings to prefer accuracy over computational speed [11]. The RealSpeak Telecom 4.0 was selected as the speech synthesis engine for its speech quality, number of English speaking voices, and the ability to change the rate of communications [11]. Specific configurations applied by the authors providing specific phonetic models, increasing the rate of speech 15%–20%, and using several English voices [11].

Performance of the enrouteTrainer was measured by a speech quality metric. Voice data was recorded for two trainees conducting four separate training events. The voice data was manually transcribed by humans and compared to the Nuance ASR 8.5 transcription. Transcriptions and the performance of the automated system were used to categorize the speech quality in the following categories as described in [11]:

1. **Verbatim match** – The human and Nuance ASR 8.5 transcriptions match character for character. Correct simulation behavior is observed.
2. **Semantic match** – Minor differences between the transcriptions that do not affect the carrying out of the controller instruction in the simulation.
3. **Action match** – Parts of a controller instruction may be incorrect, but recognition is still good enough to generate the appropriate simulation behavior and speech synthesis response.
4. **Action match or "Say Again"** – This category extends Action Match to include the "Say Again" situations. "Say Again" situations occur when there was a non-recognition and the system prompted the student to repeat their call.
5. **Incorrect** – The recognition was incorrect and generated an incorrect response or simulated aircraft behavior.

Results of the data collection showed that on average the enrouteTrainer incorrectly recognized 4.9% of trainee utterances and achieved at least an Action Match or "Say Again" in 95.1% of utterances. Removing the non-recognitions the trainer achieved at least an Action Match in 86.7%, a Semantic Match in 86.1%, and a Verbatim Match in 74.1% of utterances [11]. In addition to the qualitative data, Tarakan et al. provided a qualitative assessment of the research. Key takeaways from the qualitative assessment include remarks on the timing of voice responses from the automated trainer and impacts of "Say Again" situations on trainee performance. The timing voice responses was very quick for longer pilot readback responses, the suggestion was made to explore adding a delay to the responses to account for pilot processing time. The "Say Again" situations, or non-recognitions, arose when the trainee used improper phraseology. If a trainee received multiple "Say Again" responses in row, an instructor was needed to correct the trainee and continue the training.

2.3.3 Air Support Control Officer Individual Position Training Simulation

The most similar work completed is a Master's thesis from the Naval Postgraduate School, where a DASC officer researched how automation could be used to improve Air Support Control Officer Training.. In the thesis, Haggard [12] developed a prototype simulation trainer using the Unity game engine to support training events for Tactical Air Directors in the DASC. The research focused on building an effective training tool that could be used to increase the quality and frequency of controller training. To measure the effectiveness of the prototype, subject matter experts were brought in for a demonstration to measure their attitudes and thoughts on the prototypes use as a training tool within the DASC.

To begin, Haggard [12] provides an overview of current issues with DASC simulation training. The problems identified by Haggard include training not meeting the level of complexity in terms of aircraft volume and number of fire mission to meet training requirements, extensive time and resource costs to generate and execute effective simulations, and a lack of recorded data for after action reports or controller feedback purposes. These problems are not limited to the DASC, many of the same problems can be seen in training conducted by other MACCS agencies.

Haggard [12] developed the prototype trainer as a potential solution to the problems described above. The prototype used speech recognition and synthetic voice technology to provide an interactive voice mechanism for training. Not only did the trainer respond to controller voice communications, it also had the capability to prompt the controller in appropriate situations, such as when a simulated aircraft was established in its assigned working area. The trainer provided a graphical representation of the state of the airspace and other situational awareness tools used within the DASC. These tools were a map of the airspace, a radio in/out board, and simulated internet chat rooms used in Marine operations. The graphical state representation was updated by the voice command interactions of the student controller and text input. The speech recognition engine was provided a grammar specific to the training tasks the prototype was developed for. The grammar was able to accurately recognize 31 commands and 347 phrases [12].

The feedback provided from the subject matter experts was positive. The experts concurred that including an automated trainer into current DASC controller training would improve

the DASC community's ability to qualify controllers. Recommendations from the experts were to expand the vocabulary of the trainer to cover more controller tasks, incorporate an intelligent tutoring system, and adding the ability for scenario development and generation. The feedback provided from the DASC subject matter experts and research conducted by Haggard is valuable in the research of this thesis. Haggard's research provides a good starting point and look into the problems, requirements, and potential solutions for developing an automated trainer for the MACCS community.

The key observations to take from this review of related work are that the technologies used for speech recognition and synthesis have advanced far enough to support air traffic control functions and that several simulation training implementations have been constructed using them. These implementations show a path forward to developing a simulation trainer for the MACCS. This research will seek to develop a simulation trainer for MACCS agencies that integrates with their current equipment and can fill the gaps when there are shortages of simulation operators.

CHAPTER 3: Methodology

This chapter details the methods taken to investigate the research questions. The research was broken into two phases. The first phase was the development of a working prototype automated trainer. The second phase was the conduct of a test experiment to measure the quality and accuracy of the prototype compared to the current training methods.

3.1 Prototype Development

This section explores the development of the prototype trainer. It will cover the generation of requirements, proposed design solution, and equipment used to build the prototype. Source code for the prototype trainer can be found at <https://gitlab.nps.edu/daniel.anderson/AutoBugPilotService>.

3.1.1 Requirements

The primary requirement of the prototype was to support Tactical Air Traffic Controller Training within the MACCS. As detailed in Chapter 2, there are many various air traffic control agencies and controllers within the MACCS. To design a prototype capable of supporting training for every controller would take more resources than were available for the conduct of this research. A constraint was placed on the design that the emphasis of development would be compatibility with MACCS equipment. The training supported by the prototype would focus on the fundamentals of air traffic control common to all controllers. Further details on training functionality will be covered in section 3.1.2 under Grammar Design. The goal was to develop a prototype that provided a solid base on which further development could be used to support the specific training requirements of the different MACCS agencies.

3.1.2 Design Overview

This section provides a high level overview of the prototype design and covers the development of the higher level sub-components of the prototype. As mentioned in section 3.1.1,

the focus of the design was on compatibility with MACCS equipment. These details are contained in the paragraphs on physical system design. The second part of the design was the design of the speech recognition grammar. The design of the grammar was required to improve system recognition accuracy in the training tasks the prototype was designed to support.

Physical System Design

The focus of the system design was to develop a system that was capable of integration with MACCS equipment and simulation software. The primary piece of equipment in mind during development was the Common Aviation Command and Control System (CAC2S). CAC2S is the command and control equipment system used by all MACCS agencies with the exception of the MATCDs. This thesis will not go into great detail on the design of CAC2S; however, two key design considerations were made based on the design of CAC2S.

The first consideration was to use the same simulation software in the prototype that is embedded in CAC2S. This software is the FLAMES Automated System Trainer (FAST) and will be discussed in greater detail in section 3.1.4. The second consideration was to develop the prototype as a centralized in-process speech recognizer. FAST resides on a server within CAC2S and not the individual controller workstations. A centralized in-process speech recognizer could be used to handle multiple connections from controller workstations to the simulation server, much like an automated call center server can handle multiple phone calls. The centralized in-process design was chosen to maximize the amount of controllers that could connect to the prototype at any given time.

To meet the in-process speech recognizer design, a communications protocol was needed to standardize the audio formats being sent to the speech recognition engine. The communications protocol chosen was the Distributed Interactive Simulation (DIS) radio protocol as defined in [13]. DIS supports the simulation of radio communications for both audio and data transmission over a network. The prototype was developed to only support the transmission and reception of audio signal data. The protocol uses three types of Protocol Data Unit (PDU) to simulate radio communications. The types of PDUs used are Transmitter, Signal, and Receiver PDUs. A potential benefit of using DIS radio protocol is that the prototype is now flexible, and will be compatible with any equipment implementing the same

protocol. One final note is that all radio communications were modeled as having lossless propagation, meaning the prototype assumes all radio communications will be received regardless of environmental factors that may disrupt communications. Although DIS radio protocol is capable of simulating real world radio transmissions, this was not implemented in the prototype. Integrating this capability would have hindered the testing environment, as well as was not necessary for the level of training this prototype is designed to support.

To complete the design, several sub-components were created to break up the work into functional parts. A diagram of the high level sub- components is provided below in Figure 3.1. The prototype was split into two machines connected via a UDP multicast network. One machine contained a DIS radio the student controller used to interact with the service part of the prototype. The second machine provided the speech recognition, speech synthesis, and simulation software services.

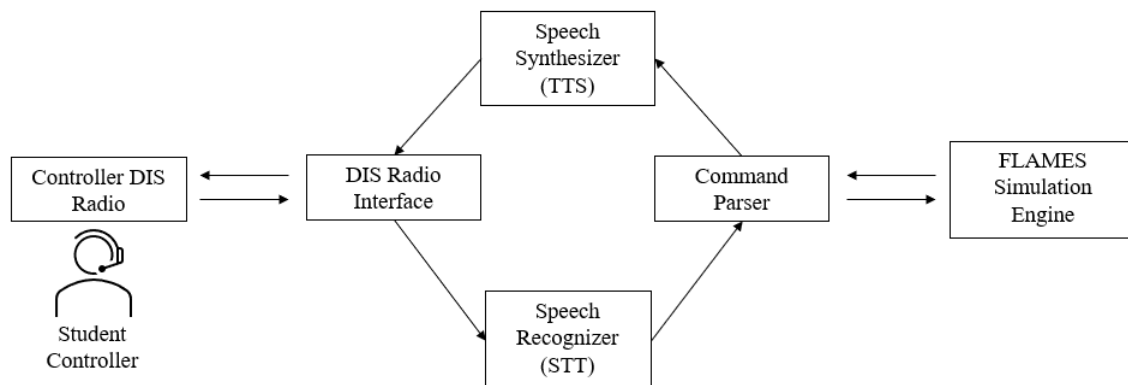


Figure 3.1. Prototype design diagram featuring high level sub-components

A brief description of the sub-components are listed below:

- **Controller DIS radio** – This component records audio from the student controller and packages it into DIS PDUs to send to the server radio interface. Additionally, it extracts audio signals received from the server radio interface PDUs and plays them back on the local machine.
- **DIS radio interface** – This component receives audio signals from the student con-

troller's radio and extracts the audio signal for speech recognition. Additionally, it takes audio signals as inputs from the speech synthesizer to package and send to the student DIS radio.

- **Speech recognizer** – The speech recognition engine takes the audio signal from the DIS radio interface and attempts to recognize phrases according to a specified grammar. It sends a text output to the command parser. The speech recognition engine used in the prototype was Microsoft Speech Recognizer 8.0 for Windows (English - U.S.). It was selected due to its capability to use a custom grammar, speaker independence, and perform as an in-process speech recognizer.
- **Command parser** – The command parser received text input from the speech recognizer and parses it to determine the type of communication received. Based on the type of communication, the command parser extracts the appropriate data and initiates commands to the FLAMES simulation engine. Additionally, it prepares a text response to the controller communication and sends it to the speech synthesizer.
- **FLAMES simulation engine** – The FLAMES simulation engine supports the design, development, and playback of simulated scenarios. Further details on the integration with the prototype are discussed in section 3.1.4.
- **Speech synthesizer** – The speech synthesizer takes the text response generated by the command parser and converts it into an audio signal. This audio signal is sent to the DIS radio interface. The speech synthesizer used in the prototype was Microsoft David Desktop - English (U.S.).

Grammar Design

A custom grammar was needed to improve the accuracy of the speech recognition engine when provided air traffic control speech. Developing a custom grammar to meet the requirements of MACCS agency's controllers is a difficult task. As discussed in Chapter 2, controllers often deviate from the appropriate communications format. This problem is particularly evident in the MACCS, as there is no single communications standard amongst the agencies. While many of the tasks the different controllers complete overlap, not every agency communicates those tasks the same way. The grammar was designed to be as flexible as possible, but can not completely cover all variations of air traffic control instructions used today. It was purpose built to support the fundamental basics of control common to each agency.

The grammar was developed in accordance with the World Wide Web Consortium Speech Recognition Grammar Specification XML format. This format allows users to develop grammars categorized as context-free grammars [14]. In this format a grammar has a recursive structure and provides a great deal of flexibility in constructing the grammar. This format provides the ability to express the complicated grammar as sequences and combinations of tokens and rules. An additional note is the recursive structure of the grammar was developed together with the command parser to allow both to take advantage of the recursive structure.

While no standard exists for Marine tactical air traffic control, a Joint standard exists for control of air-to-air and air-to-ground combat communications. These standards are defined in [15] and served as the starting point for the grammar design. The standard [15] defines four categories of transmissions as described below:

- **Directive** – Communications that direct the actions of the entity receiving the communication.
- **Interrogative** – Communications that request information from an entity and require a response.
- **Descriptive** – Communications that provide general information to all and do not require a response.
- **Relay** – The relaying of the previous types of communications between entities who are unable to communicate together, but can both communicate to a relay entity.

The base of the grammar was developed from three of the four categories. The majority of the work was on the directive and interrogative segments and a small amount of work was done for descriptive communications. Relay communications were not added to the grammar because a relay is a more advanced form of control than the prototype trainer was designed to provide.

The directive segment of the grammar contained seven different directives it was capable of recognizing. These directives were general routing, direct routing, change of altitude, speed, or heading, change of radio frequency, and a simple target directive. The interrogative segment was capable of recognizing three different interrogations. These interrogations were a radio check in, request for various states from an aircraft, and a communications

authentication challenge. While these segments provide a decent amount of capability, they do not provide coverage of all variations of the ways these communications may be transmitted to an aircraft. Additionally, they are limited to the general fundamentals of air traffic control, and not focused on the more advanced mission sets.

In addition to the rules defining the interrogative and directive segments of the grammar. Many tokens were statically provided that were necessary to support the experimentation and testing. These tokens included aircraft call signs, names of airspace control measures, as well as the phonetic alphabet and numeral digits. A complete copy of the grammar is provided in Appendix A.

3.1.3 Hardware

The hardware selected for use in the prototype consisted of two laptops and an Ethernet switch. The first laptop was used to run the student controller DIS radio. This laptop was an ASUS Model Q502L with an Intel(R) Core(TM) i5-4210U processor capable of 1.7 GHz clock speed, 12 GB of RAM, and running Windows 10 Home version 22H2. The second laptop was used to run the speech the server side of the prototype. This included a DIS radio interface, speech recognition engine, speech synthesizer, and the FLAMES simulation engine. This laptop was an Acer Aspire A515-54 with a Intel(R) Core(TM) i7-8565U processor capable of 1.8 GHz clock speed, 12 GB of RAM, and running Windows 11 Home version 22H2. The Ethernet switch was a Netgear ProSAFE GS108v4 8 port Gigabit Switch. An image of the hardware setup is pictured in Figure 3.2.



Figure 3.2. Hardware setup of prototype trainer

3.1.4 Software

Many software tools were used in the development of the prototype. This section details the software that was used as well as the purposes for using the software. The prototype was implemented in the C++ programming language. Full source code for the prototype is located at <https://gitlab.nps.edu/daniel.anderson/AutoBugPilotService>.

Microsoft Visual Studio 2019

Microsoft Visual Studio 2019 was selected as the Integrated Development Environment (IDE) for building the prototype. This IDE was selected as it was the same IDE used by the developers of the FLAMES simulation software. Specifically the environment was set up to use Visual Studio version 16.7.3, Windows Software Development Kit version 10.0.18362.0, and Platform Toolset v142.

OpenDIS

OpenDIS is an open-source implementation of the IEEE-1278.1 DIS protocol that was developed at the Naval Postgraduate School. OpenDIS maintains implementations of the

DIS protocol in several languages. The specific implementation used in the prototype was the C++ implementation. This software was used to build the DIS radio interfaces. The source code for the OpenDIS C++ implementation can be found at <https://github.com/open-dis/open-dis-cpp>.

Microsoft Speech Application Programming Interface (SAPI) 5.3

Microsoft SAPI 5.3 provides a high level interface to interact with speech recognition and synthesis engines installed as part of the Windows operating system. Microsoft SAPI 5.3 supports the use of the World Wide Web Consortium Speech Recognition Grammar Specification used to develop the prototype's custom grammar. Although SAPI 5.3 is deprecated, it was selected for the prototype because of its compatibility with C++, the language the rest of the prototype was programmed with. Another driving factor for the selection of Microsoft SAPI 5.3 was its support for generating an in-process speech recognizer. Modern Microsoft Desktop Application Programming Interfaces for interacting with the operating system's speech capabilities only offer recognition capabilities that interface with the local microphone hardware. To use the in-processing capabilities necessary for the networked communications of the prototype, you must use Microsoft Azure services. The prototype was designed with a focus on compatibility with CAC2S that would be unable to connect to Microsoft Azure, so Microsoft SAPI 5.3 was selected. More details are available on Microsoft SAPI 5.3 at [https://learn.microsoft.com/en-us/previous-versions/windows/desktop/ms723627\(v=vs.85\)](https://learn.microsoft.com/en-us/previous-versions/windows/desktop/ms723627(v=vs.85)).

Flexible Analysis, Modeling, and Exercise System

Flexible Analysis, Modeling, and Exercise System (FLAMES) is a commercial off-the-shelf simulation software that consists of a family of software products developed by Ternion Corporation. FLAMES is designed to provide a framework for constructive simulations as well as interfaces for live, virtual, and constructive simulations. FLAMES supports the development of user-defined component models that are capable of "plugging in" to the FLAMES framework. This enables users to simulate many different systems without having to develop the entire environment to run them or share them in a distributed live, virtual, or constructive simulations. The MACCS simulation software is built on the FLAMES framework and is known as the FLAMES Automated System Trainer (FAST). FAST is not

available in a development configurations, but FLAMES is available in a software development configuration. Any development done in the FLAMES development environment can be used to extend the features of FAST because it is built on the FLAMES framework.

The FLAMES framework consists of three programs, each with a specific purpose. Figure 3.3 below shows the relationship of the FLAMES programs. FLAMES Operational Requirements Graphical Editor (FORGE) is the program used for building, executing, and visualizing scenarios in a graphical manner. In this thesis, FORGE was used to create and visualize the simulated scenarios used during the testing phase. FLAMES Interactive Runtime Executable (FIRE) is an application that is used to execute FLAMES scenarios in a non-graphical manner. FLAMES Scenario Highlighter (FLASH) is a program that can be used to visualize a scenario recording of a scenario already executed by FIRE or FORGE.

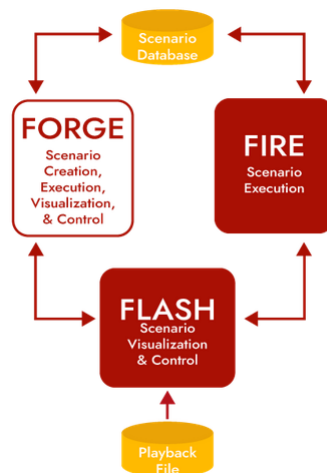


Figure 3.3. The family of applications in the FLAMES framework. FORGE is primarily used to create, execute, and visualize scenarios simultaneously. FIRE is a program that executes scenarios in a headless manner with no visualization. FLASH is program that can visualize playback of scenarios executed in either FORGE or FIRE. Source: [16].

To provide commands to the FORGE program executing the test scenarios, the prototypes command parser leveraged FLAMES's Interactive Simulation feature. This feature allows

FORGE to perform as a server that a client application may connect to. Client systems can be used for many purposes, in the prototype the command parser was used to provide commands to the simulated entities as defined by the simulated entities cognition models. An attempt was made to control simulated entity movement inside the command parser; however, all attempts to directly control entity movement resulted in the prototype crashing. Due to this, only the command method of interacting with simulated entities was used.

3.2 Prototype Testing

The second phase of this research was conducting an experiment to test the quality of the prototype as compared to the current training practices. This section provides the details on the methods used for the conduct of the testing. The research was found to not constitute human subjects research by the Naval Postgraduate School Institutional Review Board.

3.2.1 Test Scenario Overview

To test the quality of training provided by the prototype compared to the quality of training provided by a simulation operator an experimental test was devised. Three simulation training scenarios were created for the evaluation of the prototype. Research participants conducted the three scenarios in two separate roles. First, the participants completed the tasks in the role of a student air traffic controller interacting with the prototype performing as the puckster. Next, the participants changed roles to be the puckster and executed commands given to them by the research team.

The first scenario consisted of conducting radio checks and voice authentication procedures with three aircraft. This scenario was the most simple and did not require any responsiveness in the FLAMES simulation engine. The second scenario was the largest and consisted of basic traffic related tasks. Examples of these tasks are providing aircraft routing, assigning altitudes, and requesting altitude information from an aircraft. To accomplish the routing tasks the prototype issued commands to the FLAMES simulation engine. The final scenario was a basic targeting scenario. Controllers were tasked to provide two aircraft to two distinct targets. To accomplish the targeting tasks the prototype issued commands to the simulation engine.

In addition to completing the three scenarios in both roles, participants were administered pre- and post- session questionnaires. The purpose of the pre-questionnaire was to gather relevant demographic information, as well as elicit any previous experience participants had with simulation training or performance as a simulation operator. The post-questionnaire was designed to capture the attitudes of the participants towards the prototype and their assessment of its future potential as a training tool. Copies of the questionnaires can be found in Appendix B.

3.2.2 Target Population

The target population of research participants were Marines with experience in either the MACCS agencies or as a naval aviator. The target population was not required to have experience performing as a simulation operator; however, we did want Marines who were familiar with MACCS agencies and the different styles of control used in tactical air traffic control. The goal was to find Marines who represented the population of Marines who could potentially serve in the role of a simulation operator during a MISTEX or unit-level training event.

3.2.3 Variables

Dependent Variable

The dependent variable of this experiment was the quality of the training provided by a simulation operator. The quality was measured by the simulation operators recognition of student controller communications, appropriate actions taken in the simulation software, and a correct voice response transmitted back to the student controller. Further details on the metrics used to measure quality of training are provided in section 3.2.4

Independent Variable

The independent variable that was changed during the conduct of the experiment was the entity performing in the role of simulation operator. The two entities tested in this experiment were the prototype developed during the conduct of this thesis and human simulation operators from the target population. The human simulation operators were

broken into two categories, those with experience performing as a simulation operator and those with no experience in that role.

3.2.4 Metrics

To measure the quality of training provided by the entities filling the role of a simulation operator, observations were taken on the recognition of student communications, the actions taken to fly simulated aircraft in FLAMES, and the correctness of the response given back to the student. These observations were taken over all three of the simulated training scenarios. Each simulation operator task within a scenario was measured for its quality, and placed into a quality category. The percentage of calls in each category will be used to compare the quality of the prototype and the human simulation operator. The quality categories were adapted from the metrics used by Taraken et al. as introduced in Chapter 2. The adapted quality metrics are described below:

- **Perfect match** - The simulation operator correctly recognized the controllers instruction, took appropriate actions in FLAMES, and delivered an appropriate response to the controller.
- **Semantic match** - The simulation operator may have minor errors in the recognition of the controllers instruction, but still takes the appropriate action in FLAMES. The response may reflect the minor errors obtained during the erroneous recognition.
- **Non-recognition or "Say Again"** - The simulation operator does not recognize the controllers instruction and requests a re-transmission.
- **Incorrect response** - The simulation operator incorrectly recognizes the student instruction, takes an incorrect action in FLAMES, or provides an incorrect response to the controller.

Categorizing the participants communications according to these categories was conducted by comparing audio recordings of the communications to the transcripts produced by the speech recognition engine. For simplicity, the audio was recorded by the Microsoft Sound Recorder application on the server laptop. These recordings may not account for anomalies in the audio signal sent to the speech recognition engine through the network.

CHAPTER 4: Results

This chapter presents the results of the testing experimentation as described in Chapter 3. We will first cover the demographic details of the research participants, then we will examine the results of the test. The results are broken down into the quantitative results by categorizing the participants calls by quality and also observations noted from the participants interactions with the prototype trainer. Finally, the results of the post-session questionnaire will be covered.

4.1 Pre-session Questionnaire Results

In total, nine volunteers participated in the testing of the prototype trainer. This section covers the demographics of the participants as well as their general experience level with performing as a simulation operator.

4.1.1 Participant Demographics

The target population for research participants was Marines who had experience as members of a MACCS agency or as a naval aviator. All nine participants were male. The average age of the participants was 29 with a standard deviation of 2.7 years. All participants were members of the United States Marine Corps, with an average of 7.2 years of military experience and a standard deviation of 2.7 years. There was a total of seven participants with a background in the MACCS and two pilots. The Military Occupational Specialties of the participants are listed here:

- 1 x 7202 Aviation Command and Control Officer
- 2 x 7208 Air Support Control Officer
- 2 x 7210 Air Defense Control Officer
- 2 x 7220 Air Traffic Control Officer
- 1 x 7315 Unmanned Aerial Systems Officer
- 1 x 7532 Pilot, V-22

4.1.2 Participant Simulation Operator Experience

A section of the pre-session questionnaire was dedicated to determining participants previous experience as simulation operators. Five of the nine participants had at least some level of experience performing the role of a puckster. Of those five, only one claimed to have a "high level" of experience. All others claimed to have "some experience". All five participants with experience were proficient in the crew position they were providing training for. Four of the five had received training on the simulation software they used as pucksters. The volume of simulated aircraft the experienced pucksters had been responsible for while performing that role was varied. Two had been responsible for two aircraft, two were responsible for three to five aircraft, and one was responsible for five to 10. Similarly, the number of students they provided training for simultaneously was varied. Two participants had provided training for a single student at a time, one participant had provided training for two students at a time, and two participants had provided training to more than four students at a time.

When asked about the difficulties faced in performing as a puckster, the experienced participants had a common theme. Most had difficulty with the simulation software used with complaints ranging to the tediousness of building and executing the simulations, having little experience with the software, or the simulation software being vulnerable to crashing. On the opposite end, when asked about any benefits gained from performing as a puckster, the major theme was improvement of communications formats and radio communication skills.

4.1.3 Effectiveness of MACCS Simulation Training

Two five-point Likert scale questions were used to gauge the attitudes of the participants who had conducted MACCS simulation training. These questions were designed to baseline the participants attitudes toward MACCS simulation training under the current methods. On this scale, a "1" corresponded to "Poor" and a "5" corresponded to "Excellent". Table 4.1 shows the results of the six participants who had previously participated in MACCS simulation training.

Table 4.1. Effectiveness of MISTEX training in supporting skill acquisition and retention measured by five-point a Likert scale

	Effectiveness for Skill Acquisition	Effectiveness for Skill Retention
Participant 1	2	3
Participant 2	3	3
Participant 4	3	2
Participant 5	3	3
Participant 8	2	3
Participant 9	4	5
Average	2.83	3.16

Results of the questions hovered around 3 or "average" with the result for skill retention being slightly higher than skill acquisition. This is correlates with the background information provided on MISTEX training in Chapter 2, where it was discussed that MISTEX does not provide an ideal training environment for individual skill acquisition as the scenarios are more robust and complex.

4.2 Quantitative Results

Audio recordings of the scenarios were compared to the transcripts generated by the speech recognition engine to categorize every instruction. Table 4.2 shows the percentage of controller instructions that fell into each quality category by simulation operator type.

Table 4.2. Quality of training results

Quality Metric	Prototype Trainer	Experienced Participants	Inexperienced Participants
Perfect Match	61.0%	93.1%	89.4%
Semantic Match	10.4%	1.5%	0.0%
Non-Recognition	23.8%	0.0%	0.0%
Incorrect	4.8%	5.4%	10.6%

It is very noticeable the prototype trainer did not achieve as high quality of training results as the human simulation operator groups did. While the prototype had a lower percentage of calls in the incorrect category, it did not match the percentage of calls in the perfect match category. The prototype trainer also had significantly more calls in the semantic match and non-recognition categories than the human simulation operators. These results can be attributed to the limitations of the grammar and the fact that the participants did not always follow the grammar as it was programmed. These calls had little negative impact on training and show the prototype does support some flexibility in the fact that the prototype was able to semantically match 10% of calls not strictly in accordance with the grammar. To achieve a semantic match the calls needed to be extremely similar to the grammar. Typically, the semantic match calls were only off by a word or two. For example, one participant provided a routing instruction “Blade31 this is Miser proceed via the crow bird cardinal route”. The instruction as programmed by the grammar was “Blade31 this is Miser proceed crow bird cardinal”. The speech recognition engine recognized the participants call as “Blade31 this is Miser proceed crow bird cardinal rope”. While not a word for word match and an additional control point was added to the end of the recognition, the recognition was good enough the prototype took the correct action in FLAMES and gave an appropriate voice response.

When calls were off by more than a couple of words from the grammar, they became a non-recognition. Analysis of these calls was completed to differentiate between non-recognition

caused by calls delivered outside the limits of the grammar and the true non-recognitions of calls delivered correctly. In total, 55 calls were categorized as non-recognitions for the prototype trainer. Of these 55 non-recognitions, 24 of them were of calls delivered in accordance with the grammar and 31 were of calls not in accordance with the grammar.

Analysis of the categorization of calls by participant shows some interesting trends. Two participants triggered the majority of non-recognitions of calls made in accordance with the grammar. The participant with the most non-recognitions of correct calls was responsible for 12 of the 24 occurrences, and the participant with the second most was responsible for five. No other participant triggered more than two non-recognitions of correctly made calls. There was no noticeable difference in the manner these participants delivered their calls. Similarly, analysis of the calls classified in the incorrect quality category showed a large percentage of the calls attributed to a single participant. That one participant had seven of the 11 calls categorized as incorrect, when no other participant had more than one. This participant noticeably spoke faster than the other participants. The speed of delivery may account for the higher rate of non-recognitions. Further testing is required to determine the factors surrounding why some participants had much higher rates of non-recognition or incorrect quality matches on their correct calls than others.

Training did not stop in the event of a non-recognition. Participants received a communication prompt to repeat their last call. The participants who had made a correct call and received a non-recognition prompt, correctly delivered the call again that was generally recognized on this second attempt. Training was significantly impacted when the non-recognitions were for calls made not in accordance with the grammar. In these cases, the participants were provided the correct call after three wrong attempts were made in a row. A re-categorization of the 55 calls classified as non-recognitions was made and is provided in Table 4.3.

Table 4.3. Reclassification of prototype non-recognitions

Quality Metric	Prototype Trainer	Percentage of Non-recognitions
Perfect Match	38	69.0%
Semantic Match	7	12.7%
Non-Recognition	7	12.7%
Incorrect	3	0.6%

The majority of the calls classified originally as non-recognitions were re-classified as perfect match or semantic match; however, seven calls were unable to be recognized and three more resulted in incorrect recognitions. Since training did not stop when a participant received a non-recognition, the re-classified calls were used to adjust the training quality results. This adjustment helps show the training quality provided by the prototype as training sessions continued. These adjusted results are provided in Table 4.4 and show an improvement in the prototype's training quality. The improvement is good but must be taken with the context of the frequency of non-recognitions in live air traffic control. Non-recognitions do occur in live air traffic control communications; however, the rate at which they occurred in the prototype was much higher than in real life.

Table 4.4. Adjusted quality of training results

Quality Metric	Adjusted Prototype Trainer	Experienced Participants	Inexperienced Participants
Perfect Match	77.5%	93.1%	89.4%
Semantic Match	13.4%	1.5%	0.0%
Non-Recognition	3.0%	0.0%	0.0%
Incorrect	6.1%	5.4%	10.6%

The quality of training is improved after reclassifying all of the original non-recognitions. This adjusted quality of training is much more comparable to the human simulation operator groups. The perfect match category is still smaller; however, combining the perfect and semantic match categories shows comparable performance. This combination for the prototype trainer totals 90.9% of calls, which is greater than the inexperienced participant group's 89.4% but less than the experienced group's 94.6%.

4.3 Observations

This section provides further observations captured during the experiment that are not easily represented or identified in the quantitative data.

4.3.1 Prototype vs Human Incorrect Quality Differences

There is a significant difference in the incorrect quality category between the prototype and the human groups. An incorrect quality response by the prototype occurred when the speech recognizer incorrectly recognized the given call and responded in accordance with the incorrect recognition. All of the incorrect quality responses from the human groups stemmed from not being able to fly the simulated entities in FLAMES. The human groups correctly recognized the calls of the controller and gave an appropriate voice response; however, they were unable to carry out the command in FLAMES. This difference highlights a strength

of the prototype in its ability to interact with FLAMES quickly and effectively. The load placed on the human operators who were unable to fly the simulated entities appropriately was great. This load compounded as the scenario progressed and human operators received more commands they were unable to execute.

4.3.2 Participant Reaction to Non-recognition

Participant calls that were delivered outside the limits of the grammar caused significant impacts to training. These participants received the "say again last" transmission and did not recognize that their call may not have been delivered in accordance with the grammar. The general response of participants was to repeat their call in a slower manner with more spacing between words. This would still result in a non-recognition and the cycle would continue causing the participant to become frustrated. It is important to have someone who knows the limits of the grammar available to provide the student controller with correction guidance.

4.3.3 Call Sign Usage

The implementation of call sign detection for the interrogative and directive types of calls was not the same. The interrogative grammar rules required call signs for both the aircraft being spoken to and the controller delivering the interrogative call. The directive call grammar rules required a call sign for only the aircraft being given the directive, with the call sign of the controller being optional. This design decision was made because interrogative calls require the aircraft to provide information back to the controller requesting the information. The grammar and parser worked to generate responses sent back to the controller that included the interrogated aircraft and controllers call signs. Directive calls only require the aircraft to acknowledge receipt of a directive by responding with their own call sign. The grammar did not take into account the conversational aspect of interrogative calls. It is common for controllers and pilots to stop using their own call sign once good communication has been established and multiple calls will be transmitted in sequence between the two. Context of the conversation as well as the unique sounds of controllers and pilots voices eliminate the need to identify themselves in every call. This often happens during interrogative calls as the controller and pilot go back and forth to transfer the requested information.

4.3.4 Limited Vocabulary of the Grammar

The limited vocabulary of the grammar was a large factor causing non-recognitions attributed to calls made not in accordance with the grammar. The two tasks where this was most evident was responding to radio checks and transferring control of aircraft to a new control agency. These two tasks were respectively responsible for eight and seven of the 31 non-recognitions of calls that did not conform to the grammar. The grammar restricted responding to radio checks in one manner only, when there are several appropriate responses to a radio check. Similarly, the grammar was designed to recognize transfer of control calls with the TAOC controller phraseology of "push frequency for agency". During the testing it was discovered that each MACCS control agency uses a different phraseology for this same task. DASC controllers used "switch agency on frequency" and MATCD controllers used "contact agency on frequency". Adding the additionally phraseology for each agency to the grammar would also help decrease the number of non-recognitions made by the prototype.

4.3.5 Prototype Bugs and Crashes

The prototype was by no means a perfect implementation and two bugs were observed during testing. The first bug observed was that the prototype would crash when controllers used "I" in place of their call sign. A potential fix, would be adding "I" to the grammar as a call sign. The second bug observed was in the controller DIS radio. Occasionally, the radio would receive audio data from the prototype's radio interface and would have a lengthy delay before playback, or not playback the received audio at all. Further analysis is required to determine the root cause of the controller DIS radio failing to playback the received audio. A potential solution could be to source a DIS radio from the commercial sector as it is independent of the rest of the prototype.

4.4 Post-session Questionnaire Results

Following the sessions, participants were given a questionnaire to assess their attitudes toward the prototype trainer. The questionnaire included three five-point Likert scale questions, as well as text response questions on the benefits, detriments, and usefulness of the prototype trainer compared to their previous simulation training experience.

4.4.1 Effectiveness of the Prototype Trainer

Three five-point Likert scale questions were provided to the participants to rate their assessment of the overall effectiveness of the prototype and its effectiveness for skill acquisition or retention. The scale ranged from a 1 being "very ineffective" to 5 being "very effective". Table 4.5 shows the ratings provided by each of the participants. The averages taken of the participants ratings were all near four, which correlates to a "somewhat effective" category.

Table 4.5. Effectiveness of prototype trainer measured by a five-point Likert scale

	Overall Effectiveness	Effectiveness for Skill Acquisition	Effectiveness for Skill Retention
Participant 1	3	4	4
Participant 2	5	4	5
Participant 3	5	5	5
Participant 4	4	5	5
Participant 5	4	4	4
Participant 6	4	4	4
Participant 7	5	3	3
Participant 8	4	5	5
Average	4.25	4.25	4.38

4.4.2 Benefits and Detriments

In addition to the Likert scale questions, the participants were asked to comment on the benefits and detriments of the prototype compared to their previous simulation training experience. The most present theme in responses to the benefits question was the prototype reduced the workload of simulation operators. Several participants detailed using the prototype would allow instructors to focus on the students performance more as they no longer had to struggle with flying simulated entities.

The themes that arose from asking participants to comment on the detriments of using the prototype for training were the limited vocabulary and software bugs of the radios. The limited vocabulary was a great source of frustration as it could cause the participant to enter a constant non-recognition cycle and slowing down the training session. Likewise, the software bugs of the DIS radio occasionally required participants to repeat transmissions they saw had been recognized and responded to by the prototype but were unable to be played back by the radio.

4.4.3 Usefulness

The participants were asked to comment on the useful features of the prototype, as well as any features that were useless. The useful feature theme echoed the benefits of the prototype theme. Participants found the ability of the prototype to automatically control the simulated entities to be the most useful feature. Only two participants made comments on useless features. One comment was that the synthetic voice was unrealistic, and the second comment was that the grammar was too limited.

Additionally, participants were asked what capabilities they would like to see added to the prototype, as well as removed from the prototype. No participant identified any capability they would remove from the prototype. However, the vast majority requested an expanded vocabulary for the grammar. Other capabilities requested to be added were for communications initiated from aircraft, such as requests for mission data, and also the ability to support "broken" communications. "Broken" communication is when a very long transmission is "broken" into multiple smaller transmissions. "Broken" communication can occur in military air traffic control when large amounts of information are passed at a single time, such as multiple location coordinates or descriptions of targets.

The results show that the prototype trainer did not perform at as high a level of quality as the human simulation operator groups. Several observations and the data received from the participants show that there is potential for the prototype to improve and still provide an effective training experience. The results show the strengths and weakness of the prototype. These will be discussed in the following chapter.

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CHAPTER 5:

Conclusions and Future Work

This research was conducted to search for potential solutions to reduce the costs of conducting MACCS simulation training while still providing a comparable training quality. Advances in speech recognition and synthetic voice technology were identified as an opportunity to automate simulation operator functionality and alleviate the shortages of able bodied simulation operators.

To validate using modern speech technologies to automate simulation functions in military tactical air traffic control simulation training, two research questions were developed. The first, is it possible to integrate modern speech technologies with military simulation software to provide an automated training capability for tactical air traffic controllers? And second, how does the use of an automated trainer compare to the current training methods? These questions were answered in two phases of research, the development of an automated trainer prototype and an experiment comparing the training quality of the prototype to the current simulation operators. The following sections provide the future opportunities and conclusions discovered through this research.

5.1 Future Work

Going beyond fixing the problems with the prototype discovered in this research, there are more opportunities to further this research. This section provides some of the potential areas where future researchers could focus on to improve automation in MACCS simulation training.

5.1.1 Expanding Mission Capabilities

Currently the prototype only supports the training the fundamental actions common to all types of air traffic control. The MACCS agencies are a diverse group of control agencies with specific mission sets and controllers to accomplish those missions. One area of future work could be adapting the prototype to support the training requirements of a specific controller or agency and testing its effectiveness in a more complex problem set.

5.1.2 Intelligent Feedback Agent

The most significant delays to the training sessions occurred when participants repeatedly used phrases that were not in accordance with the grammar. In these situations participants needed the researchers to provide them with the appropriate phrase to use. An intelligent feedback agent could be created to recognize improper phrase formats and provide the students with the necessary corrections.

5.1.3 Simulation Operator Aid

Research could be performed to test the prototype as an aid to simulation operators rather than a replacement. The prototype could be altered to allow a human-in-the-loop simulation operator to override the actions the prototype takes. This would ease the load on the simulation operators by allowing the prototype to handle the numerous routine tasks. Simulation operators would be able to focus more on providing constructive feedback to controllers. Any non-routine tasks could still be handled by the simulation operator.

5.1.4 Call Sign Detection Flexibility

Different rules were used for the call sign detection of interrogative and directive calls. As described in Chapter 4, the strict adherence to call sign use can be dropped given the context of communications and sounds of the communicators voices. The grammar could be changed to handle call sign detection in a more flexible manner at the base rule level. This would simplify the grammar and help reduce the number of non-recognitions caused by relaxing call sign usage.

5.1.5 Flexibility of Grammar

A study could be conducted to determine if the MACCS agencies should develop a strict grammar to be followed by all the MACCS agencies or keep the status quo. This study could guide the development of the prototype as a trainer. A decision to use a strict grammar would play to the strength of the type of speech recognition engines used in this prototype. Maintaining the status quo of not having a defined communications standard could signal the requirement to find a different speech recognition technology. Advances are being made in large language models. Perhaps a large language model trained on audio recordings of

air traffic control communications could provide the needed flexibility to account for the non-standard communications.

5.1.6 Dynamic Grammar Generation

The prototype was designed with a static grammar. A static grammar supported the testing conducted during the research but would not support the training requirements of the MACCS. The MACCS often generates new scenarios to train for its various missions. Generating new scenarios introduces new information, such as call signs or airspace names, that differ from scenario to scenario. To change the static grammar for every new scenario generated would be tedious work and limit the effectiveness of the tool for use in simulation training. Future research could explore methods to produce the grammars dynamically during the scenario generation.

5.1.7 Developing Radio Interface

The current radio interface only supports a single connection to a remote DIS radio. The in-process speech recognizer design and DIS radio protocol could support many DIS radio connections. Future work could implement the capability to support multiple radio connections. This would enable the training of multiple controllers on separate frequencies. Future work could include measuring the effectiveness of the crew training.

5.2 Conclusions

With respect to the first research question it is concluded that it is possible to integrate modern speech technologies into military simulation software used in tactical air traffic control training. This research showed that using the FLAMES simulation framework with speech recognition and synthesis tools from Microsoft and other open source software, it is feasible to create an automated simulation trainer at very low cost. The prototype as developed was not fully capable of supporting all missions within the MACCS control agencies; however, it was designed to support the common fundamental techniques used for controlling aircraft.

The second phase of research provided the data necessary to compare the performance of the developed prototype to current training practices. Overall, the prototype did not meet

the quantitative level of quality that the current methods of training provide. Looking deeper into the performance, it was shown that the prototype was a stronger performer in some areas compared to the human simulation operators and weaker in others. The prototypes main strength was efficiently and correctly "flying" the simulated entities within the simulation software. The human simulation operators could struggle with this component of providing training, which would compound as training sessions progressed and negatively impact the quality of responses provided. The prototypes weakness was the recognition of the non-standardized air traffic control phraseology. Human simulation operators were much more adept at extracting the relevant information regardless of input format. The prototype was limited to the grammar as programmed and often struggled to recognize the variety of flavors of air traffic control phraseology presented.

From a qualitative viewpoint, the participants who performed the testing had generally positive attitudes towards the prototype. The participants recognized the potential impact such a technology could have on MACCS simulation training. Their feedback acknowledged the strength of the prototype in handling the difficulties of "flying" entities within simulation software, as well as the prototypes weakness of a limited grammar and vocabulary.

APPENDIX A:

Prototype Speech Recognition Grammar

```
1 <?xml version="1.0" encoding="UTF-8"?>
2
3 <!DOCTYPE grammar PUBLIC "-//W3C//DTD GRAMMAR 1.0//EN"
4     "http://www.w3.org/TR/speech-grammar/grammar.dtd">
5
6 <grammar xmlns="http://www.w3.org/2001/06/grammar" xml:lang="en"
7     xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
8     xsi:schemaLocation="http://www.w3.org/2001/06/grammar
9         http://www.w3.org/TR/speech-grammar/grammar.xsd"
10    version="1.0" mode="voice" root="base">
11
12 <meta name="author" content="Daniel Anderson"/>
13
14 <rule id="base">
15     <one-of>
16         <item><ruleref uri="#directive"/></item>
17         <item><ruleref uri="#interrogative"/></item>
18         <item><ruleref uri="#descriptive"/></item>
19     </one-of>
20 </rule>
21
22 <rule id="directive">
23     <ruleref uri="#aircraft"/>
24     <item repeat="0-1"> <ruleref uri="#agency"/> </item>
25     <item repeat="0-1"> HAVE YOU SAME </item>
26     <item repeat="0-1">
27         <one-of>
28             <item><ruleref uri="#direct"/></item>
29             <item><ruleref uri="#routing"/></item>
30             <item><ruleref uri="#changealtitude"/></item>
31             <item><ruleref uri="#changeairspeed"/></item>
32             <item><ruleref uri="#changeheading"/></item>
33             <item><ruleref uri="#changefreq"/></item>
34             <item><ruleref uri="#target"/></item>
35         </one-of>

```

```

36     </item>
37 </rule>
38
39 <rule id="routing">
40     PROCEED
41     <one-of>
42         <item> <ruleref uri="#direct"/> </item>
43         <item> <ruleref uri="#route"/> </item>
44     </one-of>
45 </rule>
46
47 <rule id="direct">
48     DIRECT
49     <ruleref uri="#waypoints"/>
50 </rule>
51
52 <rule id="route">
53     <item repeat="0-4"> <ruleref uri="#waypoints"/> </item>
54 </rule>
55
56 <rule id="changealtitude">
57     <one-of>
58         <item> CLIMB AND MAINTAIN</item>
59         <item> CLIMB TO </item>
60         <item> MAINTAIN </item>
61         <item> DESCEND AND MAINTAIN</item>
62         <item> DESCEND TO </item>
63     </one-of>
64     FLIGHT LEVEL
65     <item repeat="3"> <ruleref uri="#digits"/> </item>
66 </rule>
67
68 <rule id="changeairspeed">
69     SET
70     <item repeat="3"> <ruleref uri="#digits"/> </item>
71 </rule>
72
73 <rule id="changeheading">
74     FLOW

```

```

75   <item repeat="3"> <ruleref uri="#digits"/> </item>
76 </rule>
77
78 <rule id="changefreq">
79   PUSH
80   <ruleref uri="#frequencies"/>
81   <item repeat="0-1"> FOR <ruleref uri="#agency"/></item>
82 </rule>
83
84 <rule id="target">
85   <item> TARGET </item>
86   <item repeat="0-1"> TASKING TO FOLLOW TARGET </item>
87   <item> TRACK NUMBER </item>
88   <item repeat="5"> <ruleref uri="#digits"/></item>
89   <item repeat="0-1"> TARGET SET IS </item>
90   <item repeat="0-1"> <ruleref uri="#targetdescription"/></item>
91 </rule>
92
93 <rule id="targetdescription">
94   <item repeat="1-2">
95     <one-of>
96       <item> <ruleref uri="#digits"/></item>
97       <item> SINGLE </item>
98     </one-of>
99     <one-of>
100      <item>T72</item>
101      <item>T SEVENTY TWOS</item>
102      <item>MBT</item>
103      <item>MB TEES</item>
104      <item>APC</item>
105      <item>AP SEES</item>
106      <item>TEL</item>
107      <item>SS-21</item>
108    </one-of>
109    <item repeat="0-1"> AND </item>
110  </item>
111 </rule>
112
113 <rule id="interrogative">

```

```

114 <ruleref uri="#aircraft"/>
115 <item repeat="0-1"> THIS IS </item>
116 <ruleref uri="#agency"/>
117 <one-of>
118     <item> RADIO CHECK </item>
119     <item> <ruleref uri="#checkin"/> </item>
120     <item> <ruleref uri="#states"/> </item>
121     <item><ruleref uri="#authenticate"/></item>
122 </one-of>
123 </rule>
124
125 <rule id="checkin">
126     <item repeat="0-1"> RADAR CONTACT </item>
127     <item repeat="0-1"> HAVE YOU</item>
128     <item repeat="0-1"> LIMA CHARLIE HOW ME </item>
129 </rule>
130
131 <rule id="states">
132     SAY
133     <one-of>
134         <item>PLAY TIME</item>
135         <item>STATES</item>
136         <item>GIVE</item>
137         <item>FRAG</item>
138         <item>ALTITUDE</item>
139         <item>ANGELS</item>
140         <item>FLIGHT LEVEL</item>
141     </one-of>
142 </rule>
143
144 <rule id="authenticate">
145     AUTHENTICATE
146     <item repeat="2"> <ruleref uri="#alpha"/></item>
147 </rule>
148
149 <rule id="descriptive">
150     <ruleref uri="#agency"/>
151     ALL PLAYERS
152 </rule>

```

```

153
154 <rule id="agency">
155     <one-of>
156         <item>MISER</item>
157         <item>LANDSHARK</item>
158     </one-of>
159 </rule>
160
161 <rule id="aircraft">
162     <one-of>
163         <item>SNIPER11</item>
164         <item>HAWK21</item>
165         <item>BLADE31</item>
166         <item>LATCH55</item>
167         <item>COBRA51</item>
168         <item>VENOM32</item>
169     </one-of>
170 </rule>
171
172 <rule id="waypoints">
173     <one-of>
174         <item>COWBOYS</item>
175         <item>PACKERS</item>
176         <item>BILLS</item>
177         <item>CROW</item>
178         <item>BIRD</item>
179         <item>CARDINAL</item>
180         <item>HAMMERS</item>
181         <item>ROPE</item>
182         <item>FALCON</item>
183         <item>PISTOL</item>
184     </one-of>
185 </rule>
186
187 <rule id="frequencies">
188     <one-of>
189         <item>BROWN01</item>
190         <item>TEAL01</item>
191     </one-of>

```

```

192 </rule>
193
194 <rule id="digits">
195     <one-of>
196         <item>1</item>
197         <item>2</item>
198         <item>3</item>
199         <item>4</item>
200         <item>5</item>
201         <item>6</item>
202         <item>7</item>
203         <item>8</item>
204         <item>9</item>
205         <item>0</item>
206     </one-of>
207 </rule>
208
209 <rule id="alpha">
210     <one-of>
211         <item>ALPHA</item>
212         <item>BRAVO</item>
213         <item>CHARLIE</item>
214         <item>DELTA</item>
215         <item>ECHO</item>
216         <item>FOXTROT</item>
217         <item>GOLF</item>
218         <item>HOTEL</item>
219         <item>INDIA</item>
220         <item>JULIET</item>
221         <item>KILO</item>
222         <item>LIMA</item>
223         <item>MIKE</item>
224         <item>NOVEMBER</item>
225         <item>OSCAR</item>
226         <item>PAPA</item>
227         <item>QUEBEC</item>
228         <item>ROMEO</item>
229         <item>SIERRA</item>
230         <item>TANGO</item>

```

```
231     <item>UNIFORM</item>
232     <item>VICTOR</item>
233     <item>WHISKEY</item>
234     <item>XRAY</item>
235     <item>YANKEE</item>
236     <item>ZULU</item>
237     </one-of>
238 </rule>
239 </grammar>
```

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APPENDIX B:

Pre- and Post-session Questionnaires

Pre-Survey

* Required

1. What is your age? *

The value must be a number

2. What is your gender? *

- ☐ Man
- ☐ Woman
- ☐ Prefer not to say
- ☐ Other

3. How many years have you served in the military? *

The value must be a number

4. What branch of service do you belong to? *

- ☐ Air Force
- ☐ Army
- ☐ Navy
- ☐ Marine Corps
- ☐ Other

5. What is your Military Occupational Specialty? *

6. Are you an Air Traffic Controller or work in Aviation Command and Control? *

- ☐ Yes
- ☐ No

7. How many years of experience do you have in that Air Traffic Control/Aviation C2 field? *

The value must be a number

8. Are you a Pilot? *

☐ Yes

☐ No

9. How many years of experience do you have as a Pilot? *

10. Have you ever trained for an individual skill or crew position with simulation? *

11. Have you ever participated in a large-scale simulation training exercise such as Virtual Flag, Fleet Synthetic Training, or a MACCS Integrated Training Exercise? *

☐ Yes

☐ No

12. How adequate was the large scale simulation training in supporting

	Poor	Below average	Average	Above average	Excellent
Skill acquisition	☐	☐	☐	☐	☐
Skill maintenance	☐	☐	☐	☐	☐

13. What benefits, if any, does this training have for student controllers?

14. What detriments, if any, does this training have for student controllers?

15. Do you have any experience as a puckster / bug pilot for simulation training? *

- ☐ High level of experience
- ☐ Some experience
- ☐ No experience

16. Did you have any experience in the role you were simulating ? *

☐ Yes

☐ No

17. Were you proficient/qualified for the position you were providing training for? *

☐ Yes

☐ No

18. Were you trained on how to operate the simulation software used during the training event? *

☐ Yes

☐ No

19. How many students at a time did you provide training for during a single training event? *

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4+

20. How many simulated entities were you responsible for simultaneously controlling and role-playing? *

- ☐ 1
- ☐ 2
- ☐ 3 - 5
- ☐ 5 - 10
- ☐ 10+

21. Did you experience any difficulties in fulfilling your role as a puckster / bug pilot? *

22. Did you gain any knowledge or skills while fulfilling your role as a puckster / bug pilot? *

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Post-Survey

The survey will take approximately 4 minutes to complete.

* Required

1. How effective did you find the simulator as a training device? *

Very ineffective	Somewhat ineffective	Neither effective nor ineffective	Somewhat effective	Very effective
☐	☐	☐	☐	☐

2. How effective would an automated simulation trainer, such as the one demonstrated, be for supporting controller skill acquisition? *

	Very ineffective	Somewhat ineffective	Neither effective nor ineffective	Somewhat effective	Very effective
Skill Acquisition	☐	☐	☐	☐	☐
Skill Maintenance	☐	☐	☐	☐	☐

3. Were there any benefits the automated trainer has compared to your previous simulation training experience? *

4. Were there any detriments the automated trainer has compared to your previous simulation training experience? *

5. What attributes of the automated trainer prototype were most useful? *

6. What attributes of the automated trainer prototype were least useful? *

7. Are there any additional capabilities an automated trainer should have? *

8. Are there any capabilities demonstrated an automated trainer should exclude? *

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