IMPROVING AVIATION STUDENTS' TEAMWORK, PROBLEM SOLVING, COORDINATION, AND COMMUNICATIONS SKILLS DURING A HIGH-FIDELITY SIMULATION

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The National Aeronautics and Space Administration (NASA) Flight Operations Center – Unified Simulation (FOCUS) lab at Middle Tennessee State University (MTSU) is a high-fidelity simulation of a regional airline's flight operations center. During a simulation, a team of senior undergraduate aerospace students must work together across disciplines to manage 24 simulated Canadair Regional Jet– 200 aircraft and resolve real-world scenarios. After the simulation, the lab's staff evaluates the team's performance, which is discussed during its After Action Review (AAR). The AAR allows the team to establish strategies and an action plan to improve its performance and skills during subsequent simulations. Overall, as the lab continuously increases in standardization and fidelity through various ways, such as the utilization of WSI Fusion and WSI Fusion Replay, the lab's simulations help MTSU's aerospace students improve their problem solving, teamwork, coordination, and communication skills while also helping the lab's staff conduct reliable research on teamwork.

Every position in the aviation industry, such as flight dispatchers and pilots, operates in a complex environment requiring effective teamwork, communication, coordination, and problem-solving (Helmreich, 2000). Without these elements, accidents and incidents can occur, which can lead to a tremendous loss of life (Helmreich, 2000). Unfortunately, a gap still exists between the information and skills that students learn in the classroom and the effective application of the skills and information in the real-world setting (Sleeper & Thompson, 2008). As a result of the massive increase in computing power and various types of technology over the last decade, there has been an increase in the development and use of high-fidelity simulations in aviation to resolve this issue (Beaubien & Baker, 2004; Miller, Crandall, Washington, & McLaughlin, 2012).

A simulation is technology that is designed in such a way as to virtually reproduce one aspect of the working environment (Maran & Glavin, 2003; Sleeper & Thompson, 2008). Simulations can be classified into three different types of fidelity (Beaubien & Baker, 2004; Maran & Glavin, 2003). Fidelity is defined as the extent to which a simulation's behavior and appearance match the appearance and behavior of the replicated aspect of the working environment. The first type of fidelity is called physical fidelity (Maran & Glavin, 2003). Physical fidelity is the extent to which a simulation replicates the physical aspects of the actual working environment. Although increasing the physical fidelity of the simulation helps participants slightly improve their performance and skills, an increase in physical fidelity can cost a significant amount of money. The second type of fidelity is called equipment fidelity, which means the extent to which a simulation replicates the sensory information, such as the motion and visual cues, of the actual work environment (Beaubien & Baker, 2004). The third type of fidelity is called psychological fidelity (Maran & Glavin, 2003). This type of fidelity means the extent to which a simulation replicates the actual work environment's tasks and responsibilities. The level of psychological fidelity of a simulation depends on the task being replicated and the skills that participants need to be able to transfer to the actual working environment. For example, simulations replicating complex work environments, like the aviation industry, need to have a high level of psychological fidelity to help participants improve their skills and prevent them from experiencing a negative transfer of training (Maran & Glavin, 2003).

There are several advantages of using simulations that are high in all three types of fidelity. First, teams and individuals in simulations can practice the knowledge and skills that they have learned (Beaubien & Baker, 2004). Second, after applying or not applying their knowledge and skills to a situation in a simulation, teams and individuals can observe the positive or negative consequences of their action or inaction while in a safe environment. Third, simulations allow teams and individuals to face and respond to emergency scenarios that are impossible to train for in actual work environments (Beaubien & Baker, 2004). Fourth, simulations provide an opportunity to train teams and individuals on human interaction skills, such as coordination, communication, problem-solving, and teamwork (Shapiro et al., 2004). Finally, simulations that are immediately followed by a debriefing process allow participants to understand how they performed, identify their strengths and weaknesses, and learn how they can improve their teamwork and human interaction skills in subsequent simulations and the real-world environment (Fanning & Gaba, 2007; Hunt, Shilkofski, Stavroudis, & Nelson, 2007; Shapiro et al., 2008)

However, there are also some negative aspects of simulations that are high in all three types of fidelity. For example, the teams and individuals participating in the simulation can be reluctant to participate, which can cause them to put little effort into the simulation's scenarios and tasks (Sleeper & Thompson, 2008). Also, if unrealistic scenarios are implemented into a simulation, the teams and individuals participating in the simulation can learn inappropriate skills and information. In addition, teams and individuals participating in a simulation may feel overwhelmed by the stress, time pressure, and scenarios if they have never had an opportunity prior to the simulation to practice their knowledge and skills (Beaubien & Baker, 2004).

In conclusion, high-fidelity simulations are critical tools for training teams and individuals in the aviation industry. Although there are possible weaknesses associated with high-fidelity simulations, they have many strengths. For example, high-fidelity simulations allow teams and individuals to apply their knowledge and skills toward real-world scenarios in safe environments and learn how to improve their skills and performances during debriefing sessions. However, one of the most important strengths of simulations is that they train teams and individuals on human interaction skills, such as coordination, communication, teamwork, and problem-solving skills, that are crucial for working in the aviation industry.

History and Concept of the NASA FOCUS Lab

Before 2010, Middle Tennessee State University's (MTSU) Aerospace Department was teaching students in their specific aerospace concentrations, or educational "silos." This means that students in one aerospace concentration at MTSU were only taught the skills and information that they needed to succeed in the aviation industry and never truly interacted with students from the other aerospace concentrations. For example, the students in the flight dispatch concentration at MTSU only took classes and interacted with students in the flight dispatch concentration. This was a major problem for the department because aviation professionals from every aerospace concentration must effectively communicate, coordinate, problem-solve, and work together across disciplines 24 hours a day, seven days a week in the industry in order to conduct legal, safe, and efficient operations. In addition, several experts in the aviation industry have found that it can take up to 10 years for newly-hired aviation professionals, such as recent aviation graduates, to truly understand the big picture of the aviation industry and how their decisions and performances impact the aviation company that they work for and, ultimately, the aviation industry. In response to these issues, Dr. Paul A. Craig, an MTSU aerospace professor, decided to apply for two National Aeronautics and Space Administration (NASA) grants to build a simulation lab that could bring all of MTSU's aerospace students from every aerospace concentration together in order to break down the aerospace department's educational silos, reduce the amount of time it takes for recent MTSU aerospace graduates to understand the big picture of the aviation industry and how their performances impact the industry, and help MTSU's aerospace students enhance their teamwork skills that are critical for working in the aviation industry. In 2010, Dr. Craig was awarded both NASA grants, and he used them to create the simulation lab called the NASA Flight Operations Center – Unified Simulation (FOCUS) lab.

The NASA FOCUS lab is a high-fidelity simulation of a Part 121 regional airlines' flight operations center. Every MTSU senior undergraduate aerospace student enrolled in the "Aerospace Senior Capstone Lab" are placed into teams of 10 to work a three-hour "shift" in the flight operations center for the virtual airline called "Universal E-Lines." Also, each team's students are placed into one of the following positions that are directly related to their aerospace concentrations: Flight Operations Coordinator (FOC), Maintenance Control, Maintenance Planning and Scheduling, Flight Operations Data 1 (FOD 1), Flight Operations Data 2 (FOD 2), Crew Scheduling, Weather and Forecasting, Nashville International Airport (BNA) Ramp Tower / Duty Pilot, and Canadair Regional Jet (CRJ) – 200 Flight Crew. For example, if one student on a team is in the flight dispatch concentration, then that student will be placed in the FOC position. During a three-hour simulation, the students on a team must coordinate, communicate, problem-solve, and work together across concentrations to manage Universal E-Lines' 24 simulated CRJ-200 aircraft. These aircraft operate approximately 80 flights in the southeastern United States along a hub-spoke system to 14 spoke airports, such as McGhee Tyson Airport and Tampa International Airport, and two hub airports, which are Nashville International Airport and Jacksonville International Airport.

However, the previously-mentioned positions are not all in a single location at MTSU. These positions are in one of three locations that are utilized during every simulation. The first location is the NASA FOCUS lab, which is home to Universal E-Lines' flight operations center. The positions located in the flight operations center are the FOC, FOD 1, FOD 2, Weather and Forecasting, Maintenance Control, Maintenance Planning and Scheduling, and Crew Scheduling. The second location is the BNA Ramp Tower, which is in a room adjacent to the lab. The BNA Ramp Tower is home to the BNA Ramp Tower / Duty Pilot position where he or she manages Nashville International Airport's arriving and departing aircraft and reroutes all cargo and passengers that missed their connecting flights at Nashville International Airport. The third location is the MTSU Simulator Building at Murfreesboro Municipal Airport (KMBT). The MTSU Simulator Building is home to MTSU's Federal Aviation Administration (FAA)-certified Level 5 CRJ-200 flight training device (FTD). During every simulation, two students from a team are sent to the MTSU Simulator Building to fly the CRJ-200 FTD as three of Universal E-Lines' simulated flights. One additional location that is not home to a student's position is the office across the hall from the NASA FOCUS lab. In this office, a lab staff member plays the role of the pilot-in-command for every Universal E-Lines' simulated flight, except the flights operated by the CRJ-200 Flight Crew.

In addition, during a three-hour simulation, the NASA FOCUS lab staff, which consists of professors, graduate students, and undergraduate students from MTSU's Aerospace Department and Industrial and Organizational Psychology program, implements real-world scenarios into the simulation, which gives students on a team the opportunity to enhance their skills and apply the knowledge that they have gained throughout their undergraduate aerospace education to resolve the scenarios. After a team creates and carries out a solution for each scenario, the team immediately learns how its solution impacted Universal E-Lines through simulated financial data and immediate feedback from the lab's staff. Also, while a team is managing Universal E-Lines' flights and resolving real-world scenarios, the lab's staff conducts various measures and takes detailed notes about the team's performance. These measures and notes are used to give the team constructive and concrete feedback on their performance at the After Action Review (AAR), which is a facilitated debriefing process that helps a team identify how it can improve its performance and skills in subsequent simulations.

Implementation and Standardization of Real-World Scenarios

During a simulation, the NASA FOCUS lab staff implements real-world scenarios, or triggers, that vary in difficulty into the simulation. Before 2016, the lab's staff would implement a different number of triggers that varied in difficulty into the simulations for each team. However, during 2016, the lab's staff decided to standardize the triggers. This means that every team now faces the same number and difficulty of triggers, which increases the reliability of the data collected during each simulation. Also, after the lab's staff implements the triggers into a simulation, the team must resolve the triggers in a legal, safe, and efficient manner. After the team creates and implements a solution into the simulation, the lab's staff evaluates and determines the effectiveness and appropriateness of the solution. If the solution was not legal, safe, and efficient, then the team faces negative downstream consequences, such as a simulated financial penalty and missed passenger connections. Overall, the implementation of negative downstream consequences allows MTSU's aerospace students to understand how their decisions and performances impacts the virtual airline and, ultimately, the aviation industry.

High-Fidelity Components of the NASA FOCUS Lab

The NASA FOCUS lab relies on both specially developed and commercially available technology and software to provide MTSU's aerospace students a realistic simulation that will enhance their teamwork knowledge, skills, and abilities (KSAs) and prepare them for working in the aviation industry.

At every position in the NASA FOCUS lab and the BNA Ramp Tower, there are new Dell Optiplex 7040 desktop computers with 22-inch dual monitors that provide each student the capability to access multiple sources of information without any delays and the necessary space to organize the multiple sources of information. In addition, interactive Microsoft Excel documents have been developed for each position in the lab and BNA Ramp Tower that students can manipulate on their computers to gather the information that they need to complete their positions' tasks and responsibilities. The students also manipulate the Excel documents to gather the information that they need to share with their team in order to resolve real-world scenarios. Every position in the lab and BNA Ramp Tower has Plantronics headsets connected to their computers for direct verbal communications with any team member or lab staff member.

In addition, each position and the lab's staff utilize two computer applications called Join.Me and Skype in order to manage and communicate information to one another. "Join.Me" is a screen-sharing application that allows the lab's staff to view each position's desktop screen and analyze and record each student's performance during a simulation on a mobile-device that has internet capabilities, such as a laptop computer or tablet. Also, Skype allows every student in the lab and BNA Ramp Tower to communicate information verbally and through text messages to one another in order to manage Universal E-Lines fleet. The staff also uses Skype to communicate with the students at the positions in the lab and BNA Ramp Tower to provide them with technical assistance and respond to the team's solutions to the real-world scenarios that are implemented into the simulation.

Every position in the lab and BNA Ramp Tower has access to three new 65-inch Sony Ultra High Definition televisions on both sidewalls of the lab that display three specific sources of information. The first source is the Universal E-Lines' flight schedule. The flight schedule displays every simulated flight's number, departure airport using its International Civil Aviation Organization (ICAO) identifier, departure time, destination airport using its ICAO identifier, and arrival time. The flight schedule also has five status lights for each simulated flight to inform the students in the lab and BNA Ramp Tower when the flights are about to reach their scheduled departure time, due, in progress, delayed by more than 15 minutes, and delayed by more than 30 minutes. These five status lights are automatically updated throughout the simulation by comparing each flight's departure time to the current Zulu time. The flight schedule also displays each team's average arrival and departure performance, total time of delays, delay loss, and daily revenue, which are automatically updated when a Universal E-Lines' flight is released from its departure airport or arrives at its destination airport. The second source of information that is displayed on the televisions in the lab is the radar screen. The radar screen displays all of Universal E-Lines' simulated flights and the flights being operated by the CRJ-200 Flight Crew that are in progress, so the students in the lab and BNA Ramp Tower can monitor the progress of each flight. The third source of information displayed on the televisions in the lab is the weather radar, which displays the weather in the southeastern United States.

In the room adjacent to the lab, the BNA Ramp Tower consists of three 55-inch LG televisions, four control stations, and 12 servers. The 12 servers operate the Computer Sciences Corporation and Frasca software that provides the graphical display of each Universal E-Lines' flight on the radar screen in the lab and the programs at each control station in the BNA Ramp Tower. The software also generates a 150-degree view of Concourse C at Nashville International Airport on the three televisions that Universal E-Lines' simulated aircraft utilize. The student in the BNA Ramp Tower / Duty Pilot position uses this view to safely and efficiently manage and monitor the movement of Universal E-Lines' simulated aircraft at Nashville International Airport.

Located in MTSU's Simulator Building at the Murfreesboro Municipal Airport (KMBT), the FAA-certified Level 5 CRJ-200 FTD, or simulator, is used during every NASA FOCUS lab simulation. Two students from the team in the lab are sent to KMBT to fly three flights for Universal E-Lines. While the students are flying these flights for Universal E-Lines, the team in the lab can track the flights on the radar screen due to several network connections. Students in the lab can also communicate with the students in the CRJ-200 simulator using Voice Over Internet Protocol (VOIP) connections. Specifically, the students in the Maintenance Control, BNA Ramp Tower / Duty Pilot, FOC, and Weather and Forecasting positions will use the VOIP connections to verbally communicate information to the students in the CRJ-200 simulator that is pertinent to their flights, such as the dispatch release and weather information. Also, the students in the CRJ-200 simulator will use the VOIP connections to verbally communicate information about their flights to the students in the lab.

In March 2016, The Weather Company, an IBM business, and Southwest Airlines donated five licenses for the aviation analysis and flight tracking software called WSI Fusion and the weather replay software called WSI Fusion Replay. With WSI Fusion, the lab's staff has and continues to capture the weather on the radar; weather data; Air Traffic Control demand, ground stops, and weather reports (i.e., METARs) from the airports that Universal E-Lines services; and various weather charts (i.e., Winds Aloft charts) from any day. After capturing the data and charts, the lab's staff saves them in WSI Fusion Replay and Microsoft Word documents. Then, one week prior to a team's simulation, the Chief Meteorologist for the NASA FOCUS lab provides the student in the Weather and Forecasting position the weather data and charts to analyze and create a weather briefing that he or she will give to the team before its simulation begins. The student also creates a briefing for each flight operated by the CRJ-200 Flight Crew, which he or she must give to the CRJ-200 Flight Crew before each flight using the VOIP connections.

Once the simulation begins, the student in the Weather and Forecasting position uses WSI Fusion Replay to view the saved weather and analyze how it will impact Universal E-Lines' operations in the southeastern United States. The student also has to utilize WSI Fusion to ensure that the winds at each airport do not exceed each simulated CRJ-200's maximum crosswind or tailwind components. Based on the weather shown on WSI Fusion Replay, the student in the Weather and Forecasting position must pick the most legal, safe, and efficient route for each Universal E-Lines' flight. The student has three options for each flight that are already programmed into WSI Fusion Replay. The first option is called CP1, or company preferred 1. This route is the most direct route from a flight's departure airport to its destination airport. The other two options are called CO1 and CO2, or company option 1 and company option 2. These routes are not direct routes between a flight's departure airport and destination airport. These routes are intended to be used when a flight must fly around hazardous weather, such as thunderstorms or icing conditions. After gathering the wind and route information for each Universal E-Lines flight, the student in the Weather and Forecasting position must give that information to the Flight Operations Coordinator (FOC), who relays the information to the pilot-in-command of each Universal E-Lines flight.

Overall, WSI Fusion and WSI Fusion Replay are providing many benefits to both MTSU aerospace students and the lab's staff. One of the benefits of this software is that MTSU's aerospace students are given the opportunity to use software that current regional and major Part 121 airlines are using daily to monitor the progress of their flights, ensure that their flights do not fly into hazardous weather, and make determinations on whether to release their flights. By having experience using this software, MTSU's aerospace students will have a significant competitive advantage over other aerospace graduates. Second, the software allows the lab's staff to use the same weather scenarios across teams. Before WSI Fusion and WSI Fusion Replay, students in the Weather and Forecasting position would have to analyze live weather data and weather charts; however, if there was not significant weather in the southeastern United States, the students would not have many tasks or responsibilities to complete, reducing the usefulness of the simulation training for that student. With WSI Fusion and WSI Fusion Replay, students in the Weather and Forecasting position on every team encounter the same weather scenarios, which increase in difficulty in the teams' subsequent simulations. As a result, the software keeps the students in the Weather and Forecasting position engaged in the simulation and provides them the opportunity to enhance their problem-solving, communication, coordination, and teamwork skills. Third, by using the same weather scenarios across teams, the lab's staff can collect more valid and reliable data than ever before. Finally, since this software is used by both regional and major Part 121 airlines, this software ultimately enhances the fidelity of the NASA FOCUS lab's simulations.

When the NASA FOCUS lab was created, there were no documents that could accurately track each student's performance in the lab's simulations. Therefore, over the last four years, the lab's staff has created more than 20 documents that determine whether or not the students on a team are completing their tasks legally, safely, and efficiently. The documents also help the lab's staff determine the simulated financial penalties a team should receive due to not following federal regulations and standard operating procedures, not dispatching flights in a safe or efficient manner, or not resolving downstream consequences. After a simulation has ended, the documents used by the lab's staff are gathered and used during the lab's After Action Review to give every team member constructive and concrete feedback about how they performed in the simulation and how the team can improve its performance in subsequent simulations. Overall, the purpose of the documents is to help students realize that their decisions and performances do affect the success of the virtual airline.

After Action Review

After a team's simulation ends, the students on the team must complete an After Action Review (AAR) form, which asks the students about the strengths and weaknesses of the team, along with ways in which the team can improve in subsequent simulations. One week after the team's simulation, the students bring their AAR forms to the lab's AAR. The AAR is facilitated by MTSU's Industrial and Organizational (I/O) Psychology professors and graduate students. During an AAR, the I/O professors and graduate students provide the team feedback on how they performed during their simulation. Also, the I/O professors and graduate students ask the team members to discuss the team's strengths, weaknesses, and areas of improvement. This allows the team to learn from their mistakes, reinforce their strengths, and build new strategies that can improve their weaknesses during subsequent simulations. In addition, the I/O professors and graduate students discuss the team's decisions that violated Federal Aviation Regulations and standard operating procedures to ensure that the students on the team do not make the same decisions again in subsequent simulations and in the actual aviation industry. Overall, the lab's AAR provides

MTSU's aerospace students the opportunity to create strategies that can combat their weaknesses; enhance their strengths; and improve their teamwork, coordination, communication, and problem-solving skills that they need to become successful aviation professionals.

Summary

In conclusion, the NASA FOCUS lab is an important training and research tool for MTSU's aerospace students and the lab's staff. By participating in the lab's high-fidelity simulations and AARs, MTSU's aerospace students can enhance their problem-solving, communication, coordination, and teamwork skills that they need for working in the aviation industry and reduce the amount of time needed for fully understanding the big picture of the aviation industry. Also, the lab's high-fidelity simulations provide the lab's staff the opportunity to conduct valid and reliable research on various aspects of teamwork, which is used to publish articles in highly-respected academic journals, such as *Human Factors*. As the NASA FOCUS lab continues to improve, it will continue to be an important tool for MTSU's aerospace students, the lab's staff, and the aviation industry.

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