FUTUREFLIGHT CENTRAL: A REVOLUTIONARY AIR TRAFFIC CONTROL TOWER SIMULATION FACILITY

Nancy S. Dorighi* and Barry T. Sullivan†
NASA Ames Research Center
Moffett Field, CA

ABSTRACT

A new air traffic control tower research facility dedicated to countering potential air and runway traffic problems at commercial airports is advancing the state-of-the-art in aviation research at the National Aeronautics and Space Administration (NASA) Ames Research Center. FutureFlight Central (FFC), is a unique real-time simulator designed to safely study new technologies, airport design changes or redesigns, and procedural changes in a virtual reality setting. The facility consists of a full-scale control tower, which depicts a 360-degree view of the airport under various weather conditions and times of day. Actual air traffic controllers operate the tower and communicate with pilots, ramp controllers and vehicle operators. "Humans-in-the-loop" provide a key distinction between conventional fast time simulation and what NASA has created in FFC. Human factors such as situational awareness, reaction time, visual perception and oral communication validate new designs and tools at a significantly higher level of accuracy and confidence. Recent integration of the tower with full-mission flight simulation allows assessment of airport changes from both the controller and pilot perspectives. With this new capability, technology developers, airport planners, and airline representatives are able to make more informed decisions. This paper describes the capabilities of FutureFlight Central, provides examples of typical projects, and addresses future applications.

INTRODUCTION

In 1994, Federal Aviation Administration (FAA) and NASA visionaries partnered with the goal of applying Ames Research Center's expertise in information technology toward more efficient airport surface operations. A rapid prototype development project, called Surface Movement Advisor (SMA), was completed in 18 months to coincide with the 1996 summer Olympics in Atlanta, Georgia[1]. SMA is an information system innovation, which provides projected flight and trend information to multiple recipients at the airport. At Atlanta's Hartsfield International Airport, it was installed in the FAA Air Traffic Control Tower (ATCT), ramp towers, airport management areas, Air Route Traffic Control Center (ARTCC), Terminal Radar Approach Control (TRACON), and Delta Air Lines' strategic Operational Control Center.

Developers identified difficulties during the rapid prototyping cycles. Obtaining feedback from end users in a laboratory environment, while useful, is inherently limiting. The lab environment is not as complex, lacking, for example, the visual demands of the real tower environment and the distractions of a full crew operation. Furthermore, to evaluate how robust the tool is requires testing under off-nominal conditions, which can be impossible to recreate in the laboratory setting. Thus, SMA was moved to the real tower environment relatively early in a development cycle to obtain a full operational context for testing.

However, a live traffic operation does not lend itself well to the disruptive nature of rapid prototyping. The controllers must adhere to their #1 priority: maintaining a safe and efficient flow of traffic on the airfield. Even a new display intended to augment situation awareness diverts attention from the primary task at hand, especially during the learning curve. With less than a minute often separating landings or takeoffs during peak times, engineers were initially forced to install SMA during the graveyard shift. In that quieter familiarization period, controllers learned how they might use the information on the new display, but during periods of high traffic volume, the tool was largely ignored. Ironically, this is when the most benefit might have been gained.

Another disadvantage of testing on live traffic is the infrequent and unpredictable nature of off-nominal conditions. Developers might wait days, weeks or months for all the necessary conditions to occur for thorough testing: for example, weather induced visibility restrictions, unusual surface flow patterns, or

* AIAA Associate Fellow, Manager of NASA FutureFlight Central
† AIAA Senior Member, Chief of Aerospace Simulation Operations Branch

emergency procedures. Live testing has one additional drawback. Since every ATCT and airport is different, one cannot assume a tool such as SMA would have equal benefit for all. Ideally, the tool should be tested at each airport, not only to assess potential benefit, but also to uncover any unique requirements of that installation. However, such an undertaking would be very costly, and a needless investment if the results indicated the benefit was insufficient to justify the deployment.

Thus the interagency team spun off a parallel effort to develop a highly realistic ATCT simulator to mitigate the risk, and provide the flexibility and efficiency that was lacking in the SMA development experience. They coined a simple and descriptive name, the "SMA Development and Test Facility" (SDTF). A design team was formed spanning all aspects of airport operations that would potentially benefit from such a unique facility: air traffic control specialists, FAA supervisors, pilots, airlines, ground crews and airport operations personnel.[2] All participants felt that the simulator needed to be as operationally realistic as the available technology and funding would allow, so that conclusions drawn from simulation tests would be as applicable as possible to real world conditions.

The design team believed that a high fidelity human-in-the loop (HITL) simulation of an ATCT would provide a unique and unprecedented benefit to the FAA and NASA. It would serve as a safe platform in which controllers could more effectively evaluate SMA functionality and interface design without the concern for maintaining safety. The SDTF would provide a cost-effective way to quickly assess SMA's potential benefit for other airports. A more thorough evaluation would be possible by having the flexibility to alter test conditions such as traffic volume, fleet mix, flow patterns, visibility conditions, and various pilot deviations. SMA designs could be checked within the context of the entire tower operation. This last benefit is especially valuable due to the diverse tasks which comprise a tower controller's job: radio communications, within-tower coordination, visual airfield scanning, flight strip management, and monitoring radar and other displays. Finally, ATCT staff could be trained off-line on the new tool prior to deployment thus contributing to a successful acceptance and overall utilization.

The SDTF design team realized very early in the process that a high fidelity ATCT simulator had potential beyond just the testing and deployment of SMA. Any changes envisioned at an airport could be similarly tested with the same benefits: new air-side construction, procedure changes or integration of other technologies for the tower. The SMA Development and Test Facility was renamed the Surface Development and Test Facility to reflect the broadened scope. Later, the facility was commissioned as FutureFlight Central (FFC).

PHYSICAL DESCRIPTION

The realism begins even before entering the tower cab. Just as real ATCTs are reached via stairs that wind from below, so too in FFC, stairs bring tower cab occupants from a lower level emerging through the floor. Though there is a wide variation in tower cab dimensions in the real world, FFC's 24 ft. diameter mimics the newer and larger hub airport towers. The lower level consists of rooms for real-time simulation participants, meeting rooms, computers and equipment.

Visualization System

The out-the-window visualization system is one of the most important components of realism because visual identification is an integral part of a tower controller's situation awareness. A 360-degree field of view is accomplished using a dodecagon (twelve-sided) projection system (Figure 1). Twelve 10 x 7.5 ft. screens surround the tower cab. The screens consist of a Fresnel lenticular acrylic optical material, which provides rear projection at optimum brightness. High-brightness projectors reflect the images off of "first surface" mirrors onto the back of each screen. The mirror system was chosen to reduce the required footprint. Glass windows with mullion dividers are located approximately two feet in front of the screens to enhance depth perception.

Figure 1. FutureFlight Central Tower Cab

Graphics engineers build a 3-dimensional (3-D) airport databases in Open Flight format combining data from multiple sources: CAD layout of the airport, aerial photography, and photographs taken from the tower cab elevation. All non-stationary elements of the photographs must be removed before they are used to texture polygons in the airport scene. The run time software is Vega, which underlies the application software and provides visual effects such as fog, clouds, lights, articulation of vehicle models, rotation of propeller blades and blinking lights.

An SGI image generator (IG) computer system outputs twelve simultaneous channels of video at 30 Hz and 1280 by 1024 resolution, rendered from the database of the airport. Position updates for aircraft and ground vehicles occur at 5 Hz and must be extrapolated. The images are drawn based on a viewpoint at the center of the tower cab. The IG has 16 processors, 2 gigabytes of random access memory (RAM) and 64 megabytes of texture memory. Photo texturing adds significant visual fidelity without burdening the drawing process. A typical airport scene is composed of a background of 9,000 to 12,000 polygons, 50 to 60 megabytes of photo textures, and 100 to 120 3-D moving models of aircraft and ground vehicles. In order to optimize the computational demands of rendering the scene, aircraft models are drawn at four levels of detail, depending on the distances of the model from the eye point. The distance thresholds are configurable and must be set based on the unique geometry of each airport.

Tower Cab

The tower interior was designed to be as flexible as possible to account for the variation in equipment that exists in real tower facilities (Figure 2). There are 9 perimeter positions for local and ground control and up to 3 positions at the center console. The center console is composed of modular sections which can be recombined to form different shapes to model the variation among real ATCTs. FFC's emulation of Airport Surface Detection Equipment (ASDE-3) provides a surface radar display. Similarly, Airport Surveillance Radar (ASR-9) provides radar imagery typically 10-30 miles from the airport. FFC can present ASR-9 both at the console level or on up to 6 hanging monitors, which replicate the Bright Radar Indicator Terminal Equipment (BRITE) displays.

Figure 2. FutureFlight Central Cab Interior

Voice communication equipment, which also varies widely amongst tower facilities, is represented at each position in FFC's tower cab as the more modern touch screen communication (comm) panel, with multiple frequencies, multiple pages, intercom and interphone connection to outlying facilities. The comm system emulates the VHF radio and is used to communicate with pseudo-pilots and pseudo-ramp controllers in the lower level of the facility. The comm panel is reconfigured for each airport's dedicated frequencies. Separate channels are also used for coordination by FFC's staff throughout the facility. The FFC team prepares nearly exact replicas of the Flight Progress Strips for each simulation exercise. These are the strips of paper controllers use to keep track of each departure flight. They can be loose, in strip holders, or in strip bays depending on the method employed in the airport tower being modeled.

Pseudo-pilot Room

Aircraft targets are controlled in real-time by pseudo-pilots who "fly" the planes using a graphical user interface (GUI), from the pseudo-pilot room on the first floor. Pseudo-pilots provide the cockpit communications with the tower, and control airplanes from typically 5-10 miles out, through landing, taxi-in, docking at the gate, pushback, taxi-out, and departure. As many as 25 pilots are needed to manage the high volume and pace of aircraft activity of a busy airport. Pseudo-pilots are required to have a background in aviation operations so that they are intimately familiar with phraseology and airport procedures. Extensive practice on the subject airport ensures they conduct the movement of airplanes and communicate in a way that makes the simulation as realistic as possible.

Test Engineer's Room

The nerve center of FFC is the Test Engineer's Room on the first floor, where the simulation is controlled and monitored. The test engineer is responsible for configuring, starting up and monitoring the simulation software called MaxSim, a commercial-off-the-shelf package from Adacel Inc. The test engineer launches traffic exercises called "scenarios" that have been prepared in advance. The software allows the test engineer to change the weather, lighting conditions, or insert new aircraft dynamically into the running simulation. The test engineer can cue a pilot to simulate an emergency or a deviation. Video monitors in the room display a portion of the tower cab's out-the-window scene, radar displays, and views from four remote cameras located in the tower cab.

A flexible audiovisual Integrated Control System (AVICS) enables recording and routing of various audio and video signals throughout the facility. Any out-the-window video signal, camera video or radar image can be recorded to VHS, Betacam or DVD. A digital audio system records pilot-controller voice communications for later analysis. Microphones located on the consoles and in the ceiling capture ambient communications between controllers. A suite of video editing equipment is used to create professional quality videos for FFC customers to share the simulation experience and results with airport stakeholders.

RESEARCH CAPABILITIES

The research capabilities of FFC incorporate a variety of features. Custom traffic scenarios, a wide array of data collection, and the ability to integrate external software or simulators, provide experimenters with ready access to the tools they need for research studies.

Traffic Scenarios

Accurately representing an airport's traffic can be a challenging task. Data on actual flights including call sign, aircraft type, arrival or departure time, runway, and route waypoints are all needed to prepare a realistic scenario. Several sources of this data exist, although no one source contains all the information that is needed. ATC analysts must "fill in the blanks" for every flight. Simulation engineers program an arrival sequence that typically extends 45 minutes to an hour. At the same time, they place aircraft at appropriate gates and prepare a departure schedule for the scenario(s). If the study requires simulation of future traffic projections, simulation engineers can augment the scenarios to add additional flights and adjust the fleet mix accordingly.

Data Collection

The research value of a simulator is directly related to the data that can be collected during the runs. Studies of airport efficiency utilize FFC's airport surface metrics software that calculates data such as taxi times, holds or stops, runway occupancy time, and airport departure rate. In addition, subjective data is frequently gathered from controller and pilot questionnaires. Cumulative airport noise based on simulation data can be mapped upon completion of a run, using a custom interface to the FAA's Integrated Noise Model. Safety studies and technology development projects typically use data such as counts of runway crossings, measurements of controller task load and radio frequency congestion, and survey responses. Human factors research is especially interested in video and audio recordings to correlate activities in the tower cab with events on the airfield. Time stamped video recordings and quad-split video allows four sources to be correlated on the same video image. Researchers use audio recordings to measure transmission rate and distribution as one indicator of workload. They may also analyze them post-simulation, for subtle contextual insights.

Live Web Casting

Web-based video streaming allows remote viewing of the simulations in real-time over the Internet. Up to 200 remote viewers can watch and listen simultaneously to a particular portion of the airfield under study or activities within the tower cab. Login and password protection can control access for privacy. The only software required is QuickTime 5 or 6, free and downloadable to either Mac or PC platforms.

Integration with External Software and Facilities

One of the key features of FFC is it's ability to integrate and test new or emerging technologies such as decision support tools (DSTs) to help air traffic controllers better manage surface traffic, incoming approaches or departures. This unique capability enables FFC to link the tower simulator with other simulation components and/or facilities using the industry standard High Level Architecture (HLA) protocol. This was successfully demonstrated for the Surface Management System (SMS) Study conducted at FFC, in September 2001 and January 2002. SMS is an enhanced DST that enables controllers and Traffic Management Coordinators (TMCs) to better manage traffic by matching arrival and departure capacity with time-varying airport demands. SMS consists of a map display which gives controllers a bird's eye view of an airport depicting each of the runways, taxiways, terminals and gate locations, as well as all ground traffic. The traffic is identified with an aircraft symbol and optional flight specific information, including flight identification and aircraft type. SMS forecast runway demand 30 minutes ahead for the tower TMCs, who then entered this data into the Traffic Management Advisor (TMA). TMA adjusted the airport acceptance rate, rescheduled new arrival times for inbound flights and departure times for outbound flights. TMA is another DST developed in support of the Center TRACON Automation System (CTAS), and is currently in use at the Fort Worth Center. It is used to assist TRACON and Center TMCs in arrival flow management planning. For this study, FFC sent data to SMS via the HLA interface to emulate the radar feeds that SMS would receive in the field. This data provided the arrival and departure demands for the upcoming hour to the tower TMC who then used this data to better schedule arrival traffic. For these studies, the tower TMC was able to determine when runway usage could be changed to better meet traffic demands at the simulated airport, successfully demonstrating the viability of integrating the efficient use of DSTs such as SMS and TMA.

In addition to integrating SMS, FFC has been linked to other flight simulation facilities at NASA Ames. These include the Crew Vehicle Systems Research Facility's (CVSRF) Boeing 747-400 Flight Simulator, and one of the cabs at the Vertical Motion Simulator (VMS) Complex. This interface is requisite for supporting future work such as the Virtual Airspace Modeling and Simulation (VAMS) Project and the Access 5 Remotely Operated Aircraft (ROA) Project. For these projects, NASA envisions a need to link various simulation facilities and/or components to better emulate operations in the national airspace system. These projects will require not only integrating various air traffic control facilities, but also the vehicles flying within the given airspace. Traffic traversal between simulation environments will support human factors research across both airborne and surface domains. For example, there will be a need to pass control of ownership between targets of the various Air Traffic Management Simulations tools such as the NASA Ames developed Pseudo Aircraft System (PAS), and FFC's target generation tool. PAS is an integral component of the CVSRF's ATC Simulation, the Airspace Operations Laboratory (AOL) and the CTAS ATC Laboratory at NASA Ames. As the target generation tool for each of these simulations, PAS provides commonality between each of the given simulations and it would be beneficial to be able to transfer PAS-generated targets along with other targets within the FFC simulation environment. This capability will enable FFC to participate in gate-to-gate simulations in which traffic can take-off from one airport environment, fly through the terminal airspace, en route and then to another terminal area and airport environment. FFC could act as one of the two chosen airports or, by reinitializing and rejoining the simulation, act as both airports if needed.

APPLICATIONS

LAX Safety Studies

Due to increasing traffic and airport congestion in the late 1990s, there was a growing trend in the number of runway incursions nationally each year, each with a potential for collision and fatalities. A runway incursion is a loss of safe separation of an arriving or departing aircraft with another aircraft, vehicle, person or object on the ground. Los Angeles World Airports (LAWA), along with the FAA and United Airlines conducted a series of studies at FFC to determine how to reduce the increasing number of runway incursions at Los Angeles International Airport (LAX). The studies evaluated proposed procedural changes as well as a taxiway redesign in an effort to improve surface operations and airport safety. Tested conditions concentrated on redistributing surface traffic on the congested south side of the airport, historically associated with runway incursion events by reducing the need for runway crossings, and potentially improving the manageability of the surface traffic. The studies were broken up into two phases. The first phase demonstrated that FFC could simulate the amount of traffic representative of LAX. The second phase simulated the proposed changes and assessed their potential to improve safety and alleviate surface congestion. During the simulations, researchers measured airport take-off and landing capacity, including runway occupancy time, inbound and outbound taxi times, hold times, and arrival and departure rates. Additionally, researchers measured controller-pilot communications, controller workload, delays and other factors. These data, along with video and audio recordings, allowed the project team to understand the impact of possible new runway procedures and construction on ground traffic flow and airport capacity.

DFW Master Planning

In an effort to deal with the problem of increasing capacity and congestion issues, Dallas/Fort Worth International Airport (DFW) in conjunction with the FAA conducted a study at FFC to demonstrate the viability of perimeter taxiways. Perimeter taxiways allow aircraft to move from the runways to the gates without crossing another runway. Under current operations, the departure demand causes delays in the arrival operation, and vice-versa. The local controller is especially impacted because he must conduct all runway crossings before the aircraft can be released to the ground controller. Radio frequency congestion increases as the controller works to balance all operations and meet airport demand. The problem is most evident during peak traffic periods. As a potential solution, airport planners designed taxiway extensions to circumnavigate the runways and enable arrival and departure traffic to operate independently of each other. To demonstrate the improvement and gain acceptance of this concept, FFC integrated NASA's 747-400 simulator as part of the test to provide both pilots and controllers with a perspective of what the proposed design changes would look like. The results of this effort are anticipated to reduce runway incursions and improve airport safety.

Remote Science

Another unique application for using FFC was in support of the Haughton Remote Science Experiment, under the sponsorship of the Center for Mars Exploration at NASA Ames. For this study, FFC's viewing tower was used to evaluate the ability to conduct geological science research at remote locations (Figure 3). The objectives of this experiment were to display live panoramic and standard digital images from the Haughton site (a crater in the Arctic region) in Canada, evaluate the contents of the images, and to direct a camera-equipped all terrain vehicle

Figure 3. Researchers in FFC view image transmitted from Canadian high arctic

(ATV) at the Haughton site to new locations for additional image generation. The project required FFC to display, in near real-time, the up-linked images from the arctic site onto FFC's visual displays. This experiment successfully demonstrated FFC's ability to conduct remote research activities by providing a unique platform that could continuously display updated images and data from a remote research laboratory.

FUTURE CAPABILITIES AND APPLICATIONS

Voice Recognition

Advances in voice recognition and synthesis over the past decade have made it a viable alternative to human pseudo-piloting for some ATC simulation applications.[3] Although some researchers may prefer the realism that only the human contributes in the voice realm, activities such as training may proceed equally well or better with voice recognition and synthesis. FFC is considering a voice recognition and synthesis system in a flexible mixed mode where both humans and the automated voice software could co-operate. The approach and departure phases of flight, for example, could then be voice automated without impacting study results of surface flow. Reduced operational cost for simulations is an additional anticipated benefit.

Visualization of Live Data

Besides being able to use it's own target generator tool or some other tool such as PAS, it is highly desirable to be able to externally feed traffic data either previously recorded or from a "live" feed for viewing purposes. This would be useful in visualizing real life scenarios as they would have occurred but through FFC's virtual environment. This could play a powerful role in studying human factors issues or in accident investigations based at a particular airport location.

Another potential future use of live ATC data is to enable the facility to act as a remote tower in cases of emergencies. It is highly possible to feed "live" data into the facility to remotely monitor and control traffic during emergency situations such as in the event of an earthquake or some other disaster. Using live data, controllers would be able to virtually control traffic from FFC where it may not be possible at the airport in question.

Command and Control for Military and Space

Although FFC is primarily an ATC tower simulator, it would not be difficult to imagine the facility being used as a Command and Control Station for some type of military application, or quite easily as a remote viewing station for space exploration applications. Thanks to it's large field of view, FFC could easily be adapted to support military operations by establishing a remote battlefield command post in which military personnel could manage military campaigns from a centralized remote location. In support of space exploration initiatives, FFC could be used as a remote viewing observatory to monitor external spacecraft docking operations or for Crew Transfer Vehicle (CTV) operations for shuttling crews back and forth to space stations as envisioned in support of the Orbital Space Plane Program.

Figure 4. Researchers in FFC viewing potential space operations

NASA and the Department of the Navy have also had discussions about using FFC as a virtual aircraft carrier operations flight deck to research fleet mix studies for next generation aircraft carriers. In support of future command and control concepts, FFC could enable Navy personnel to monitor and control ship-based operations aboard future aircraft carriers from a remote location without requiring a view of the actual carrier deck.

SUMMARY

In just three years of operation, NASA's FutureFlight Central has exceeded the vision of its designers in supporting a wide array of applications from airport expansion planning to proof of concept for remote exploration. The key value it offers across all uses is the inclusion of human performance in simulation studies. Human factors is increasingly recognized as a critical early consideration in science and technology development. A successful plan or tool is one in which the end users have contributed early to the design and tested the idea in a real life operational setting. When real life testing is not feasible, high fidelity simulation such as that offered by FutureFlight Central fills a critical need. As complex interactive simulation becomes increasingly robust, this national resource will play a major part in predicting the performance and benefit of new concepts for aeronautics and space, with minimal initial investment.

---

[1] Glass, B. (1997), Automated Data Exchange and Fusion for Airport Surface Traffic Management, Proceedings of AIAA Guidance, Navigation and Control Conference, New Orleans, LA

[2] Minutes of the SMA Development and Test Facility (SDTF) Preliminary Design Review, May 23-24, 1995

[3] Pearson, Gary M., (2003). Recognition and Synthesis. *Air Traffic Technology International, 126-128.*