

AUTONOMOUS AIR TRAFFIC MANAGEMENT SYSTEM (AATMS): THE MANAGEMENT AND DESIGN OF AN AFFORDABLE GROUND-BASED AIR TRAFFIC MANAGEMENT (ATM) SYSTEM

Student team: Kenneth H. McKneely Jr., Keegan E. Johnson,
Khang L. Nguyen, Abdulaziz R. Faghi, Pirooz Javan

Faculty Advisor: George L. Donohue, PhD.
Department of Systems Engineering and Operations Research

Client Advisor: Lori DeLorenzo
CACI Technologies, Inc.
Tactical Systems Division
Chantilly, VA
ldelorenzo@caci.com

KEYWORDS: Air Safety, Air Traffic Management, Airspace Planning, Automated Systems, Runway Incursion Prevention, Communication, Navigation, Surveillance (CNS), Systems Engineering

ABSTRACT

The goal of this project is to provide a cost effective, all-weather automated Air Traffic Management capability that will increase pilot situational awareness at small, non-towered, regional airports. By providing this capability, this project intends to significantly increase the volume of aircraft over current levels at these airports without significantly increasing the risk of catastrophic or near-catastrophic events.

This project is subdivided into five basic areas. First is the development of operational requirements, design alternatives, and the accomplishment of a functional decomposition. Second is an evaluation of existing technologies that have the potential to perform the needed functions. Third is the collection of cost and performance data for the technologies and creation of system functional and physical architectures for each design alternative. Fourth is the development of a discrete event simulation for performance and a system cost analysis. Fifth and finally, is the analysis of the simulation results and selection of the final system design.

This project is intended to provide the operational functions of a Class D Airspace Air Traffic Control Tower (ATCT), to include local airspace: 1) Surveillance, 2) Sequencing to assure Separation, 3)

Communications, and 4) Flight Planning. These functions will be performed by hardware and software installed in a mobile facility. This mobile facility will enable ease of transportation and movement from one location to another.

INTRODUCTION

The volume of aircraft that may use a non-towered airport during any given time period is directly limited by the weather conditions surrounding that airport over that time. Once weather conditions deteriorate to the point of Instrument Meteorological Conditions (IMC), the number of aircraft allowed to depart or arrive in these conditions is significantly reduced due to the fact that only Instrument Flight Rules (IFR) flight plans are authorized. In regions in which local businesses rely on air transportation, the cancellation or reduction of flights has a negative effect on the local economy. However, it is often cost-prohibitive for the federal government or the airport owner to pay for the construction and certification of a Federal Aviation Administration (FAA) certified control tower and all related equipment and manpower operating expenses. In an effort to address this quandary, the National Aeronautics and Space Administration (NASA) has initiated the Small Aircraft Transportation System (SATS) research program to develop cost effective solutions. In fact, the NASA SATS Program Plan includes the following two objectives, which form the foundation of this project: 1) higher volume operation at non-towered/non-radar airports, 2) lower landing minimums at minimally equipped landing facilities.

OPERATIONAL REQUIREMENTS

Candidate AATMS airports are those without an operational ATCT and, in most cases, are simple airports with a single runway and taxiway and no existing instrument approach capability. An airport with the AATMS will supply simultaneous Visual Flight Rules (VFR) and IFR operations. AATMS will provide services to aircraft with the minimum equipment required for Category I Instrument Approach, which is assumed to be a VHF communications radio and an operational Air Traffic Control Radar Beacon System (ATCRBS) transponder with encoding altimeter, two independent radio navigation systems, and a Global Positioning System/Wide Area Augmentation System (GPS/WAAS). The underlying principle behind this assumption is that the functions of a surveillance system that provides aircraft location, altitude, and positive identification are necessary to fulfill the requirement to provide separation services. The VHF voice radio and the ATCRBS transponder in the aircraft support this requirement.

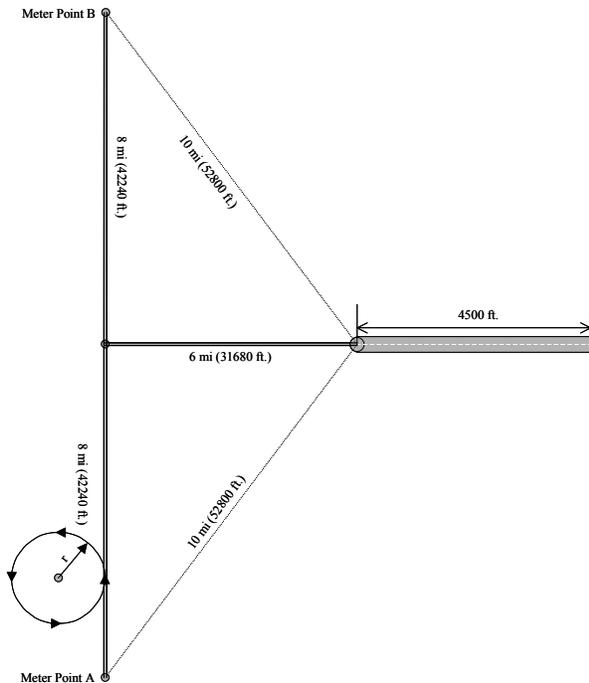


Figure 1 Aircraft Approach Paths to Airport.

The airspace managed by a Class D airport is generally within five nautical miles and 2,500 feet above the airport, including the airport runways and taxiways. The Terminal Radar Approach Control (TRACON), on the other hand, is responsible for the airspace within 20-

30 nautical miles of principal airports and up to approximately 4,000 feet above the airport surface (Class C airspace) or 10,000 feet above mean sea level (Class B airspace).

AATMS will provide these services out to ten miles and up to an altitude of 6,000 feet, primarily to single pilot operators, whose flight plans have been filed under FAA Code of Federal Regulations (CFR) Parts 91 and 135. AATMS will be designed for pilots who are instrument rated and fly at least 80 hours per year.

In order to meet the objective for lower landing minimums, the minimum ceiling and visibility distances that will achieve the maximum benefit are 450 feet and 1 statute mile respectively. The flight path of arriving aircraft is shown in figure 1. Note that the figure shows the landing path for one direction only. In reality, the landing paths are symmetrical (i.e., aircraft can land at either end of the runway), depending upon the direction of wind.

DESIGN ALTERNATIVES

The major factor in determining design alternatives for AATMS is the separation and sequencing logic. There are two basic alternatives for this function. The first is to assume that all decision-making capabilities reside with the aircraft (either human or equipment performed). The second is to place all decision-making capabilities within AATMS. For the purposes of achieving an affordability goal, AATMS will also offer two physical architectures. The first will meet the minimum availability (min A_0) requirement set forth for ground based ATM systems by the FAA. The second architecture will provide “soft” failure modes to achieve a significantly increased availability threshold, referred to as the maximum availability (max A_0) architecture.

ENABLING TECHNOLOGIES

The key technologies that AATMS will take advantage of is what is known as radar multilateration, infrared tracking and GPS ADS-B. Multilateration systems provide positive identification and location of all transponder-equipped aircraft in the airport area and on the airport surface in all weather conditions. AATMS will implement multilateration technology in conjunction with an Automatic Dependent Surveillance-Broadcast (ADS-B) ground system. This is a more advanced version of the Traffic Collision Avoidance System (TCAS) that uses aircraft

transponder data to perform collision avoidance algorithms. The TCAS calculates the approach rate between aircraft and provides the pilots with a warning or instruction to take evasive maneuvers when the probability of a midair collision is high. AATMS will implement VDL Mode 4 digital data link and VHF voice for ground-to-air communications. As a primary resource to determine runway occupancy, AATMS will use Focal Plane Array (Infrared (IR)) cameras. The reason for using IR technology is based on the benefits of multi-sensor fusion for surveillance false-alarm reductions and independence for fail-soft redundancy. Dr. Kim Cardosi (2001) identifies that runway collisions are the highest risk of aircraft collision and the number of runway incursions has steadily increased since 1999. Gerard W. H. van Es (2001) found that the total number of runway incursions involving significant aircraft damage or personal injury from 1980 to 1999 was 145.

SYSTEM FUNCTIONAL DESCRIPTION AND PHYSICAL ARCHITECTURES

AATMS Physical Architecture (Maximum Ao)

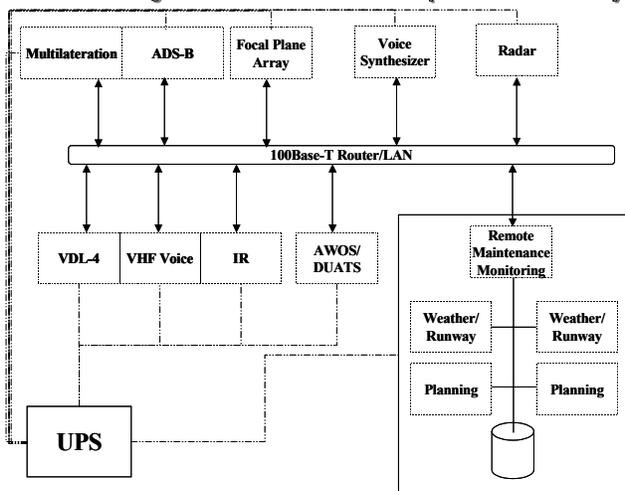


Figure 2 AATMS Physical Architecture

In addition to the components previously identified in the Enabling Technologies section, AATMS will include the following additional functions:

- VHF - Voice synthesizer, which will provide situational awareness to aircraft that are not ADS-B or TCAS equipped
- Radar (primary and/or secondary) – to provide diversity and redundancy for the primary surveillance components (ADS-B/TCAS)

- Remote Maintenance Monitoring – a network based maintenance capability for monitoring by external facilities
- AWOS – Automated Weather Observation System, to provide terminal weather conditions to IFR aircraft and the national weather database
- DUATS – Direct User Access Terminal Service, an Internet based service to enable pilots to file flight plans.

Two different AATMS hardware configurations were designed. The primary difference was cost to acquire and was related to availability, redundancy, and accuracy. It is assumed that higher operational rates will require higher performance and the airport can afford a slightly more expensive system. The more expensive system is shown in figure 2 and is estimated to cost \$860,000 (acquisition + first year operations and maintenance).

The components are interconnected through a 100Base-T Router/LAN, which ensures any aircraft can receive any information. The van is capable of being connected to the Internet through an Integrated Digital Subscriber Network (ISDN) line. The components will be installed in a fault tolerant network comprising of multiple redundant servers. The servers will be clustered and mirrored to maximize performance and reliability. The fault tolerance and redundancy switches will be constantly monitored by these servers to reinforce its high availability. The key aspect of these servers is to ensure every component has proper data collection services, routine back-ups, and self-diagnosis tests. Located in the van is a one-kilowatt Emergency Power Generator, which is capable of keeping the van operational for 20 hours in the event of a loss of shore power, and a 30 minute battery backup uninterruptible power supply (UPS).

ENGINEERING PERFORMANCE DATA

Reliability data for most of the function specific equipment were not readily available. However, we used the fact that in order to be certified as operational by the FAA, surveillance equipment should have an end-to-end reliability of not less than 0.999. Similarly, communication equipment should have an end-to-end reliability of not less than 0.99999. Based on performance data obtained from the respective vendors, reliability for network equipment is estimated to be 0.999 and shore power (electricity) with UPS is 0.99999.

PERFORMANCE SIMULATION

The AATMS team performed a Monte Carlo simulation to obtain expected reliability data. For this simulation, the team used the reliability requirements set forth for ground based communications (COMM) and surveillance equipment in the RTCA, Inc. Task 4 Final Report of Certification of February 1999. These data were 0.999 for surveillance (SURV) equipment and 0.99999 for communications equipment. Both of these types of equipment were considered to be end-to-end. AATMS also included two other groups of components. These are Power (PWR) and Network (NET). The Power group pertains only to the ability of the local utility to provide shore power, which is estimated to be 0.99999. The Network group includes all servers, routers, hubs, and other equipment that provides connectivity. Based on data provided by the equipment manufacturers, the Network group reliability is estimated to be 0.999 in the maximum A₀ architecture. The predicted reliability of the AATMS is $(R_{PWR} * R_{SURV} * R_{COMM} * R_{NET} \Rightarrow 0.99999 * 0.999 * 0.99999 * 0.999) = 0.99798$.

Based on the results of the Monte Carlo simulation using a 20-year lifecycle, the reliability of the AATMS is estimated to be 0.99945, which exceeds the AATMS reliability requirement.

The primary intention of the simulation is to provide a dynamic model for accurately creating scenarios to determine system reliability & operational effectiveness. With this objective, a stochastic model with discrete events was designed to properly represent the AATMS in a small regional airport setting. Each event in the simulation represents an aircraft arrival that occurs over a normal probability distribution that can be adjusted by the user. Surveillance for the system is conducted in a stateless environment and updated in 20-second intervals. At the end of each interval, the function monitors and calculates the arriving aircrafts position along a standard GPS "T" landing approach (see figure 1 above). If the aircraft separation distances are below the minimum allowed (four nautical miles), a Standard Rate Turn (SRT) maneuver is simulated within the program. This SRT is a typical spacing maneuver performed by aircraft whom have situational awareness information such as that provided by TCAS, ADS-B, or radar. A SRT is defined as the rate at which the aircraft heading changes by 3° per second. Regardless of aircraft speed at the time the turn is initiated, the 360° circle takes approximately two minutes. The simulation also supports a generic aircraft

type traveling at different speeds: 120 knots and 90 knots.

The purpose of the simulation is to calculate the aircraft separation distances and the accuracy of the AATMS decision-making under a varying number of operations. On every iteration that occurs, the primary AATMS decision making algorithm determines which resources of the system is needed to perform the required service.

As each service is performed, the simulation can accurately log failure rates on the components and maps a redundant path (based on other components offering similar services). We can then adjust our redundancy levels and tune the existing paths needed from the results of the tests. This model also allows us to see the maximum threshold for arrivals while maintaining aircraft separation distances accurately.

Aircraft arrivals are introduced into the simulation at one of two points (Meter Points A & B). Once the aircraft is detected, the AATMS surveillance services will reposition the aircraft on each 20-second interval based on speed. When repositioning each aircraft, the system uses TCAS and its own separation algorithms, to determine the distance from the nearest aircraft in the current airspace. A value of four nautical miles was used as the minimum aircraft separation distance before the AATMS sends a broadcast signal with Flight ID and instructions to perform the SRT. After following the instructions, the aircraft with the Flight ID arrives back at the same position and direction in 120 seconds.

In an effort to improve safety, the AATMS also considers aircraft speed & direction when accounting for separation services. For example, if two aircraft arrive at Meter Points A & B simultaneously, the simulation takes into account that the minimum separation distance should not be used because the rate of closure has doubled. In this instance where two aircraft are approaching from opposite directions, the simulation doubles the minimum separation distance. The system provides adequate separation services for the aircraft before they reach the final landing approach in the direction of the runway. At that point, the aircraft should have the proper separation and are not required to perform any SRTs.

The objective of the simulation is to determine the maximum operational capability of the Air space with an AATMS. Data was computed for periods of 30 days on 6, 10, 12, and 15 operations per hour. However, due

to the fact that only arrival events were simulated, these operations are equivalent to 12, 20, 24, and 30 operations per hour respectively, if departures were included. Logs were generated to keep track of aircraft separation, component warnings/failures, and the number of times aircraft had to reposition to increase its separation distances from other aircraft. With over a million records of data for each test run, the simulation gave us a sufficient amount of information to properly conduct an analysis.

The results imply that the AATMS design is capable of providing adequate surveillance services for up to 12 aircraft arrivals per hour while maintaining a separation distance of not less than 3.3 nautical miles between any two aircraft. However, there was a significant increase of aircraft that required repositioning as the arrivals increased. Aircraft in the simulation must reposition if they fall below the minimum separation distance.

During a 30-day cycle of 12 arrivals per hour (normally distributed random arrivals $\sim(5,1)$), there were an average of only 90 repositioning events that took place. A 15-arrival per hour (normally distributed random arrivals $\sim(4,1)$, or with exact optimal distribution with out randomness) over the same number of days increase this average to approximately 3,750 while a 10-arrival per hour (normally distributed random arrivals $\sim(6,1)$) did not reposition any aircraft. Figure 3 shows the frequency distribution of separation distance at 12 arrivals per hour.

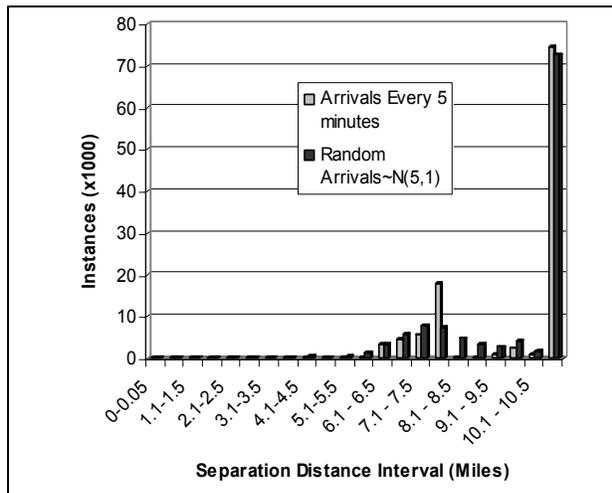


Figure 3 Frequency Distribution of Separation Distances (12 Ops/hr)

A 30-day period with 15 operations per hour produced a total of 976 component warnings that

indicated an individual path contained a component and either failed or was delayed when giving a response. The difference between a warning and a full failure is that a warning acts as a soft failure where another component providing similar services acts on a redundant path. A full failure occurs when all component paths providing a specific service fails which requires the system to shut down for the designated Mean-Time-To-Repair (MTTR) period. Our simulation produced no full failures during any given 30 day period. This was expected due to the high number of integrated technologies in the system.

SYSTEM COST AND DECISION ANALYSIS

The AATMS Cost Analysis develops an inclusive understanding of the AATMS Total Purchasing Cost estimation, its' cost components, and assumptions for the various cost components. After an extensive data search it has been found that cost data on many of the components that make up AATMS is not generally available to the public, however, approximations and estimates were determined based upon in-depth research of those and similar components. Also, research has revealed an "unofficial" estimate of an FAA acquisition cost of \$2 million for an Air Traffic Control Tower (Class D), which is almost double the cost of a maximum availability architecture AATMS. Figure 4 graphically depicts the AATMS per System Cost for both types of architectures versus the estimated cost of building a Control Tower. Operations and maintenance of an automated system is much less than a manned control tower.

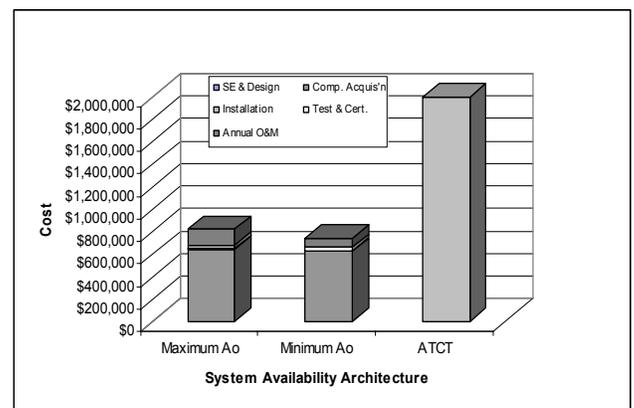


Figure 4 Total Cost Comparison of AATMS vs. ATCT

Component selection was based on a detailed decision and corresponding sensitivity analysis. These analyses used weighted objectives and value functions.

The result for the primary radar component is shown in figure 5. The graph shows the sensitivity of the radar equipment under evaluation to the change in the weight of the cost objective. This type of analysis was performed for each major element of the design.

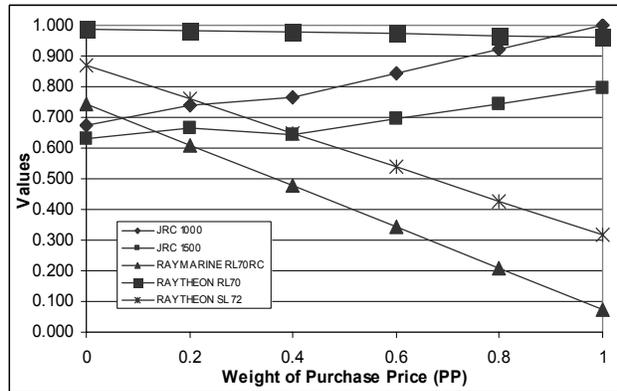


Figure 5 Radar Sensitivity Analysis

CONCLUSION

In light of the performance simulation and cost/decision analysis, we have shown that the AATMS design provides a highly reliable, mobile system that meets the system cost and performance objectives. AATMS achieves this through the use of existing commercial technology and diverse components that provide a high failure tolerance.

REFERENCES

NASA Small Aircraft Transportation System Program Plan V0.8

Donohue, George L. SATS Program Requirements and CONOPS Review. 31 Jan 2002.

Cardosi, Kim Controller and Pilot Error in Surface Operations. 4th USA/Europe Air Traffic Management R&D Seminar. December 2001.

Van Es, Gerard W. H. A Review of Civil Aviation Accidents Air Traffic Management Related Accidents: 1980-1999. 4th International Air Traffic Management R&D Seminar. December 2001.

RTCA, Inc. "Final Report of RTCA Task Force 4 Certification." 1140 Connecticut Ave, NW, Suite 1020, Washington, D.C. 20036-4001. February 26, 1999.

BIOGRAPHIES

Kenneth H. McKneely, Jr. is a fourth year Systems Engineering major at George Mason University from Wheaton, Maryland with a concentration in System Modeling and Performance. Ken is currently considering several career opportunities in a broad range of industries.

Keegan Johnson is a fourth year Systems Engineering major at George Mason University from Richmond, Virginia, with a concentration in Electrical Engineering. Next year, Keegan will be applying to attend graduate school at George Mason University.

Abdulaziz Faghi is a fourth year Systems Engineering major at George Mason University from Vienna, Virginia, with a concentration in Economic Systems. Following graduation, Abdulaziz will be attending the University of Maryland at College Park, pursuing a graduate degree in Engineering Project Management.

Khang Nguyen is a fourth year Systems Engineering major at George Mason University from Falls Church, Virginia with a concentration in Data Modeling. Khang is currently a government employee at Software Engineering Center – Belvoir in Alexandria, Virginia.

Pirooz Javan is a fourth year Systems Engineering major at George Mason University from Fairfax, Virginia with a concentration on Decision Making and Risk Analysis. Next year, Pirooz will continue to work at MetroStar Systems, Inc. as the Chief Operating Officer.