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NAVIGATING THE SKIES

The Aerial Surveying Industry's Quest for Airspace Recognition

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REAL-TIME FLIGHT SAFETY INTELLIGENCE WITH ADVANCED TRAJECTORY PREDICTIONS

Empowering Decisions for Air Traffic Controllers and Pilots

By Sean Daugherty, Ph.D., and Shelby Condray, Metron, Inc.

As air traffic continues to soar, the air traffic control (ATC) industry must embrace a technological revolution to stay ahead. Projected to grow by 3.4 percent annually over the next two decades, air traffic is set to become more complex and challenging than ever before (IATA's 2023 Global Outlook). The rise of unmanned aerial systems (UAS), air taxis, commercial space launches, and other new entrants further intensifies this complexity. The question now is how swiftly we can adapt to these changes.

Next-generation platforms like UAS and electric vertical take-off and landing vehicles (eVTOLs) are poised to transform the Advanced Air Mobility infrastructure. With over 780,000 UAS already registered in the USA and the anticipated surge of eVTOLs by 2025, our skies are becoming increasingly crowded. This surge demands sophisticated, cutting-edge technologies to manage all airspace users safely and efficiently.

The global understaffing of controllers also remains a problem, with the USA currently several thousand controllers below its target. When combined with increasing traffic volume and new entrants, this creates an opportunity for intelligent decision aids that can assist with monitoring the airspace and cueing controllers to risks in real time.

Recent loss-of-separation incidents and near midair collisions (NMAC) highlight the urgent need for advanced solutions in ATC. Leveraging technological advances in artificial intelligence, data fusion, and machine learning, we can integrate validated software solutions into existing systems. These innovations present

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to enhance the safety and efficiency of air traffic systems. By integrating these advancements, we can transform air traffic control, mitigate risks, enhance safety, and boost operational capabilities across the ATC value chain.

Current State of Air Traffic Control

The ATC industry stands at a pivotal moment, grappling with unprecedented opportunities and formidable challenges. On one side, significant technological advancements promise to enhance safety and efficiency. On the other, the increasing number of aircraft – both manned and unmanned – competing for the same airspace demands a comprehensive reevaluation of existing systems. To control air traffic effectively, the industry must adopt more advanced, integrated solutions.

Emerging Challenges in ATC

The future of ATC will be significantly shaped by the integration of UAS traffic, AI-powered air taxis, and other new entrants, especially where they share airspace with traditional aircraft. These advancements present opportunities for innovation and efficiency but also increase the complexity of controlling the airspace. Controlling this diverse array of aerial vehicles requires advanced predictive capabilities and real-time data integration to ensure safety and operational efficiency.

- **Increased traffic density:** The growth of traditional aviation and rise of UAS, air taxis, and other new entrants will lead to higher air traffic density, especially in urban areas and near airports. This surge in traffic density poses significant challenges for air traffic controllers, who must provide separation assurance of a growing number of aircraft operating in proximity.
- **Coordination:** Effective coordination between manned and unmanned vehicles will require advanced systems capable of handling dynamic and diverse traffic patterns. Preventing conflicts and ensuring the safe integration of various vehicle types into the airspace is crucial. This is especially critical for coordination between traditional aircraft movements and 4D airspace reservations made by UAS, AAM, space launches, and military operations.
- **Safety:** Ensuring the safety of all airspace users, especially those operating at lower altitudes including higher-risk departures and arrivals, is paramount. This involves managing collision risks and ensuring all vehicles operate within safe parameters.
- **Efficiency:** Increased traffic density may require reduced separation distances in situations where safety can be assured. This includes reducing the separation between traditional aircraft under certain conditions and, for example, reducing the size of corridors for UAS and AAM operations.

Reaching the Limits of Available Tools and Methods

ATC systems such as Standard Terminal Automation Replacement System (STARS) and onboard systems such as Traffic Alert and Collision Avoidance System (TCAS) / Airborne Collision Avoidance System (ACAS) traditionally rely on "constant course and speed" or "dead reckoning" approaches for short-range trajectory predictions that power conflict alerts in the terminal area. Longer-range trajectory predictions in en route airspace, such as those from the En Route Automation Modernization (ERAM) Conflict Probe also use basic trajectory estimates for conflict alerting. The reliance on these basic trajectory estimates and lack of a complete characterization of uncertainty leads to nuisance alarm rate estimates of 62 percent for en route conflict alerts and 44 percent in the terminal environment.[1] Additionally, they generate missed or late conflict alerts because they cannot anticipate the turns and altitude changes that are especially common in the terminal area. There is an opportunity to modernize this approach through machine learning techniques for dynamic trajectory prediction, conflict alerting, and anomaly detection.

Over the past year, the aviation industry has seen increased scrutiny of loss of separation and NMACs, underscoring the need for enhanced safety measures in air traffic control. Figure 1 illustrates a situation where two aircraft lost lateral separation and required a last-minute maneuver to ensure vertical separation. The conflict was only alerted after the southbound aircraft made its left turn such that "dead reckoning" was accurate. Had advanced predictive technology been in place, this conflict could have been anticipated and avoided earlier and less aggressively by predicting the left turn. This compelling case, along with many others for departures and arrivals, highlights the necessity of integrating innovative tools into existing systems to ensure the safety and efficiency of our skies.

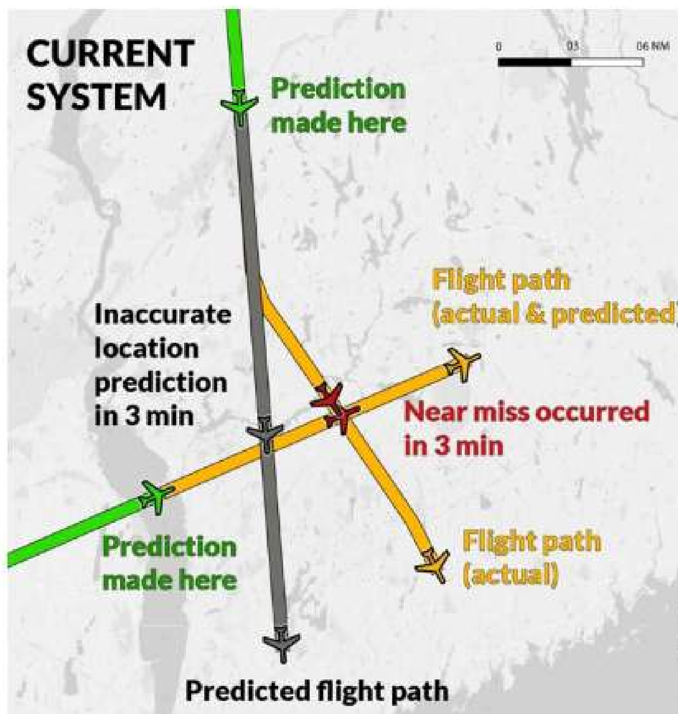

Image: Metron

Figure 1: Current systems rely on "dead reckoning" trajectory estimates that fail to anticipate heading and altitude changes. Here, a conflict alert was not generated until the southbound aircraft made a left turn.

Shaping the Future of ATC

AI and Machine Learning: Revolutionizing ATC

Artificial intelligence (AI) and machine learning (ML) are expanding the potential for ATC. By enhancing predictive capabilities and decision-making processes, these technologies can enable ATC systems to offer more accurate, context-aware trajectory forecasts with uncertainties. This accuracy is essential for managing the complex and dynamic nature of modern air traffic, ensuring safer and more efficient skies.

Remote Air Traffic Control Towers: Centralized Efficiency

Innovations in remote ATC towers are transforming how air traffic is controlled. By allowing controllers to operate from centralized locations, these towers increase efficiency and reduce costs. With advanced tools and real-time data integration, remote ATC towers empower controllers to make informed decisions swiftly, enhancing operational effectiveness.

Unmanned Traffic Management: Seamless Coordination

As drones and unmanned aircraft populate our skies, integrating unmanned traffic management (UTM) systems becomes crucial. These systems must work seamlessly with traditional ATC to ensure coordination and safety. Cutting-edge technologies provide real-time data and predictive analytics, facilitating better management and coordination between manned and unmanned vehicles.

NextGen Air Transportation System: The Future National Airspace System

The FAA's NextGen initiative continues to improve the USA's National Airspace System (NAS) with advanced technologies and procedures that enhance safety, efficiency, and predictability. Key components like the Info-Centric NAS and Trajectory Based Operations (TBO) are central to this modernization, promising a more streamlined and efficient air traffic landscape.

Innovative Solutions for Emerging Challenges

To meet the challenges of modern ATC, next-generation solutions must be scalable, leverage existing data repositories, and integrate seamlessly into current infrastructure. Here's what the future holds:

- **Advanced predictive capabilities:** Leveraging AI and ML to provide dynamic, context-aware trajectory forecasts, significantly enhancing controllers' ability to anticipate aircraft movements.
- **Real-time data integration:** Merging data from multiple sources, including UAS and AI systems, to offer a comprehensive view of the airspace is crucial for maintaining situational awareness and safe operations.
- **Enhanced conflict alerts:** Utilizing sophisticated algorithms to identify and alert controllers to potential conflicts and suggesting resolutions well in advance, allowing for proactive measures and improved airspace efficiency.
- **Anomaly detection:** Applying ML to identify anomalous flight tracks in real time to cue controllers to aircraft that are taking unusual routes, monitoring the skies to catch potential issues early.
- **Seamless system integration:** Ensuring new tools integrate smoothly into existing ATC systems without disrupting workflows, enhancing situational awareness without adding cognitive load.

By embracing these innovations, the ATC industry can navigate the complexities of modern airspace with confidence and efficiency.

AirCue: Addressing Modern Air Traffic Challenges

The Future of ATC

Metron's AirCue provides Aviation Indicators from Real-time Course Uncertainty Evaluation and is at the forefront of addressing modern air traffic challenges. It provides tactical-level trajectory predictions that enable earlier and more accurate conflict alerts and anomaly detections. Developed and enhanced over the past decade under multiple NASA-sponsored research projects, AirCue exemplifies Metron's commitment to enhancing aviation safety and efficiency through advanced information processing and ML prediction. This product has been tailored to meet the rigorous demands of contemporary ATC.

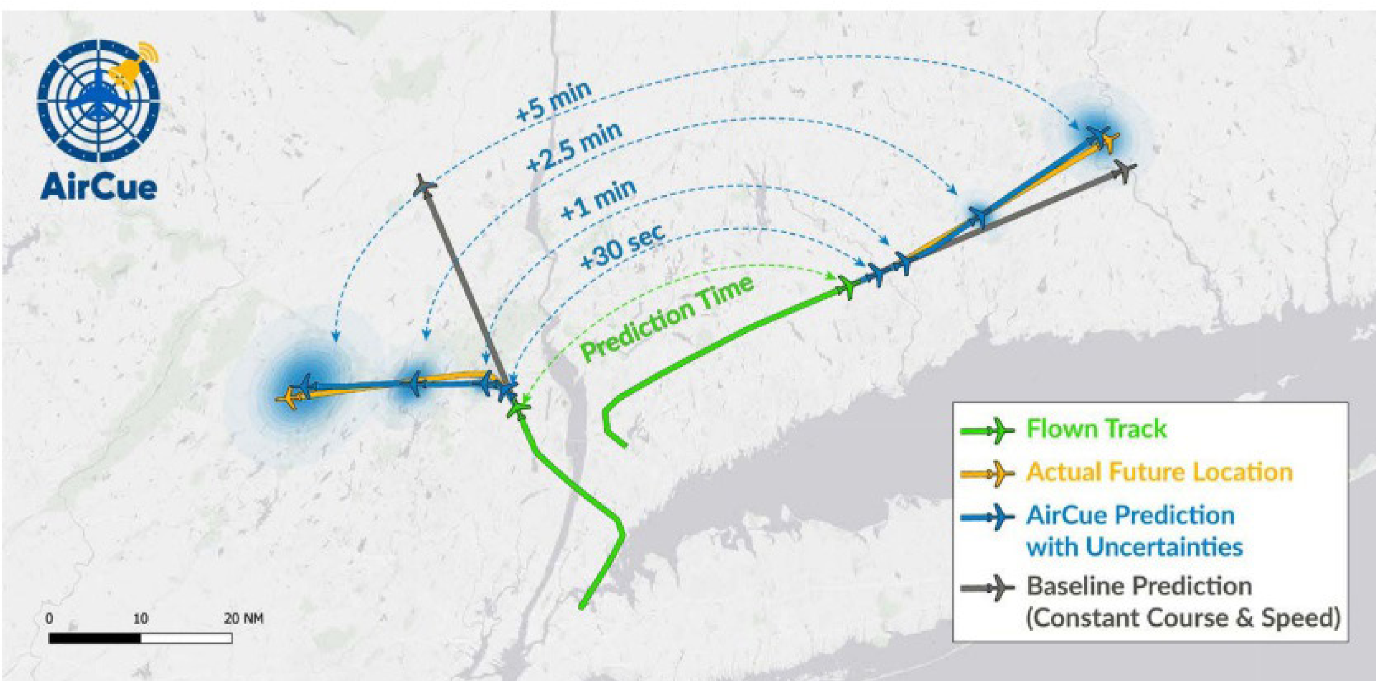

Image: Metron

Figure 2: AirCue's 4D trajectory predictions include uncertainties that enable the calculation of conflict probabilities.

Proven Effectiveness in Complex ATC Environments

AirCue integrates with FAA System Wide Information Management (SWIM) data feeds to provide predictive analytics in some of the most complex ATC environments. Its effectiveness has been proven on live data and historical replays, providing unprecedented insights into air traffic dynamics. By ensuring controllers have the most accurate and timely information, AirCue can empower them to make informed decisions that enhance safety and reduce disruptions.

Key Capabilities

Real-Time Trajectory Predictions with 3D Uncertainty

At the heart of AirCue's functionality is its advanced trajectory prediction engine, which uses deep learning models to predict aircraft movements with remarkable accuracy and associated uncertainty estimates. Figure 2 (previous page) illustrates these predictions for two departures within the N90 TRACON. By training on historical flight data – including filed flight plans, location/track histories, flight metadata, and environmental factors – AirCue can accurately anticipate turns and altitude changes, especially critical in TRACON airspace. These predictions include 4D uncertainty regions that capture normal trajectory variations, crucial for managing the complexities of both commercial and general aviation flights.

Conflict Alerts

One of AirCue's standout features is its ability to predict aircraft conflicts well in advance (current models are tuned for up to five minutes into the future). Figure 3 illustrates such a conflict alert that occurred minutes earlier than those of current systems that rely on simple "dead reckoning" trajectory predictions. Early conflict alerts can enable controllers to take proactive measures, reducing the need for aggressive maneuvers and improving airspace safety. Additionally, the longer lead times enhances efficiency by reducing disruptions such as go-arounds and cascading effects, leading to better fuel efficiency and shorter flight times.

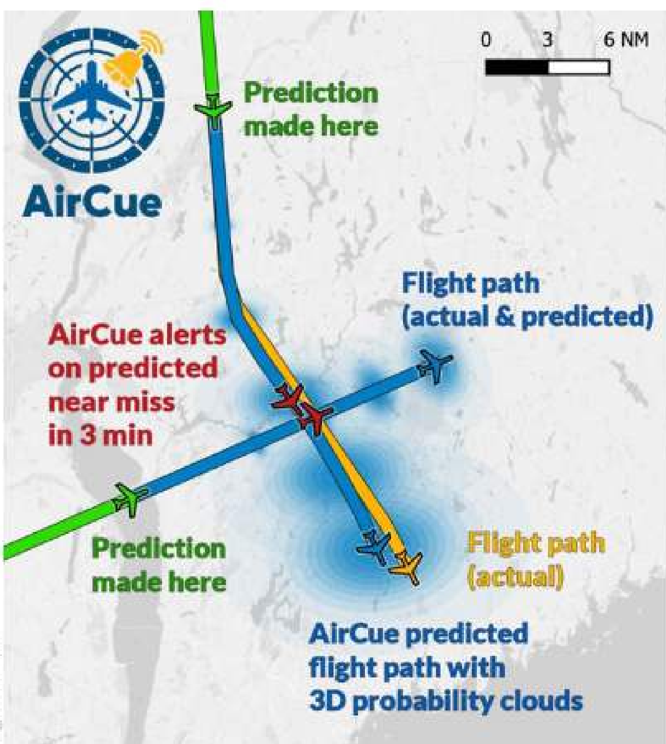

Image: Metron

Figure 3: AirCue anticipates heading and altitude changes with uncertainties to generate probabilistic conflict alerts minutes earlier than the current systems shown in Figure 1.

AirCue in Action: N90 TRACON Case Study

To illustrate AirCue's impact, consider its application in the N90 TRACON airspace, one of the busiest and most complex ATC facilities in the USA. N90 TRACON oversees the intricate flow of aircraft in the New York metropolitan area, controlling dense traffic and challenging low-altitude operations due to the presence of nearby major airports JFK, LGA, EWR, and TEB.

Testing with historical SWIM data showed that implementing AirCue in N90 TRACON will lead to significant improvements in traffic safety. The system's precise trajectory predictions and real-time data integration would enable controllers to make better-informed decisions, reducing delays and enhancing safety. Integrating AirCue into existing controller systems, such as STARS, would ensure that alert information is directly incorporated into the radar display, maintaining workflow efficiency, and minimizing the learning curve for controllers.

Figure 4 shows a recent screen capture of live five-minute aircraft tracks within the N90 TRACON. Track color indicates altitude. White 30-second leader lines illustrate the heading and speed of the aircraft, showing the basic predictions used by current operational systems. The red lines with ellipses show AirCue trajectory predictions at 15 and 30 seconds with probabilistic containment regions sized according to the specific context of each flight.

Proven Strategic Advantages

Enhanced Safety and Efficiency

AirCue's accurate predictions and real-time data significantly enhance the safety and efficiency of air traffic operations. Controllers can anticipate and mitigate potential conflicts, reducing the risk of near midair collisions and other safety hazards. This proactive approach ensures a safer flying experience for passengers and crew.

Recent near midair collisions highlight the urgent need for advanced solutions in air traffic control.

Image: Metron

Figure 4: AirCue's prediction accuracy in New York's congested N90 TRACON airspace shows its ability to handle diverse aircraft operating at low altitudes. From the orchestrated movement of commercial departures and arrivals to free-roaming general aviation flights and helicopters, AirCue delivers reliable predictions to help pilots and controllers deal with the intricate dynamics of aerial navigation.

Improved Alerts

The high nuisance alarm rates and missed or late alert rates of existing systems have adverse effects on performance. By providing reliable alerts, AirCue enhances trust to eliminate the current "cry-wolf effect" where controllers ignore or deprioritize the unreliable alerts.

Cost Savings and Environmental Benefits

AirCue helps reduce flight disruptions and delays, translating into cost savings for airlines. More efficient operations result in lower fuel consumption, thereby reducing the environmental impact of aviation. These benefits align with broader sustainability and operational excellence goals within the aviation industry.

Adaptability to Emerging Challenges

As the aviation industry evolves, new challenges such as integrating unmanned aerial systems (UAS) and advanced air mobility (AAM) systems into the airspace will arise. AirCue is well-positioned to address these challenges, providing the necessary tools and insights to ensure safe and efficient operations in increasingly complex environments. For instance, with the anticipated rise of eVTOLs by 2025, AirCue's real-time data integration and predictive capabilities will be essential in managing their seamless integration into urban airspace and near airports. Additionally, AirCue's ability to adapt to new flight patterns provides a constantly adapting deconfliction tool. This evolving trajectory modeling capability is crucial for incorporating new NAS entrants.

Continuous Innovation and Improvement

Metron's dedication to continuous innovation ensures AirCue will remain a cutting-edge solution in the evolving landscape of air traffic control. The company is advancing AirCue's features, integrating sophisticated machine learning algorithms and enhanced data capabilities. One of their key initiatives focuses on developing systems that can deliver accurate flight path predictions several minutes earlier than previous TRACON systems, a crucial advancement for the industry.

Looking to the future, Metron's vision involves expanding AirCue's capabilities to meet the emerging trends and challenges in aviation. For instance, as UAS and eVTOLs become more prevalent, AirCue's enhanced real-time data integration will provide comprehensive situational awareness, ensuring these new aerial vehicles can be seamlessly integrated into existing airspace control systems. Aircue will support UAS and AAM deconfliction including among such vehicles and traditional aircraft. The system's predictive capabilities will support air traffic controllers by anticipating and mitigating potential conflicts, enhancing

The future of air traffic control depends on the ability to manage a crowded and diverse airspace.

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Artificial intelligence and machine learning are expanding the potential for ATC. By enhancing predictive capabilities and decision-making processes, these technologies can enable air traffic control systems to offer more accurate, context-aware trajectory forecasts with uncertainties. This accuracy is essential for managing the complex and dynamic nature of modern air traffic, ensuring safer and more efficient skies.

safety during peak traffic times and in complex airspace environments. By proactively addressing these challenges, AirCue will continue to be an essential tool for air traffic controllers and pilots, significantly contributing to the advancement of aviation safety and efficiency. Metron's forward-thinking strategies and commitment to technological excellence position AirCue as a pivotal force in shaping the future of air traffic control.

Conclusion

The aviation industry is on the cusp of a transformation driven by rapid growth and the integration of next-generation platforms such as UAS and eVTOLs. As air traffic continues to increase, the need for advanced technological solutions with improved accuracy that can seamlessly integrate with existing systems and provide real-time, accurate data becomes critical.

Metron's AirCue addresses these emerging challenges by providing real-time insights and proactive alerts that empower air traffic controllers and pilots to navigate the complexities of modern airspace with confidence. Its precise trajectory predictions significantly enhance safety and operational efficiency.

The future of ATC depends on the ability to manage a crowded and diverse airspace. Solutions like AirCue, leveraging AI, ML, and real-time data integration, are essential for ensuring safety and efficiency as part of the FAA's Info-Centric NAS. These technologies equip air traffic controllers and pilots with the tools to anticipate and mitigate potential conflicts, optimize flight paths, and maintain situational awareness.

By embracing innovation and continuously improving upon existing technologies, the aviation industry can meet the demands of increased air traffic and new types of aerial vehicles. This proactive approach not only enhances safety and operational efficiency but also supports sustainable industry growth.

The challenges of modern ATC require forward-thinking solutions that can adapt to the evolving aviation landscape. Through a commitment to excellence and continuous innovation, the industry can ensure the skies remain safe and navigable for all users. Metron's AirCue is poised to play a pivotal role in this future, providing the necessary tools and insights to effectively manage the complexities of the skies.

Sean Daugherty, Ph.D., is a senior research scientist at Metron, Inc. He joined Metron in 2009 and has served as the PI, technical, and algorithms lead on R&D projects for NASA, ONR, DHS S&T, and DARPA. Under NASA, he led the conception, design, and development of the AirCue technology, as well as a post-flight anomaly detection and analysis suite integrated into NASA's Sherlock Big Data System computing cluster. Daugherty's areas of expertise include machine learning (e.g., neural networks, regression, anomaly detection, clustering, and classification), cluster computing, graph theory, and graph algorithms. He holds a Ph.D. in computer science from the University of Victoria, and an M.S. in mathematical sciences and B.S. in computer science from Clemson University.

Reference

[1] *Friedman-Berg F, Allendoerfer K, Pai S. Nuisance Alerts in Operational ATC Environments: Classification and Frequencies. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2008;52(1):104-108.*