WAKE TURBULENCE MITIGATION FOR ARRIVALS (WTMA)

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Abstract

The preliminary Wake Turbulence Mitigation for Arrivals (WTMA) concept of operations is described in this paper. The WTMA concept provides further detail to work initiated by the Wake Vortex Avoidance System Concept Evaluation Team and is an evolution of the Wake Turbulence Mitigation for Departures concept. Anticipated benefits about reducing wake turbulence separation standards in cross-wind conditions, and candidate WTMA system considerations are discussed.

1 Introduction/Background

The current air traffic system is not prepared for the two- to three-fold increase in traffic projected for the 2025 time-frame [1]. Current system limitations, procedures, and the absence of automation-based tools define a highly constrained environment. To cope with future traffic demands, fundamental changes are required to effectively manage traffic and maximize the utility of airports. In the U.S., the Next Generation Air Transportation System (NextGen) is being developed to meet this projected traffic growth [2].

An important area for supporting the potential air traffic growth is to improve the capacities of airports when weather deteriorates from Visual Meteorological Conditions (VMC) to Instrument Meteorological Conditions (IMC). When ceiling and visibility are reduced such that aircrew cannot visually navigate, or reliably see and avoid other traffic, then Instrument Flight Rules (IFR) must be used. Air Traffic Control (ATC) shifts from allowing aircrew to fly visual approach procedures to Instrument Approach Procedures (IAPs). While instrument approaches are often used in visual conditions, an airport’s acceptance rate is degraded when the weather forces instrument-only conditions for aircraft navigation and traffic separation, and ATC must control aircraft according to radar and wake separation standards.

This paper includes a background description of the current or state-of-the-art of operational approach procedures including applicable research, and then provides a description of the WTMA concept and system architecture considerations to improve those procedures for NextGen traffic projections. Finally future research efforts and recommendations are described. The authors are passionate about supporting operators with appropriate technology and procedures, so this paper emphasizes that perspective.

1.1 CSPR Description

Closely Spaced Parallel Runways (CSPRs) are defined as runways whose centerlines are separated by less than 2500’ [3]. Many airports throughout the U.S. have CSPRs, and NextGen includes a vision for better utilizing them in IMC.

When CSPRs are used for arrival operations, the capacity can vary significantly based on whether visual approaches or instrument approaches are in use. When visual approaches are used, simultaneous arrival operations can be conducted to both CSPRs, and visual separation must be applied between traffic on the parallel runways when standard (radar) separation does not exist. In the case of instrument approaches, simultaneous operations are not permitted, so the arrival rate is significantly smaller than when visual approaches are in use. Concepts for increasing the CSPR arrival rate could increase the utility of these airports to assist meeting increased traffic projections.

1.2 Wake Separation Standard for In-Trail Approaches

Terminal Radar Approach Control (TRACON) and Airport Traffic Control Tower (ATCT) controllers apply radar separation (R) of 2.5 NM or 3 NM [3] between aircraft on approach. In addition, if specific pairings by weight category occur, wake separation standards are applied (Figure 1). These minima are applied for single-runway Instrument Landing System (ILS) approach procedures and straight-in approaches including approaches to CSPRs where the lateral separation between approach paths is less than 2500 ft. Although not explicitly stated, these minima account for wake vortex descent and decay to acceptable levels of safety for wake avoidance.

Radar Approach Separation Minima				
	Trailing Aircraft			
Lead Aircraft	Small	Large	B757	Heavy
Small	R	R	R	R
Large	4 NM	R	R	R
B757	5 NM	4 NM	4 NM	4 NM
Heavy	6 NM	5 NM	5 NM	4 NM

Fig. 1. ILS Approach In-Trail Wake Separation Minima at the Threshold [3]

1.3 Wake Vortex Avoidance System Concepts for CSPR Approaches

In 2005, a multi-organizational Wake Vortex Avoidance System (WakeVAS) Concept Evaluation Team (CET) documented five generic CSPR instrument approach geometries and procedures [4]. For each of these concepts, approach controllers position aircraft as a "dependent-stagger" operation with a minimum 1.5 NM diagonal stagger at the runway threshold during appropriate cross-wind conditions. The concepts require cross-wind surveillance within an alternate separation zone (ASZ), a 3-D volume encompassing the IAPs of concern, so that wake separation standards may be reduced according to a "red-light/green-light" condition (Figure 2). The "green-light" condition occurs when cross-winds reach a specified threshold value (a local constraint dependent upon runway center line spacing and IAP geometry), that will inhibit the transport of lead aircraft wake vortices to the CSPR approach path of an "up-wind" trailing aircraft. Conceptually, this will allow ATC to reduce the lead-trail wake vortex separation within the ASZ for specific diagonal pairs.

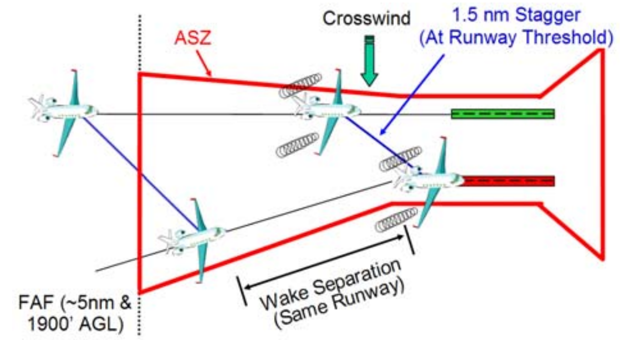

Fig. 2. WakeVAS CET Dependent-Stagger Procedure

Another IAP-based concept and wake avoidance procedure analyzed by the OTB Research Institute, Delft University of Technology, Netherlands, included assigning trailing aircraft to IAPs with steeper approach paths. This ensured that trailing aircraft would avoid the wake of a lead aircraft by procedural separation and flight path guidance [5]. Another feature of this concept took advantage of CSPRs with displaced thresholds, using the displacement in conjunction with the steeper approach for the trailing aircraft to fly above and land beyond the leading aircraft's wake vortices.

1.4 Wake Turbulence Mitigation for Departures (WTMD) Summary

A concept focusing on wind-dependent departure operations has been developed [6]. The current version of this concept is called Wake Turbulence Mitigation for Departures (WTMD) depicted in Figure 3.

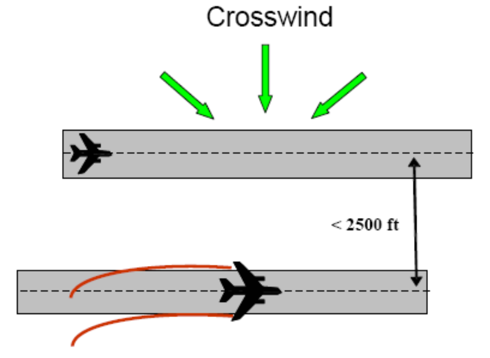

Fig. 3. WTMD Depiction

This concept would be applied to operations at airports with CSPRs, and takes advantage of the fact that cross-winds of sufficient velocity transport wakes generated even by “heavy” and “B757” category aircraft on the downwind runway away from the upwind runway. This means that departures on the upwind runway are not affected by wakes generated on the downwind runway; therefore wake separation of upwind runway departure traffic from traffic on the downwind runway is not required. Wake separation standards would still have to be applied between consecutive departures from the same runway and for departures from the downwind runway following departures from the upwind runway. Human-in-the-loop simulations were conducted that focused on the role of the “local” ATCT controller, who would apply the requisite separation standards [7]. The results clearly indicate that using the WTMD procedures was relatively easy, with workload remaining within acceptable limits. Further, the prototype interface provided adequate information to accomplish responsibilities with respect to the procedure. Finally, departure rate improvements were observed when WTMD operations were in effect [7]. Supervisory Air Traffic Controllers would be responsible for authorizing use of the WTMD procedure. An assessment of the information requirements needed to support approval of the procedure was also conducted. Supervisors felt that the required information was currently available in the ATCT and that the decision to approve and monitor use of the procedure could be integrated into their workload. A full reporting of the results can be found in [8].

1.5 Current CSPR Approach Procedures and Application of Wake Separation Standards

Approach procedures are most efficient in VMC so the challenge is to improve Airport Acceptance Rates (AARs) in IMC. The following procedures are the state-of-the-art for CSPR approaches.

1.5.1 Visual Pairings

Air Traffic Control (ATC) positioning of two aircraft to approach CSPRs so they arrive as a “visual pair” is currently conducted at several U.S. airports. These aircraft often fly a Charted Visual Flight Procedure (CVFP) highlighting key visual navigation features and ATC contact points. Aircraft may be paired by ATC under visual approach conditions where aircrew assume the responsibility for visual navigation to the runway, traffic separation and wake vortex avoidance from traffic they are following to a CSPR. Within the pair, aircraft may be separated laterally during the final approach by only the runway centerline spacing, (minus a wingspan distance), since they may be adjacent to each other “wingtip to wingtip.” Wake separation standards (Figure 1) are applied between pairs by approach controllers until aircrew can assume separation responsibility.

1.5.2 Simultaneous Offset Instrument Approach

As a way of maximizing CSPR throughput, Simultaneous Offset Instrument Approach (SOIA) procedures (Figure 4) have been developed to enable dual arrival streams in conditions of limited ceiling and visibility.

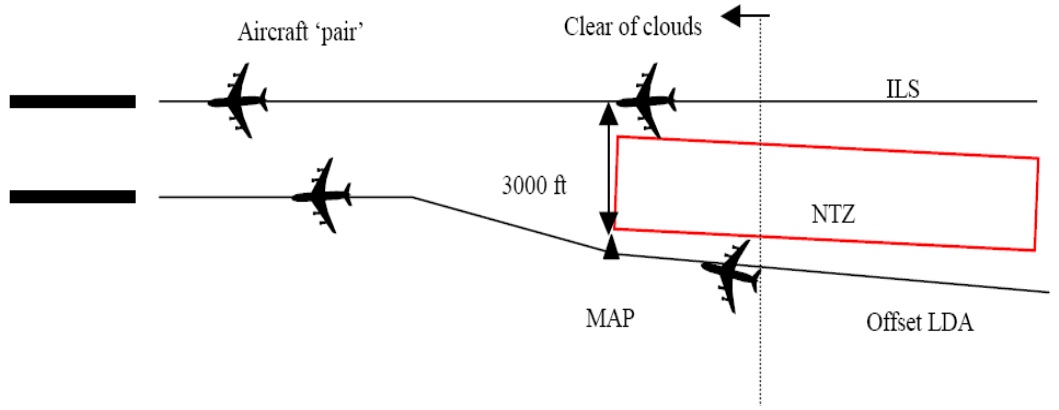

Fig. 4. SOIA Depiction

During SOIA operations, aircraft transition from *independent* IAPs to *dependant* procedures. The aircrew also transition from ATC separation responsibility to aircrew separation responsibility and visual navigation. An aircraft flying a Localizer Directional Aid with Precision Runway Monitor (LDA/PRM) IAP is positioned by ATC to "join" onto a parallel aircraft flying an Instrument Landing System approach with Precision Runway Monitor (ILS/PRM) and the two become a pair. For SOIA, controllers must position both aircraft precisely and point out the parallel ILS traffic to the LDA aircraft before the LDA Missed Approach Point (MAP). Both IAPs are kept separate from a No Transgression Zone (NTZ) which is 2000' wide and is an alerting zone for the SOIA approach controller and the PRM monitor controller. PRM updates at a <2 sec rate so controllers have more frequent aircraft position data. Penetration of the NTZ by one of the aircraft is cause for an ATC directed breakout from the IAP. Before reaching the MAP, the LDA aircrew must visually acquire the traffic and the runway environment and report "traffic in sight" before proceeding to follow the ILS aircraft as a pair. The aircraft pairs may include aircraft of any weight category, but generally with compatible descent/speed profiles and aircrew who have met special training requirements. Again, wake separation standards (Figure 1) are applied by approach controllers until aircrew assume visual separation responsibility.

FAA research efforts have focused on supporting the SOIA join-up procedure for TRACON approach controllers by depicting a "wake protection zone," or WPZ on the PRM monitor display. This is to aid in precisely positioning the LDA aircraft so it will join up in-trail of the ILS aircraft, and ahead of the ILS aircraft's wake. This WPZ research tool is depicted in Figure 5 as it was evaluated during controller simulations in Northern California TRACON for San Francisco International Airport (SFO) [9]. Note the yellow and green circles on the display that are the WPZ limits bracketing the LDA aircraft, depicted with the star symbol.

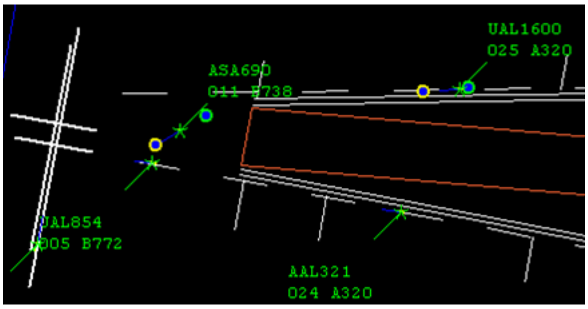

Fig. 5. Wake Protection Zone Concept on PRM Controller Display

1.5.3 Lambert-St. Louis International Airport (STL) CSPR Waiver

Based on wake turbulence data collected and analyzed by the Wake Turbulence Research Program, the FAA approved the requested change for STL air traffic control's operation of its CSPRs. The change allows STL to conduct dependent instrument landing system (ILS) approaches to both its parallel runways under IMC weather conditions that previously would have caused the airport to shift to single runway operations [10].

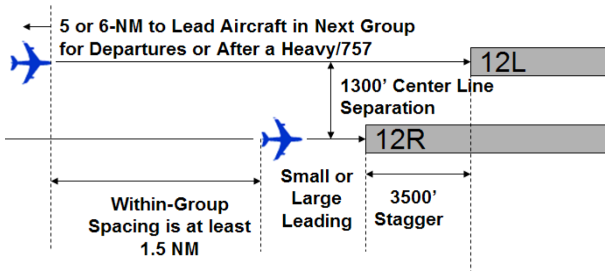

Fig. 6. STL IMC CSPR Waiver

As depicted in Figure 6, aircraft arriving to the CSPRs (1300 foot separation) at STL can be controlled to arrive by a minimum of a 1.5 nm dependent stagger with only a small or large aircraft in the lead. The trailing aircraft lands to Runway 12L, a 3500 foot staggered threshold from Runway 12R. If the trailing aircraft is a heavy/B757 category aircraft, then wake turbulence separation is required for aircraft following it [11].

2 WTMA Concept

Reducing the wake separation standards, especially for CSPRs for aircraft trailing behind B757 and heavy category aircraft was identified in the FAA's FACT 2 report as a lucrative benefit goal, and is an FAA area of planned improvement [10, 12]. The WTMA concept ensures aircraft avoid wake turbulence, not relying on the ability to encounter wakes at an acceptable level. While research to determine acceptable encounter levels has been conducted [13], relatively little data has been collected in controlled flight tests to determine what wake turbulence encounter levels are acceptable to aircrew, passengers, and aircraft operators. Therefore, wake avoidance remains at the core of the WTMA concept. Should levels of acceptable encounter become better understood and defined, this basis could be altered.

WTMA uses automated decision support that monitors meteorological inputs to predict when wakes generated by aircraft approaching a runway cannot impact aircraft arriving to an upwind CSPR. When such cross-wind conditions exist, the runway of interest is considered a wake independent runway (WIR), shown as runway 9L in Figure 7.

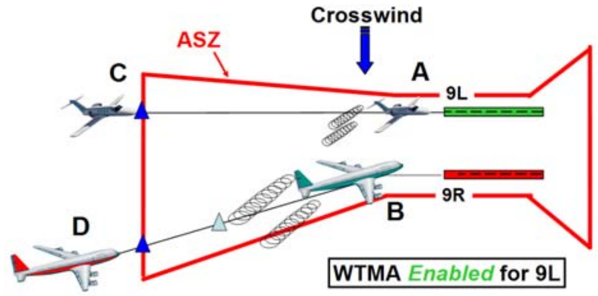

Fig. 7. WTMA Depiction (with Wake Independent Runway 9L)

The WTMA system provides a "red-light" or "green-light" indication of the WIR status of each runway to the approach controllers in the TRACON and simultaneously to the ATCT local controllers. If WTMA indicates the runway of interest is a WIR ("green-light"), the wake turbulence separation standards are not required for IAPs to that runway based on the parallel traffic (between aircraft B & C in Figure 7). Otherwise, the current wake separation standards are implemented.

2.1 Transition into and out of WTMA

The TRACON and ATCT supervisors will enable the WTMA system based on an expectation that favorable weather conditions will exist for an operationally useful period by assessment of current and forecast weather conditions. In both the TRACON and the ATCT, the supervisors will inform each other and the controllers at the respective facilities whenever WTMA operations are enabled or terminated. The WTMA system will facilitate this coordination between facilities and produce a WIR status indication for each runway that is continuously updated. The "green-light" WIR status indication will be considered safety critical and meet appropriate performance requirements for integrity. Note: This safety-critical determination applies only to those WTMA system components responsible for the positive WIR indication. A Failure Modes and Effects Analysis (FMEA) will need to be performed to appropriate design assurance categories for each system component.

Anytime weather conditions not meeting preset criteria for WTMA operations are detected or are predicted to occur within the system look-ahead period or when there is an internal fault, the WTMA system will remove the positive WIR indication for the affected runways. This is a "red-light" condition. Aircraft arriving within the ASZ at the time the WIR status changes to "WTMA off," will be permitted to continue based on the previous positive WIR status indication. Following any system initiated "WTMA off" status, the TRACON or ATCT supervisor would be responsible for re-enabling WTMA operations. The TRACON or ATCT supervisor may also disable a WIR indication or the entire WTMA system whenever desired.

2.2 Anticipated Benefits: Reducing the CSPR Pair-to-Pair Separation

Reducing the wake separation minima during cross-wind conditions to the radar separation minima is the target benefit for WTMA on a per aircraft-pair case. Determining benefits by airport was the focus of a 2005 MITRE report [14]. It highlighted nine of the busiest 35 U.S. airports as potentially benefitting by WTMA due to the CSPR configuration and cross-wind availability. The specific airports analyzed were Boston (BOS), Cleveland (CLE), Detroit (DTW), Newark (EWR), Los Angeles (LAX), Philadelphia (PHL), Seattle (SEA), San Francisco (SFO), and St. Louis (STL).

A key benefit being sought by using WTMA is to enable reducing the wake separation requirement between pairs (Figure 8), and if successfully implemented, could increase CSPR arrival capacity.

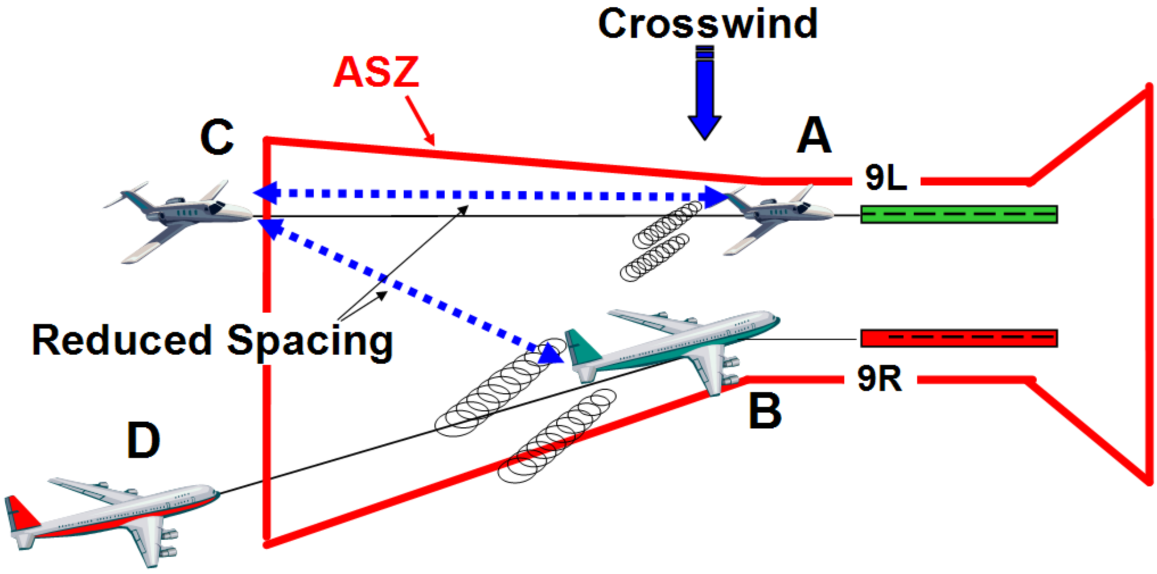

Fig. 8. WTMA with Reduced-Spacing

For the depicted approaches, one-angled/one-straight-in, and similarly for straight-in parallel approach procedures, the separation between a leading pair of aircraft, A&B, and the following pair, C&D, is limited to the wake turbulence separation standards, and local airport spacing procedures, often to interleave the release of departures. When the wake independent cross-wind condition is available, WTMA can be enabled and controllers can apply a reduced separation between pairs of aircraft within the ASZ. Also, approach controller's may choose to turn-on aircraft to their approach procedures so they can be setup for a reduced pair-to-pair spacing, allowing for flow compression before entering the ASZ. Without having to apply restrictive wake separation criteria from the ASZ limit to the threshold, the throughput may be increased.

For example, in Figure 8, the crosswind condition and a WTMA system would allow reducing the spacing between aircraft B&C, perhaps by as much as 3.5 NM for a small or large category aircraft that is following a heavy/B757 category aircraft on the adjacent runway. This would be a significant spacing reduction and potentially a significant AAR throughput improvement. It should be noted that if WTMA becomes certified for reducing single-arrival stream wake separations, this would allow further throughput improvement to the CSPR arrivals in addition to reducing the pair-to-pair spacing. In Figure 8, this would mean allowing reduced spacing between A&C, and potentially between B&D, aircraft flying the same procedure to the same runway. As depicted, it should be noted that the spacing between B&D may potentially be reduced, but the wake transport from A into D's path needs to be understood as it may preclude reducing the spacing between B&D.

2.3 Designing for Operator Acceptability of WTMA

The WTMA design should include simple indications and alerting, integrated with ATC systems and procedures including WTMD in order to best support ATCT and TRACON supervisors and controllers in their management of overall traffic flow and airport operation. For aircrew, an indication of WTMA operations in effect (e.g., broadcast by Digital-Automated Terminal Information Service or D-ATIS) may be sufficient to meet aircrew requirements for conducting WTMA operations, but acceptability of the procedures and being able to handle off-nominal situations must carefully be considered and researched.

Supervisors in the TRACON and ATCT hold the responsibility of initiating or cancelling the WTMA procedure. Most of the pairing of aircraft occurs in the TRACON, so the primary authorization of WTMA would logically reside in that facility; however, user input will determine which operating procedure is best. For WTMD, the ATCT supervisor is responsible for initiating or cancelling WTMD operations. WTMA clearly is a broader scope system since it requires coordination between the two facilities managing aircraft within the ASZ and in the surrounding airspace. Regarding integrating WTMA and WTMD, the two sets of operational procedures should be functionally integrated if at all appropriate, especially in airport environments where CSPRs are jointly used for departures and arrivals. The operator acceptability of an integrated WTMA and WTMD system with accompanying procedures is a subject for further development and study.

For approach controllers in the TRACON and ATCT local approach controllers, keeping track of the possible combinations of aircraft and the corresponding wake separation standards (Figure 1) is currently a mental task that is acceptable, but increasing in complexity as the number and diversity of aircraft types increases. To ensure safety, separation is cross-checked by other controllers and the aircrew. It's critical for WTMA to be developed in concert with user input to ensure controller and aircrew workloads are kept at safe levels. An unsafe workload would be caused by compressing usable margins (and safety margins within the standard itself) too far by procedure design or by a system design that issues WTMA system status changes too frequently. These situations must be considered during the design phase to ensure operators have flexibility for handling an unplanned event, and so that the resulting CSPR approach operation is stable and predictable.

In addition to system status and alerting, WTMA should also include a decision support tool for controllers to ease operator workload. Perhaps this could be a visualization tool integrated directly into their radar display akin to the WPZ tool for PRM approach controllers (Figure 5), or it could be integrated into a supporting display system like Automated Surface Observing System (ASOS) Controller Equipment - Information Display System (ACE-IDS). As much as possible, the WTMA decision support capability should be "platform-independent" to ease the integration into a facility's existing and future ATC system architecture. This WTMA decision support capability would aid controllers in applying the wake separation criteria for the various combinations of aircraft (by weight category or eventually by a specific aircraft configuration). Should the FAA adopt new wake turbulence spacing standards that are specific to aircraft configuration (current state), a WTMA decision aid should adapt easily, continuing to help reduce controller workload in applying wake separation.

3 WTMA System Architecture Considerations

The WTMA system would include an operator interface that will be integrated into other ATC systems as part of the broader ATC system architecture. It would include a WIR status and alerting indication for TRACON and ATCT supervisors and controllers to facilitate a coordinated decision-making process. The interface(s) would reflect which runway is or is not wake independent, and would cue and support the operational decision-making that WTMA requires. For example, "WTMA available, WTMA enable, or WTMA off," are status indications analogous to those identified during the WTMD supervisory assessment [8].

In support of WTMA, exploratory research must be conducted in order to define a simple cross-wind sensing and forecasting system that meets wake avoidance safety criteria and required operational performance. Acceptable cross-wind sensing error and weather forecasting error (for accuracy, integrity, and availability) must be determined. The error magnitudes in cross-wind sensing and forecasting directly affect the pair-to-pair spacing reduction that is possible with WTMA, but operational improvements may still be feasible with errors as long as they are quantifiable and part of the system design.

Using WTMA requires wind and weather surveillance, profile modeling, and forecasting throughout the ASZ with sufficient accuracy, integrity, and availability to ensure flight safety and mission success. Design of the WTMA wind surveillance and forecasting system may include ground-based and airborne sensor data and 4-D wind-profile modeling. Cross-wind, wake transport, surveillance and navigation error buffers are needed to ensure against any hazardous encounters.

WTMD uses a simple and robust wind forecast algorithm (WFA) system that takes current airfield ASOS wind data combined with data from the Rapid Update Cycle (RUC) model, in order to provide column forecasts up to 1000' above ground level (AGL). Controllers are provided a 20 minute forecast with a 3 minute safety guarantee to allow departing aircraft to continue with reduced wake separation should the wind condition change abruptly. The WTMA ASZ has different requirements than WTMD since it includes a wind forecast that extends throughout the ASZ volume (as depicted in Figure 2, the ASZ includes up to 2500' and about 5 NM from the airport). Whether the WTMD WFA can be used for WTMA remains to be determined.

Other systems which could be used for WTMA sensing and as inputs to wind forecasting models, include ground based anemometers like ASOS, and the Low Level Wind Shear Alert System (LLWAS). Remote sensing and analysis capabilities also need to be investigated for suitability, including the use of operational Doppler radar information from Terminal Doppler Weather Radar (TDWR) and Weather Surveillance Radar 1988 Doppler (WSR-88D) the system used by NEXRAD (or

Next-Generation Radar). Meteorological measurements downlinked from routine aircraft flights are a promising source of data for 4-D approach profile wind field data. Such systems include Meteorological Data Collection and Reporting System (MDCRS), and Tropospheric Airborne Meteorological Data Reporting (TAMDAR) [15, 16]. While airborne systems are often susceptible to aircraft accelerations that contaminate these data, research may limit these errors and make the data useful for weather and wind-field modeling. Transmission of aircraft avionics sensor data through Aircraft Communication Addressing and Reporting System (ACARS) and Automatic Dependent Surveillance-Broadcast (ADS-B) may provide additional utility, assuming it is subjected to sufficient quality control.

4 Future Research

4.1 Procedure Development, Acceptability, and Research Priorities

New procedures needed for WTMA should be researched in tiers of priority. At the most important tier, research should identify the global procedures that will eventually result in national rule changes to FAA JO 7110.65 and other applicable FAA Orders. The IAPs described in this paper, one-angled and one-straight-in, provide a template for deeper investigations in simulation, building in fidelity to human-in-the-loop (HITL) usability and concept validation studies. They have been described as "generic" procedures and still have detail to be defined, but in simulation, specific airport, airspace, and aircraft issues will have to be developed and investigated. The WTMA system architecture, including its communications, interfaces, system health monitoring and alerting will have to be developed in concert with user input to be able to represent the concept at a high enough fidelity for HITL validation experimentation and testing. The WTMA concept and procedures need to be qualified as "acceptable" to TRACON and ATCT supervisors, controllers and aircrew. Controller and aircrew workloads need to be acceptable as well. Studies should also determine how operators will be trained. Research should analyze data of cross-wind effects on wake transport and decay within the ASZ so the limits for cross-wind direction and speed are known in relation to the range of possible CSPR centerline separations. Finally, local procedures should be investigated to ensure WTMA is palatable to the end users. This process of increasing the research fidelity in tiers from concept development through simulation development, to prototyping will ensure WTMA procedures and system architecture are developed with rigor in order to be fielded successfully.

4.2 Advanced Topics

4.2.1 Datalink concepts

Because of Automatic Dependent Surveillance-Broadcast (ADS-B) information exchange, aircraft state and intent data can be shared between aircraft and incorporated into on-board avionics and the aircrew can be advised to avoid the wake hazard generated ahead.

As part of NextGen research, NASA is researching advanced flight management system (FMS) "merging and spacing" operations [17], dependent upon ADS-B information exchange, that includes the concept of applying wake separation standards. The premise of merging and spacing is to identify a lead aircraft while still in the en route phase of flight, enable the path-merge with that leader through intent information and speed guidance, and to successfully space behind that leader with an efficient descent profile to the runway or to a CSPR.

4.2.2 Traffic and Wake Hazard Visualization Technologies

Development advances in aircraft datalink information sharing, flight displays, aircraft navigation systems, and FMS's point to the potential for aiding aircrew in following aircraft with increasing levels of precision while avoiding hazards like wake turbulence. Providing visual guidance to fly an approach above the leading aircraft's flight path and wake hazard areas may be feasible with these technologies in IMC and will be the focus of future research. Key to this technology area is safety, simplicity and robustness of design to achieve flight-critical certification.

5 Summary

The FAA is pursuing research and development of WTMA as part of the *NAS Architecture 6*. The preliminary WTMA concept of operations is described here along with system architecture considerations. The WTMA concept provides further detail to work initiated by the Wake Vortex Avoidance System Concept Evaluation Team and is an evolution of the Wake Turbulence Mitigation for Departure concept. Anticipated benefits will be achieved through the reduction of wake turbulence separation standards in cross-wind conditions. WTMA appears feasible for deployment to at least nine of the top 35 U.S. airports, and is worthy of continued research support into simulation and system architecture development.

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