The NASA Aircraft VOrtex Spacing System (AVOSS): Concept Demonstration Results and Future Direction

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Introduction

Since the late 1990s the national airspace system has been recognized as approaching a capacity crisis. In the light of this condition, industry, government, user organizations, and educational institutions have been working on procedural and technological solutions to the problem. One aspect of system operations that holds potential for improvement is the separation criteria applied to aircraft for wake vortex avoidance. These criteria, applied when operations are conducted under instrument flight rules (IFR), were designed to represent safe spacing under weather conditions conducive to the longest wake hazards. It is well understood that wake behavior is dependent on meteorological conditions as well as the physical parameters of the generating aircraft. Under many ambient conditions, such as moderate crosswinds or turbulence, wake hazard durations are substantially reduced. To realize this reduction NASA has developed a proof-of-concept Aircraft VOrtex Spacing System (AVOSS). Successfully demonstrated in a real-time field demonstration during July 2000 at the Dallas Ft. Worth International Airport (DFW), AVOSS is a novel integration of weather sensors, wake sensors, and analytical wake prediction algorithms. AVOSS provides dynamic wake separation criteria that are a function of the ambient weather conditions for a particular airport, and the predicted wake behavior under those conditions. Wake sensing subsystems provide safety checks and validation for the predictions. The AVOSS was demonstrated in shadow mode; no actual spacing changes were applied to aircraft. This paper briefly reviews the system architecture and operation, reports the latest performance results from the DFW deployment, and describes the future direction of the project.

System Design

The AVOSS architecture is shown in Figure 1. The weather subsystem was developed in cooperation with the Massachusetts Institute of Technology (MIT) Lincoln Laboratory, North Carolina State University, and the National Oceanographic and Atmospheric Administration (NOAA). The system consisted of two instrumented towers, Doppler radar and sodar profilers for measuring winds aloft, and a radio acoustic sounding system (RASS) to measure temperatures aloft. At 30-minute intervals, data from these sensors as well as two Terminal Doppler weather radars were integrated into vertical profiles of winds, temperature, and turbulence using a fusing algorithm developed at MIT Lincoln Labs [1]. This data is used as a short-term forecast of the weather that is input to an analytic wake-prediction model [2]. This model provides estimates of wake transport (lateral and vertical) and strength. Northwest Research Associates developed the prediction subsystem, with participation from NASA and the Naval Postgraduate School.

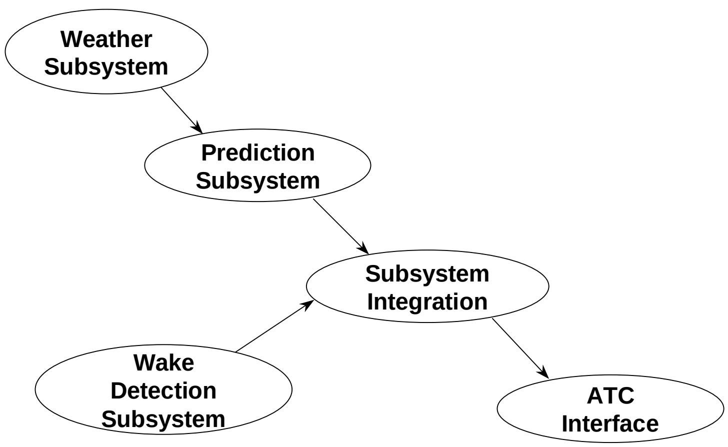

Figure 1 AVOSS architecture.

The subsystem integration logic applies the estimates of wake behavior to a corridor of airspace about the nominal flight path (the center of the localizer and glide slope). Wakes can cease to be a hazard by drifting or sinking out of the corridor or by decaying to a circulation strength comparable to background turbulence. The dimensions of the corridor are based on a 3-sigma buffer applied to observed aircraft position dispersion data from radar tracking data [3].

To determine the AVOSS recommended spacing, the wake hazard times are computed for each aircraft type (e.g., B-747) present in the traffic mix for a given airport. The computations are performed at various points along the approach corridor to capture the changes in wake behavior with altitude. The wake factor (position or strength) that first clears the corridor at those points sets the wake existence time for that aircraft at that point. The worst-case spacing for each aircraft type is then taken as the required spacing for that aircraft's category (e.g., heavy). Using the average approach speeds for each aircraft type and the predicted headwinds, the wake hazard times are converted to minimum spacing values (in nm) for each leader/follower pair. This results in the most conservative spacing being applied. The spacing is output as a category-indexed table in nautical miles.

The wake detection subsystem consists of various wake sensors that track the wakes from the approaching aircraft and provide time histories of wake position and strength as well as observed wake hazard times. These are used as a safety check and to validate the predictions. Figure 2 conceptually shows the safety corridor and a sensor placement. The subsystem used in the DFW deployment consisted of a continuous-wave (CW) lidar system operated by Lincoln Labs, a pulsed lidar operated by NASA, and a ground wind vortex-sensing system (GWVSS), or windline, operated by Volpe.

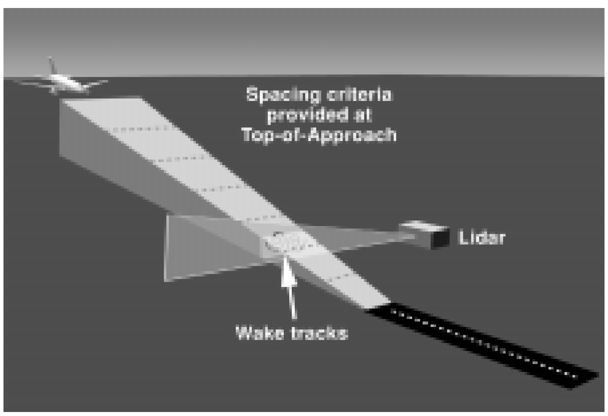

Figure 2 Safety corridor/sensor geometry.

The AVOSS demonstration did not include an ATC interface, although a model that accounts for the performance impact of interfacing to ATC was included to add utility to the results. The model includes rounding of spacing values to ½ nautical mile increments and a buffer to simulate variances in aircraft delivery to the top of approach. Performance statistics were collected for continued system evaluation and development.

System Performance

Analysis of the field data from the 1999 and 2000 DFW deployments reveals the maximum Instrument Flight Rules (IFR) throughput gain averaged 6%, while ranging from 0% to 16%. The gain is computed by comparing the throughput using the AVOSS spacing recommendation to that achieved with the default FAA spacing. The 0% gain indicates that on some days the AVOSS did not recommend reducing the default spacing.

The 16% gain in throughput is approximately equal to the maximum gain possible when comparing the default spacing to the minimum runway occupancy time (ROT) limited spacing. The average throughput gain translates to 15-40% reductions in delay when applied to realistic capacity ratios at major airports [4].

Field data from the DFW deployments was also used to validate the AVOSS predictor algorithms. Of 2301 wake measurements that were compared with the predictions, 99% indicated AVOSS reduced separation could be applied based solely on the predicted behavior (i.e. observed wake hazard times did not exceed the predictions). In almost 2/3 of the cases, AVOSS recommended the minimum separation possible (ROT limited) with no sensor measurements contradicting the recommendation. The 1% of cases where observed wake hazard times exceeded the predicted times were all exceedances of less than 20 seconds, with half under 5 seconds. These cases are not necessarily an indication that an inadvertent wake encounter would have occurred, since the wake hazard time is taken when the wake is observed to be clear of the safety corridor or indistinguishable from the background turbulence. As designed, an aircraft would have to be flying with a significant deviation from the localizer or glide slope course to encounter the wake, which is unlikely given FMS-coupled approaches and typical pilot performance.

Future Plans/Roadmap to Operation

A future AVOSS development notionally referred to as a Wake Vortex Advisory System (WakeVAS) may embrace one of the following concepts: single in-trail or closely-spaced parallel approaches, departures, or intersecting runway operations, depicted in Figure 3. Each of these concepts would also require customization to a particular airport. Subsystems for weather and wake sensing, as well as initial procedure development will be site-specific, while weather forecasting and pilot and controller interfaces will be more generic.

A NASA-led government/industry team is currently laying the groundwork for a WakeVAS. Participants include: the FAA, MIT/Lincoln Labs, MITRE, NASA, and the Volpe Center. The group is researching subsystem issues such as evaluating existing technologies (including sensors, wake vortex prediction, and other factors) with regard to maturity for deployment of wake-vortex-related systems and procedures.

Work is also focused on identification of candidate airports for the development and deployment of a prototype WakeVAS. Airport selection criteria is based on several factors, including a cost and benefit analysis, the projected impact of the various WakeVAS concepts on airport delay and capacity, and the willingness and ability of the airport authority to participate in advocating and funding a WakeVAS.

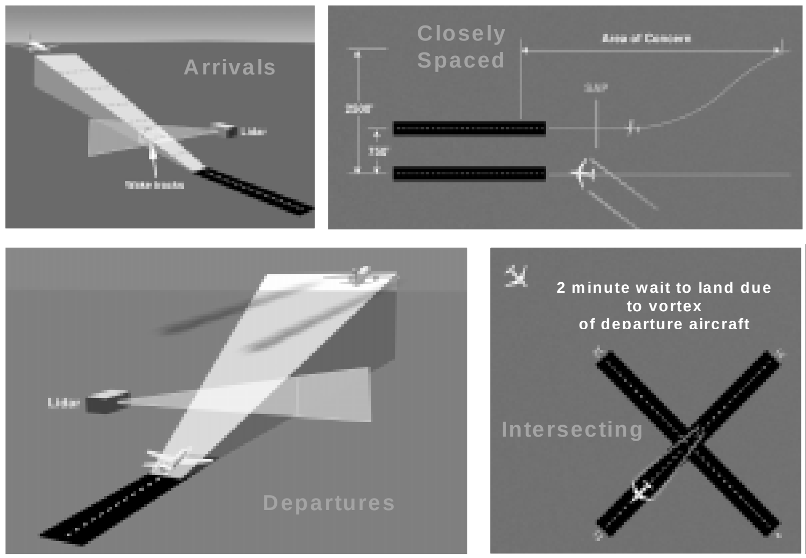

Figure 3 Potential WakeVAS terminal

Specific definition of user needs at those airports deemed promising will follow. An initial system architecture concept along with an analysis of the technical and operational risks of each type of system will also be developed. An exploration of the proposed architecture will lead to the development of candidate procedures.

The successful development of an ambitious system such as a WakeVAS will not be possible without the participation of all affected users. The formation of working groups is anticipated to focus the entire operational development. These groups will include, at a minimum, professional controller and pilot organizations, airport authorities, airlines, industry, and government agencies.

References

[1]. Cole, R., Denneno, A., Matthews, M.; *The AVOSS Winds Analysis System*, Project Report NASA/L-5, Lincoln Laboratory, Massachusetts Institute of Technology, April, 2001.

[2]. Robins, R. E., Delisi, D. P.; *NWRA AVOSS Wake Vortex Prediction Algorithm Version 3.1.1*, NWRA-CR-00-R229A, Northwest Research Associates, November 2000.

[3]. Hinton, D.A.: *An Aircraft Vortex Spacing System (AVOSS) For Dynamical Wake Vortex Spacing Criteria*, AGARD 78th Fluid Dynamics Panel Meeting and Symposium on the Characterisation & Modification of Wakes from Lifting Vehicles in Fluids, Trondheim, Norway, 20-23 May, 1996, AGARD CP-584, Paper 23.

[4]. Credeur, L.; *Basic Analysis of Terminal Operation Benefits Resulting from Reduced Vortex Separation Minima,* NASA-TM78624, October, 1977.