NASA WAKE VORTEX RESEARCH FOR AIRCRAFT SPACING

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ABSTRACT

The National Aeronautics and Space Administration (NASA) is addressing airport capacity enhancements during instrument meteorological conditions through the Terminal Area Productivity (TAP) program. Within TAP, the Reduced Spacing Operations (RSO) subelement at the NASA Langley Research Center is developing an Aircraft Vortex Spacing System (AVOSS). AVOSS will integrate the output of several inter-related areas to produce weather dependent, dynamic wake vortex spacing criteria. These areas include current and predicted weather conditions, models of wake vortex transport and decay in these weather conditions, real-time feedback of wake vortex behavior from sensors, and operationally acceptable aircraft/wake interaction criteria. In today's ATC system, the AVOSS could inform ATC controllers when a fixed reduced separation becomes safe to apply to "large" and "heavy" aircraft categories. With appropriate integration into the Center/TRACON Automation System (CTAS), AVOSS dynamic spacing could be tailored to actual generator/follower aircraft pairs rather than a few broad aircraft categories.

ACRONYMS

ATC	Air Traffic Control
AVOSS	Aircraft Vortex Spacing System
CTAS	Center/TRACON Automation System
DOT	Department of Transportation
FAA	Federal Aviation Administration
ILS	Instrument Landing System
ITWS	Integrated Terminal Weather System
MIT	Massachusetts Institute of Technology
MOA	Memorandum of Agreement
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
RSO	Reduced Spacing Operations
TAP	Terminal Area Productivity
TASS	Terminal Area Simulation System
TRACON	Terminal Radar Approach Control

INTRODUCTION

Air travel delay and traffic congestion at major airports, projected increases in air travel, and environmental restrictions on new airport construction, together with associated costs to the traveling public and to the air carriers, have led to an increased interest in maximizing the efficiency of the national airspace system. The National Aeronautics and Space Administration (NASA) is responding to this interest through its Terminal Area Productivity (TAP) program. The major goal of the TAP program is to develop the technology, during instrument meteorological conditions, which allows air traffic levels to approach or equal levels presently achievable only during visual operations. Presently, a degradation in weather conditions which causes a loss of visual approach capability degrades capacity due to numerous factors. These factors include reducing the number of available runways and the longitudinal wake vortex separation constraints used by air traffic control (ATC) in the spacing of aircraft to a runway. Two major initiatives under TAP are the enhancements of basic ATC automation tools and the development of a wake vortex spacing system to improve terminal area efficiency and capacity. The NASA Ames Research Center is developing enhancements to the base Center/TRACON Automation System (CTAS). This automation will provide aids and interfaces to the controller to effectively schedule and sequence arrivals and minimize variations in desired interarrival spacing. Enhanced CTAS automation will provide an opportunity to dynamically alter the longitudinal wake vortex separation constraint as a function of both the weather effects on wakes and aircraft leader/follower pair types.

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The Reduced Spacing Operations (RSO) subelement of TAP, at the Langley Research Center, is developing the Aircraft Vortex Spacing System (AVOSS) which is described by Hinton[1]. The purpose of the AVOSS is to integrate current and predicted weather conditions, wake vortex transport and decay knowledge, wake vortex sensor data, and operational definitions of acceptable strengths for vortex encounters to produce dynamic wake vortex separation criteria. By considering ambient weather effects on wake transport and decay, the wake separation distances can be decreased during appropriate periods of airport operation. With the appropriate interface to CTAS, spacing can be tailored to specific leader/follower aircraft types rather than just a few broad weight categories of aircraft. In a manual ATC system, a simplified form of the AVOSS concept may be used to inform ATC when a fixed alternate, reduced wake separation standard becomes safe for the “large” and ”heavy” aircraft categories.

The AVOSS development program has as its target a field demonstration of a prototype AVOSS system in the year 2000. To support this goal, current plans include three increasingly complex AVOSS field deployments to be conducted at the Dallas-Fort Worth International Airport. This paper describes the AVOSS concept and development program, the related wake vortex modeling effort, the wake vortex hazard definition studies, and the wake vortex sensors development.

AVOSS CONCEPT

AVOSS is envisioned as an automated process which combines meteorological data, rules describing the atmospheric modification of wakes, and aircraft and airspace operational procedures to provide dynamic wake vortex separation constraints to ATC. The AVOSS system concept by Hinton borrows from previous efforts conducted in the 1970's by Eberle[2] et al. The philosophy behind the AVOSS system is to avoid aircraft encounters with vortices above an "operationally acceptable strength." This avoidance is obtained through consideration of two factors, wake vortex motion away from the flight path of a following aircraft and wake vortex decay. Since these factors are highly dependent on ambient meteorological conditions, as well as the generating aircraft position and type, the wake vortex constraints on aircraft separation are expected to vary significantly with the weather. The AVOSS will quantify the wake separation required for generator/follower aircraft pairs during final approach, or the initial climb, and provide this matrix to an automated ATC system such as CTAS described by Erzberger[3] et al. Capacity gains can be expected due to considering both wake transport and decay, and also by providing a large matrix of aircraft pair separations to ATC automation rather than just the three category system utilized in today’s system.

The wake separation constraints will be delivered to the automated ATC system with adequate lead time and stability to be used in the process of metering and spacing. Final approach aircraft spacing may be established 5 to 10 minutes prior to landing, while the metering rate at which aircraft are accepted into the TRACON is established earlier. Since a current weather observation will frequently not reflect the wake situation 5 to 50 minutes in the future, an effective AVOSS must utilize short-term weather predictions (nowcasting) to provide the lead time required for increasing terminal area capacity. Although AVOSS/CTAS interface simulations have not yet been performed, the concept currently envisions a zero to 15 minute weather prediction being used to establish individual aircraft pair spacing for final approach and a 30 to 60 minute prediction being used to regulate the rate at which aircraft are accepted by the TRACON facility from enroute airspace. This nowcasting capability, coupled with CTAS and the AVOSS predictor capability, will ensure that adequate aircraft are available for approach when minimal spacing is possible and the arrival rate is reduced when larger spacing is required to avoid inefficient low altitude path stretching and holding. This weather predictive requirement will drive all efforts in the development areas of meteorological sensors and system architecture. The automated nowcasting element is an important difference between the AVOSS concept and earlier concepts that proposed to utilize only real-time surface weather observations to regulate final approach spacing.

A number of ground rules will be followed during the AVOSS development. The development effort will be focused on a practical system that can be approved for operational use. This will require a large degree of robustness, reliance on readily available meteorological and wake sensors, graceful system degradation when sensors or subsystems fail, and cost realism. The safety provided must be equal to or greater than the current system. The AVOSS will not require an increment in pilot skill levels or training requirements, nor any aircraft structural or on-board systems modifications. The AVOSS will not alter current pilot functions nor change airborne/ground responsibilities. ATC controllers will not be required to monitor or predict weather conditions. During peak traffic demand periods, however, efficient “vortex-limited” spacing operations may require special ATC or flight procedures compatible with current skill levels. Examples may include executing only straight-in Instrument Landing System (ILS) approaches and no intentional operations above the glide slope by “large” or “heavy” category aircraft. Finally, the AVOSS system must provide a meaningful increment in airport capacity during most instrument meteorological conditions and not reduce capacity during visual meteorological conditions.

AVOSS will provide a time-based matrix that provides only the wake vortex constraint for a leader/follower aircraft pair. The automation/ATC interface will combine this constraint with other factors including radar resolution of aircraft position and runway occupancy time to determine the actual approach spacing. For maximum efficiency with an automated ATC system, the vortex spacing constraint will be dependent on individual aircraft leader/follower pairing, although the matrix could be reduced in real time to the current “small,” “large,” and “heavy” categories for use by a manual ATC system. Automation interface issues to be investigated during the development include required controller interface and displays, controller acceptance, maximum spacing update rates, and overall system stability with dynamic spacing.

An important aspect of AVOSS is that it is not intended to be a fix to any perceived safety problems, nor is it intended for routine use at all airport facilities. The AVOSS purpose is to improve airport capacity at major facilities that are capacity limited and that will be equipped with ATC automation tools such as CTAS, and state-of-the-art meteorological systems such as the Integrated Terminal Weather System (ITWS). This focus on capacity has strong implications for the development of AVOSS. For example, the wake sensor will not be required to detect the weak wakes from “small” category aircraft, since current separation standards behind those aircraft are driven by runway occupancy time rather than wake vortex separations. Likewise, the interaction between small aircraft and wakes may not be modeled in the initial AVOSS since small aircraft typically contribute a small percentage of the traffic during capacity limited periods at major airports. Under those traffic mix conditions, retaining current separation standards for small aircraft in the subset of weather conditions that stall vortices in the approach corridor should have little impact on overall airport capacity levels. These considerations have led to an AVOSS development activity that is somewhat different from traditional efforts to protect small airplanes from large aircraft wakes. The AVOSS will require improvements in the current state of knowledge of wake behavior in ground effect, meteorological predictions, and wake/aircraft interaction.

The derivation of the approach corridor dimensions was described by Hinton in 1995, refined in Hinton[4], and depicted in Figure 1. These dimensions will likely be further refined based on industry and FAA inputs as the system is developed and demonstrated. The departure corridor shape has not yet been defined and will likely only include lateral separation due to the wide variation in climb angle between different aircraft.

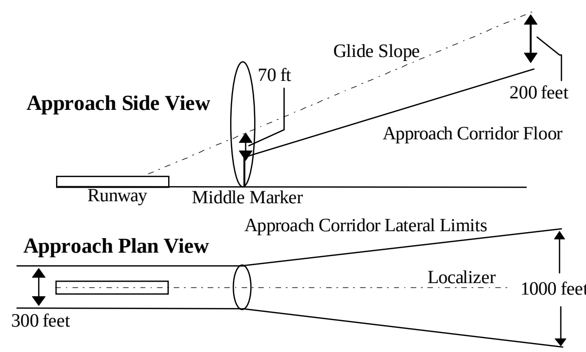

Figure 1. AVOSS Approach Corridor Dimensions

The AVOSS subsystem architecture is shown in Figure 2. Each of the AVOSS subsystem areas will be described in turn.

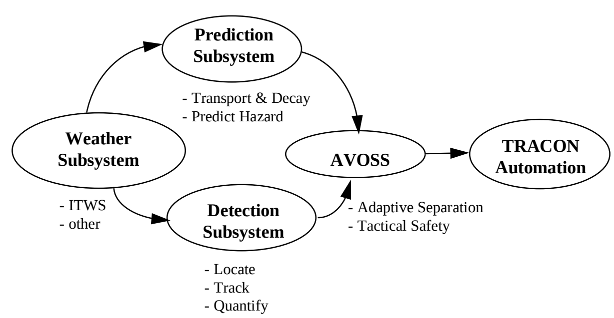

Figure 2. AVOSS Subsystem Architecture

Prediction Subsystem

The core of the AVOSS system is the prediction subsystem. The predictor will utilize weather data, an aircraft data base to predict the initial wake and the threshold of wake vortex strength for an acceptable encounter (acceptable strength definition), airport configuration data, and wake sensor feedback. Using weather data for current and projected times, at a number of "windows" along the path, the predictor will compute both the time required for vortices from each aircraft to clear the AVOSS corridor (transport time) and the expected time to decay to an acceptable strength (decay time) for each follower aircraft. At each window, the lesser of either the transport or decay time will be taken as the wake spacing constraint at that point. For each aircraft pair, the recommended final approach wake constraint will be the largest of the wake constraint times from the various windows. Appropriate uncertainty buffers will be applied to the predictions to accommodate weather uncertainties, as well as expected aircraft flight total system error on the approach path. A number of efforts are underway to develop the prediction subsystem, including development and validation of two-dimensional and three-dimensional wake and planetary boundary layer simulation codes, field studies to validate the numeric codes and implement the infrastructure required for AVOSS testing and demonstration, and simulation and flight test to quantify the interaction between aircraft wakes and following aircraft.

Weather Subsystem

The weather subsystem is crucial to the AVOSS. This subsystem must provide detailed wind, vertical wind shear, turbulence, and temperature gradient information to the prediction subsystem for the current time and for times up to an hour in the future. The weather subsystem should anticipate boundary layer changes associated with sunrise and sunset, and provide discrete information to AVOSS when the atmosphere is about to be modified by frontal passages or other phenomena. The AVOSS is not attempting to predict how a particular vortex will behave 30 minutes in the future. Instead, the predictor is setting the bounds of expected vortex behavior given that the supporting weather predictions will have some uncertainty. Wind values and their confidence boundaries will be specified. The predictor will use these uncertainty values to estimate a range of wake behaviors. In a weather situation with moderately steady wind, for example, the uncertainty values may be small compared to the wind, and accurate wake predictions should result. In a weather situation with moderate but highly variable winds, such as would be expected near air-mass type thunderstorms, the uncertainty values may be quite large. In this environment, AVOSS will prescribe conservative spacing with a maximum value equal to current separation rules. The weather subsystem will utilize several available resources, including existing and planned products from the FAA's ITWS program, off-the-shelf acoustic sodars or radar profilers, and advanced numeric modeling techniques under development.

Sensor Subsystem

The wake vortex sensor subsystem is included for several purposes. Operational test and evaluation of any particular AVOSS installation will require a wake sensor to validate the performance of the weather and predictor subsystems at that airport. Once operational, the wake sensor would be used to continuously monitor actual wake behavior and compare to the prior predictions. In normal operations, the actual wake behavior should fall close to the prediction and well inside the uncertainty buffer times provided to ATC. When actual behavior begins to deviate from predictions, the wake sensor feedback to AVOSS will be used to refine aircraft spacing prior to any aircraft encountering an unsafe wake remaining in the corridor. In the event of a wake unexpectedly persisting much longer than expected, the wake sensor input to ATC would be used to provide a go-around to the next aircraft and increase subsequent spacing. Obviously this last situation must be extremely rare. A secondary use of a wake vortex sensor is that some of the potential technologies can also provide high quality approach corridor wind information to the AVOSS predictor system.

The basic requirements for a wake vortex sensor are to detect, locate, and quantify the strength of aircraft wake vortices. The sensor should perform this function in clear weather as well as in low ceiling and visibility conditions compatible with the instrument approach minima for the airport facility. The sensor should protect the critical region of the approach, which begins near the aircraft touchdown zone and extends to a distance of approximately two miles from the runway. This definition of the critical region will be refined during development, but must include that region where terrain and changing boundary layer characteristics make vortex prediction most difficult, and where the potential danger of an error is unacceptable. A sensor that does not meet all of the above requirements may be useful in a subset of weather conditions, and the effectiveness of that sensor would be evaluated with cost/benefit studies.

NASA RESEARCH SUPPORTING AVOSS DEVELOPMENT

NASA is conducting a broad range of research, both in-house and out-of-house, to support the development of AVOSS. In broad terms, AVOSS requires: 1) a knowledge of the characteristics of vortices which are generated by different aircraft, 2) a predictive capability for the effects of weather on the motion and decay characteristics of vortices from the time at which they are generated until the arrival of a following aircraft, 3) feedback from a sensor system to support the vortex motion and decay predictive capability, and 4) criteria for determining when a wake is not a concern on the approach path. Although research in each of these areas, or subsystems, will be described separately, the results of the research will be integrated in the AVOSS system.

Numerical Fluid Dynamics/Atmospheric Modeling

The NASA Langley numerical modeling effort is expected to provide key support in the development of the AVOSS system. The Terminal Area Simulation System (TASS), a multi-dimensional large-eddy weather model by Proctor[5,6], and by Proctor and Bowles[7], has been adapted to accomplish this goal. The TASS model was highly successful in the completed NASA-FAA wind shear program as described by Proctor[8]; and by Proctor[9] et al., and more recently has been modified to include initialization routines for post roll-up simulations of aircraft wakes. The model includes the effects of turbulence and ground stresses, and is capable of simulating wake vortices within a wide range of atmospheric environments that may include vertical wind shear, stratification, fog, and precipitation. Other recent modifications to the initial and boundary conditions now permit simulations of the Earth's planetary boundary layer, and including thermals and turbulence eddies as described by Schowalter[10] et al., and by Lin[11] et al. This is a first step for investigating the interaction between three-dimensional wakes and atmospheric turbulence. The ultimate goal is to inject three-dimensional wakes into realistic boundary layers accompanied by a spectrum of scales for ambient turbulence. This will allow a full understanding of how eddy scales effect wake transport and decay, for example, the determination of which scales of turbulence act to decay wake vortices versus those that are most responsible for transport. Output from the TASS modeling effort will be used for wake vortex characterization and for development of AVOSS predictive algorithms.

The NASA Langley wake vortex research required the acquisition of planetary boundary layer and wake vortex data for the validation of numerical models. This element has been addressed through an agreement with MIT-Lincoln Laboratory which was initially funded in early 1994. Within that year Lincoln designed, constructed, and deployed a van-mounted 10.6 micron, continuous wave coherent laser (lidar), equipped the Memphis International Airport with a 45 meter meteorological tower, soil temperature and solar radiation sensors; and established agreements with the prime aircraft operators at Memphis to supply aircraft landing weight data. An existing FAA/Lincoln facility was used by Lincoln to collect aircraft beacon and flight plan data to identify each aircraft passing the lidar.

The National Oceanic and Atmospheric Administration (NOAA) contributed by acquiring and deploying a radar profiler and radio acoustic sounding system as well as an acoustic sodar at Memphis in 1994. Volpe National Transportation System Center provided an acoustic sodar and the deployment of a line of anemometers (wind line) in 1995. Lincoln conducted dedicated rawinsonde balloon launches during the observations and NASA Langley deployed an OV-10A aircraft to measure atmospheric conditions at spatially remote locations from the meteorological site at the airport. The resulting system provided the most complete facility to date to simultaneously collect wake vortex data, meteorological data, and aircraft data in an operational setting. The deployments conducted are described in more detail by Campbell[12] et al., Dasey and Heinricks[13], and Campbell[14] et al. The data and operational experience gained at Memphis in 1994 and 1995 will be utilized to complete validation of numeric wake simulation models, to develop improved wake prediction algorithms, and to begin the engineering and software build of an engineering model AVOSS in the 1997 through 2000 year time frame.

As in past studies conducted with the TASS model, it is very important that all aspects of the model simulations be compared and validated with observed data. For the planetary boundary layer simulations, mean and turbulence flux profiles are being compared against those measured in field studies. Results to date have been very encouraging. Validation of the wake vortex simulations are well underway as well. Recently, promising results have been obtained from comparing the two-dimensional version of TASS with measured field data from the 1990 FAA Idaho Falls and the 1994 and 1995 Memphis field experiments, as described by Proctor[15].

Wake Vortex Hazard Definition

A wake vortex that moves out of the traffic corridor by the time the next aircraft passes through is not a hazard to that aircraft. However, if the wake stalls in the traffic corridor or moves very slowly, the AVOSS must determine if the next aircraft can safely and satisfactorily complete its intended operation, even if it encounters the wake. This determination follows the notion that a perfectly acceptable terminal area operation may be completed with a wake in the traffic corridor, e.g., for a "heavy" aircraft following a business jet or when conditions or time increments allow a wake to decay to satisfactory levels. For these cases, the AVOSS will determine the correct longitudinal spacing for the specific leader/follower aircraft pair based upon the required characteristics of the wake for satisfactory passage through it.

The adequate definition of an acceptable wake encounter requires that three key issues be addressed as depicted in Figure 3. First, the effect of the wake on the encountering aircraft's trajectory must be determined by developing and validating aircraft/vortex interaction simulator models. Second, the metrics characterizing a satisfactory terminal area operation, regardless of whether a wake is present in the traffic corridor, must be defined in order to determine if the resultant wake encounter trajectory is acceptable. Finally, for the AVOSS system to realize its full potential, a method must be devised for applying these operational metrics and validated models to the entire commercial aircraft fleet.

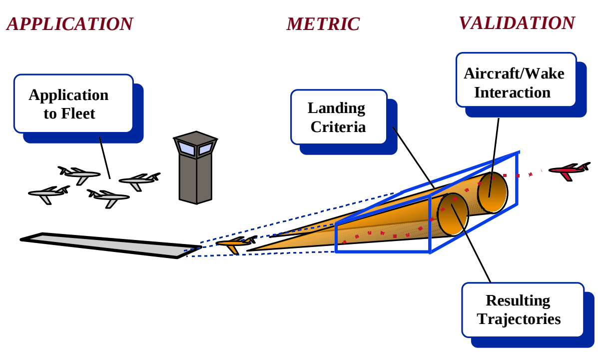

Figure 3. Major Hazard Definition Issues

To address the aircraft/wake vortex encounter issue, several experimental and analytical efforts are being conducted to provide a basis for the selection of a valid aircraft/wake interaction model. Key to these efforts is the development and validation of a wake vortex encounter simulator which can be used to assist in the model selection process. The encounter simulation will employ results from NASA wind tunnel and flight experiments designed to examine the effects of wakes on representative aircraft configurations.

The second major issue in defining an acceptable wake encounter is the determination of the metric for satisfactory terminal area operations. In the 1970's and 1980's, several key piloted simulation studies were conducted by Sammonds[16,17,18] et al., Jenkins and Hackett[19], and by Hastings and Keyser[20] to obtain an estimate of the magnitude of vortex-induced motions that would be acceptable near the ground. These simulations provided data on the wake vortex hazard perceived by pilots with repeatable encounter conditions, and have provided preliminary guidance into suitable metrics for satisfactory operation that can be used for a wake vortex hazard definition. In these studies, the separation of occurrences into hazardous and non-hazardous categories was found to correlate with maximum roll or bank angle, proximity to the ground, vortex strength, and the encounter geometry. However, there is no similar correlation on the metrics which would define a satisfactory encounter, which may not be quite the same as those for a non-hazardous encounter and may also include consideration of, for example, passenger comfort, chance of missed approach, and runway occupancy times as additional factors. One could conclude that if the metrics for a satisfactory terminal area operation could be defined, regardless of the cause of an upset or deviation, then the definition of whether a wake encounter is satisfactory will directly follow, given an assumed model of the encounter dynamics, pilot, and autopilot.

Candidate metrics for satisfactory terminal area operations could include limits on airplane attitude, angular rates, flight path deviations and the amount of control required to correct them, touchdown requirements, and ride quality. Some of these limits can be derived from the FAA certification regulations, from manufacturer's aircraft limitations, and other sources to augment the first-order estimates from the previous piloted simulations. However, many of these limits must come from subjective opinion, which necessitates a strong consensus among a team comprised, in part, of the operators, the regulators, the manufacturers, and government research agencies. Presently, efforts are underway to gather the information needed to define an initial candidate operational metric using the results of the previous simulation studies, the certification requirements, and opinions of experienced airline pilots. Government/industry interaction will be used to address the long-term consensus of a suitable metric, quite possibly involving additional simulation efforts to refine and augment the first-order estimates.

The final hazard definition issue addresses how these wake encounter and terminal area operational metrics are applied to the whole fleet. An initial assessment was provided by Stuever and Greene[21]. The solution to this problem will likely depend on several analytical techniques which consider the "correctness" of a given aircraft model for the size/weight of aircraft it represents, the accuracy of the predicted encounter dynamics, and the likelihood that the severity of a representative encounter will approximate the worst case for a given initial condition.

The constitution of the fleet will need to be defined and then a representative sample of that fleet will need to be agreed upon through government/industry interaction. From that sample, a data base of suitable fidelity for those representative aircraft will be developed and used. Presently, a data base of some 67 aircraft has been prepared at NASA Langley which will be used to establish the fleet representation for follow-on work. Next, the issue of errors in the data base parameters, differences in data base parameters among representative aircraft of about the same size, and even sensitivity to metrics must be addressed to determine how robust the hazard definition must be. A simulation capability is being implemented at NASA Langley to evaluate these effects as described by Reimer and Vicroy[22]. Given the metrics of allowable path deviation and bank angle for a satisfactory encounter, very small differences in allowable vortex-induced bank angle can give significant differences in the strength of a vortex that can be encountered.

Wake Vortex Sensors

The requirements for a vortex sensor subsystem are not completely defined at present because they are driven by current technology limitations. There are four broad ranges of technologies under consideration: mechanical sensors (such as propeller anemometers), acoustic sensors, lidar, and radar. At the present time, none of these sensors have demonstrated all of the characteristics desired for the vortex sensor subsystem. Mechanical anemometers are used routinely in all weather conditions for a variety of applications. They are currently being used as wake vortex position sensors in field tests being conducted by the FAA. Due to their technical maturity, low cost, and reliability, these sensors are candidates for use as part of a sensor package but cannot meet all of the current AVOSS sensor requirements. Acoustic sensors have also been proven to be valuable through many years of FAA wake vortex research. However, these sensors at present do not have the capability to operate in precipitation and have limited range and tracking capabilities. Lidar has the potential for increased range and tracking capabilities, and has demonstrated the capability to detect and measure vortex velocity fields in clear air. However, lidar capability in rain and fog has not been demonstrated. Finally, radar has the potential for all weather capability, but has not yet demonstrated the capability to detect and track vortices using radar systems that have reasonable power outputs and antenna sizes. To address all these wake vortex sensor technologies, NASA is planning to conduct a series of field experiments in conjunction with the Volpe National Transportation System Center at the John F. Kennedy International Airport beginning in late 1996.

Based on the state of readiness and potential of the sensor technologies mentioned above, the NASA Langley wake vortex sensor research is presently concentrating on both lidar and radar technologies.

NASA is working with Coherent Technologies, Inc. through a small business innovative research contract to develop a 2 micron diode-pumped Doppler lidar. Coherent Technologies, Inc. has previous experience in developing a 5 pulse per second, 2 micron flash lamp-pumped lidar system as reported by Hannon and Thomson[23]. This flash lamp-pumped system has successfully detected and measured vortex velocity fields in a number of different locations. The 2 micron diode-pumped system will have a greatly increased pulse repetition frequency and should provide increased detection area coverage, better capability to detect in low signal to noise conditions, and increased definition of velocity fields in the vortices.

In order to determine the expected performance of the experimental system and to assist in the system development, extensive computer simulations have been conducted. Simulation runs to date have predicted that the system will successfully detect, track and quantify vortices in clear air at sensor offset distances of 1 to 3 kilometers. Simulation of detection sensitivity during inclement weather and fog are presently underway. Preliminary results indicate that detection range during rainy conditions should be approximately equal to the ambient visibility. Detection range in fog is more difficult to predict and will be measured during actual field tests. Field test results will be used to modify the lidar simulation as necessary to obtain correlation with actual lidar performance in the field.

Initial efforts toward the development of a radar sensor for wake vortices were motivated by the desire for all-weather capability. It was determined that before attempting an all-weather design, models for estimating the clear air reflectivity of vortices would be developed and preliminary field experiments would be performed to attempt clear air detection and to validate and calibrate the models. In the event that all-weather capability is determined to be unreasonable or unobtainable, a foul-weather capability could be developed which could complement a lidar sensor that might perform well in clear air, but have limitations in adverse weather such as fog and rain.

Preliminary reflectivity models concentrated on Bragg scattering due to turbulent eddies with a diameter of one half the radar signal wavelength. These initial reflectivity models indicated the potential for useful reflectivity at microwave frequencies up to and including X-band. Previous field experiments by Chadwick[24], Nespor[25], and Gilson[26], which detected vortices in clear air at wavelengths from 3 m to 5 cm, appeared to support these models. Based on these results, target of opportunity field experiments were conducted at the NASA Wallops Flight Facility and White Sands Missile Range during 1995 using a C-130 airplane, and the data are currently being analyzed.

Presently, planning is underway for the development of a millimeter wave radar system to be available for initial field testing in 1998. This system is targeting operational capability in rain and fog conditions where many wake vortex sensors tested to date have not been able to provide adequate wake detection.

SUMMARY

A concept and research program has been presented for the development and implementation of a prototype AVOSS. The AVOSS development is being conducted by the RSO subelement of the NASA Terminal Area Productivity Program. The purpose of the AVOSS is to use current and nowcasting predictions of the atmospheric state in approach and departure corridors to provide, to ATC facilities, dynamical weather dependent separation criteria with adequate stability and lead time for use in establishing arrival scheduling by CTAS. The AVOSS will accomplish this task through a combination of wake vortex transport and decay predictions, weather state knowledge, defined aircraft operational procedures and corridors, and wake vortex safety sensors. Work is presently underway to address the critical disciplines and knowledge requirements necessary to implement AVOSS. These disciplines include short term atmospheric state prediction (nowcasting), validated computational fluid dynamic simulations of wake vortex behavior, quantification of aircraft/wake encounter effects (hazard definition) wake vortex sensor assessment and development, and field data acquisition and systems deployment. The effort is scheduled to culminate in a AVOSS system demonstration in the year 2000.

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