APPENDIX

FAA Integrated Wake Vortex Program Plan

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Research and Development
Service
Washington, D.C. 20591

FAA Integrated Wake-Vortex Program Plan in Support of the DOT/FAA/NASA Memorandum of Agreement Concerning Wake-Vortex Systems Research

Program Plan
August 1994

U.S. Department of Transportation
Federal Aviation Administration

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FAA INTEGRATED WAKE-VORTEX PROGRAM PLAN
IN SUPPORT OF THE DOT/FAA/NASA
MEMORANDUM OF AGREEMENT CONCERNING
WAKE-VORTEX SYSTEMS RESEARCH

This is not an acquisition program. However, the plan contains all steps necessary for such a program should it proceed. These steps are carried out per Circular A-109 and per FAA Order 1810.1F. This program also includes coordination with the NASA Program and other NASA activities.

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1. INTRODUCTION

This program plan is a "living-working" document that will be updated as events require. The Federal Aviation Administration (FAA) provides guidelines, advisories, and regulations that assure the safe and efficient conduct of civil aviation activity. Much of this is done by applying the results of scientific inquiry to the solution of aviation problems. One such area of inquiry is the wake-vortex phenomenon. Frequently asked questions regarding wake vortices are: (1) Are aircraft classification standards, as they exist today, adequate to achieve the desired level of safety? and (2) Why are greater wake-vortex spacings required under Instrument Flight Rules (IFR) than are used routinely by pilots operating under Visual Flight Rules (VFR)? These are reasonable questions, since during VFR operations there have been no documented instances of an accident or an injury occurring when the recommended practices of Section 3, Chapter 7 of the Airman's Information Manual (AIM) (reference 1) have been followed.

The current wake separation standards were established during the 1970s. At that time there were logical break points in aircraft size by which to categorize aircraft. For example, heavy aircraft such as the Boeing B-747, Lockheed L-1011, and the Douglas DC-10 were clearly in a class by themselves, and there were very few smaller "commuter size" aircraft. Today there is almost a continuum of aircraft size as the "aircraft family" concept has been widely adopted and there are many new transport aircraft. This continuum of aircraft in terms of initial wake-vortex strength is illustrated in Figure 1. The theoretical predictions for maximum landing weight and empty operating weight are discussed in reference 2. In this figure the calculated vortex strengths have been normalized to a value of 1 for a mid-weight B-737. The data points superimposed on this figure were obtained during field measurements made by the Volpe Center at O'Hare during 1976 / 1977 and at Idaho Falls Airport (IDF) in 1990, and tower measurements made at IDF by National Oceanic Atmospheric Administration (NOAA) in 1990. The measured data and theoretical calculations show excellent agreements, including the data point for the stripped down B-767. The important point of Figure 1 is that there is no natural break point in wake-vortex strength for the continuum of aircraft. In addition, there has been evolutionary growth of existing aircraft models such as the DC-9 and the B-737 and there are new, much larger aircraft on the drawing boards. Also, new operational procedures have been adopted that relate to noise abatement approaches and fuel conservation approaches.

In view of the need to increase system capacity and of the change in the fleet size and mix, it is appropriate to review the aircraft classifications and vortex separation standards. We have learned that, in addition to the dependence of wake vortices on wing span, weight, and span ratio, there is a strong dependence on the characteristics of the atmosphere. Different spacings have evolved for IFR and VFR operations. The greater spacings used under IFR were developed for a variety of reasons, and are usually not needed solely to satisfy wake-vortex constraints.

By developing proper training and system technology, separation standards for IFR operations may be reduced, with increased spacing used only when necessitated by weather or particular aircraft pairings. This will result in increased capacity under IFR when it is needed most; meanwhile special advisories can be developed to improve safety under VFR operations. To accomplish the goals of this program, a joint effort by the FAA and the National Aeronautics and Space Administration (NASA) has been initiated through a Memorandum of Agreement (MOA) (reference 3).

Both FAA and the NASA will ensure the participation of industry and the international community throughout this program. The NASA wake-vortex effort is an element of a larger NASA Terminal Area Productivity (TAP) Program effort and is a significant undertaking with an overall goal of ameliorating wake-vortex constraints on system capacity. The FAA portion of the program will address training; capacity improvement, e.g., through runway spacing; validation of proposed wake-vortex solutions leading to potential validation / reduction of separation standards; and air traffic system integration. The NASA portion of the program is structured to meet the needs of the FAA by focusing on development of sensor technology, wake-vortex prediction techniques, automated approach spacing concepts, human factors considerations, system integration techniques, and hazard modeling technology. Figure 2 illustrates the rationale underlying the Wake-Vortex Program, and depicts the "why, who, what, how, and when" elements of the program. It is noted that the program will culminate in a technology validation and demonstration of a system concept that includes dynamic, adaptive separation criteria.

The Wake-Vortex Program includes a review and recommendation for changes in aircraft classification and separation standards with the aim of maintaining the current high level of safety. A primary objective of the program is to mitigate the influence of wake vortices on separation. This in turn may lead to increased airport capacity and system capacity through implementation of several vortex capacity improvement concepts: more efficient wake-vortex separation standards; a system designed to increase capacity for close-spaced parallel, converging, and single-runway configurations; and an automated real-time separation system. Figure 2 illustrates all of the program elements needed to develop and implement wake-vortex capacity improvements. For all candidate capacity improvement concepts, the effectiveness of the algorithms and recommended procedures will be determined by means of validated vortex decay and vortex encounter hazard models which are based on vortex data, and encounter simulations. The utility of an improvement concept will be determined through capacity studies and simulation. A tactical safety vortex sensor will be used to assure system safety during system demonstration and may become a permanent part of the system where needed. The recommended operational concept may require interfacing with airport weather systems such as the Integrated Terminal Weather System (ITWS), and will provide outputs to air traffic controllers (ATC), and automated separation systems such as Center TRACON Automated System (CTAS) and Converging Runway Display Aid (CRDA).

All of the elements of Figure 2 now exist in some form for some of the intended capacity improvement options. The program tasks are designed to upgrade and validate all system components to the level where safety and utility can be assured.

The Wake-Vortex Program will be carried out jointly by the FAA, NASA, and industry in a manner that utilizes the unique strength of each agency and organization. NASA's wake-vortex efforts are part of the NASA Program to increase IFR airport capacity to the level achieved in VFR. The FAA and NASA will work together on many of the development activities shown in Figure2. Initial steps have been taken to develop cooperation with France, Germany, The Netherlands, Canada, and the United Kingdom to ensure that the program will use to best advantage the contributions of all participants.

The FAA, as the regulatory agency, will have primary responsibility for developing system requirements and coordinating efforts with other program offices, such as Terminal Air Traffic Control Automation (TATCA), ITWS, etc., as required to accomplish program goals. NASA responsibilities include the meeting of program requirements, vortex-encounter modeling, vortex-hazard definition, sensor technology development, and system concept work described in Figure3. As a part of NASA's TAP Program the NASA effort will be aimed at the development and demonstration of a specific concept designated as Aircraft Vortex Spacing System (AVOSS). The role of industry will emphasize training and, through government partnership, aid in system design and implementation.

2. BACKGROUND

2.1 BASIC PROBLEM

Wake vortices are generated as a consequence of lift generated by the wings (or rotor) of an aircraft or helicopter. The vortices from one aircraft may pose a hazard to following aircraft. In the U.S., aircraft are currently classified in three classes: Heavy, Large, and Small, which have specified minimum separation standards for following aircraft. These standards have been established on the basis of runway occupancy time, with the intention of preventing hazardous encounters. The program participants have agreed that according to all known records no wake-vortex-related accidents have occurred when air traffic standards and procedures (reference4) and the recommended practices of the AIM were followed. The fundamental aims of this plan are to reduce, if possible, these separation standards and to develop procedures and / or systems to further increase capacity.

2.2 PRIOR FAA PROGRAM ACTIVITIES

Early FAA wake-vortex activities are documented in several publications. A brief history of the results may be found in references 5, 6, 7, 8, and 9. A synopsis of past work is described in this section.

1. The early years (1969-1976) of the FAA Wake-Vortex Program were devoted to the initial exploration of the vortex phenomenon and to defining the current separation standards. An extensive data collection effort showed that the original 1969 separation standards were indeed safe for commercial aircraft, but that an additional mile of separation was needed for Small following Heavy and Large aircraft (these standards changed in 1976).

2. The FAA Wake-Vortex Program completed a decade of major data collection efforts in 1980. These efforts were designed with the expectation that a better understanding of wake-vortex behavior would help in recovering some of the capacity lost as a result of the imposition of increased separation standards. The program was terminated in 1981 after the data had been reduced, but before all of it had been analyzed. During this period the first vortex-encounter hazard and vortex-decay models were developed and used to study alternative separation standards.

3. In the late 1970s, the first wake-vortex system, the Vortex Advisory System (VAS) was developed. This system was tested but did not become operational.

4. In 1984, the program was reactivated to investigate helicopter wake-vortex issues and to complete the analysis of the earlier data. Several reports were written during this period but were never published because the program was terminated in 1987. **These reports are under evaluation at this time and analysis will determine their suitability for publication.** During this period an aircraft classification model that considered both landing and take-off was developed.

5. The FAA Wake-Vortex Program was again reactivated in 1989 and terminated at the end of 1991. During this period, vortex data were collected during tower fly-by operations leased B-727, B-757, and B-767 aircraft at Idaho Falls, ID. Data was also collected on aircraft landing at Dallas-Fort Worth (DFW) airport. As in 1981, the data from these tests have been reduced, but very little analysis has been carried out. It should be noted that the Idaho Falls tests were conducted using single-tower fly-by procedures that produce useful measurements, such as velocity, but do not produce information related to decay of wake-vortex strength. **However, a reevaluation of the Idaho Falls Test Procedures and Analysis has been under way since September 1993, and will be part of the current program. Any useful data will be reduced and compiled in a comprehensive database that will include all work completed to date. This database will be prepared and made available to interested members of the scientific and international community, and aviation policy makers.**

FAA-sponsored wake-vortex work has produced a better understanding of vortex behavior and created several databases containing aircraft-specific vortex characteristics. In addition to the 1976 change in the Small aircraft separation standards, this information has been used to support Localizer (Type) Directional Aid (LDA) (reference 1) approaches, with the reduction in IFR landing separations to 2.5 miles for selected Large and Small aircraft. The sensing systems, analysis methodologies, and the system requirements developed during the past two decades provide the foundation for the current plan.

2.3 ON-GOING ACTIVITIES

1. NASA is addressing the problem of defining and validating an accurate vortex-encounter hazard model. The basic parameters of the simple static model previously used to assess the wake-vortex hazard were uncertain by as much as a factor of two. The new NASA model will take into account the dynamics of the encounter, including both pilot and aircraft response times, and will be validated through flight tests.

2. German investigators are studying operations using closely spaced parallel runways (500 meters – 1,700 feet) at Frankfurt. They measured the transport of wake vortices between the runways using a lidar and anemometers and are developing a system concept (based on the measured crosswind) which is not yet completed. They attempted to determine the effects of turbulence on vortex lifetime, but have not obtained definitive results.

3. In the United Kingdom a vortex incident reporting system has been in operation for more than twenty years. Most of the data is specific to Heathrow Airport. The incident statistics have been used to justify a number of changes in longitudinal separation standards. In connection with this effort some modeling work is also being performed in India.

4. The French involvement is in the area of modeling. A recent international meeting examined this work and other efforts which has been undertaken with varying resources. Most areas of interest were site specific and did not encompass the wide range of meteorological and site variations that exist in the United States (U.S.) today. The conclusion was that these other efforts should continue with coordination and data exchange to the maximum extent possible.

A major result of the program will be a scientific understanding of wake vortices. The science and technology gained from the successful windshear program and the wake-vortex program should lead to technology and guidelines for avoidance of aeronautical hazards, both en route and in the terminal area. NASA's TAP Program addresses this goal for the terminal area, and the study of the wake-vortex phenomena, which is being performed in cooperation with the FAA, is an important element of this program. The TAP Program has been coordinated with the FAA and was presented to the FAA Research and Development Committee on August 24, 1993. The results from this area of study are expected to lead to an increase in airport capacity for operations under IFR by mitigating the effect of wake vortices on aircraft without compromising safety.

3. APPROACH

The approach adopted for the current Wake-Vortex Program is to define a multi-year program comprising a number of initiatives which will result in operationally implementable products. An important point about the program is that no wake-vortex-avoidance system will make use of techniques for “encountering and flying through vortices.” It is the intention of the program to ensure the understanding of how the wake vortex is integrated into the environment and how it responds to the variables within that environment. Any recommended practices that result from the program will be aimed at wake-vortex avoidance.

3.1 FAA ACTIVITIES

Six specific areas of activity have been identified. In all areas, the goal is to minimize the limitations caused by the wake-vortex on separation standards.

1. ***Training.*** Initial steps have been taken to develop a training program aimed at ensuring avoidance of hazardous encounters with wake vortices made by other aircraft. The training program development will follow the same procedures as were used in the development of the training for avoidance of encounters of microburst wind shears during the course of the successful joint FAA / NASA Wind Shear Program. Training will be developed to support the implementation of each phase of the Wake-Vortex Program as necessary.

2. ***Capacity Analysis.*** A comprehensive review and validation of airport capacity studies and assessment of the fundamental algorithms applied to assure that the capacity improvements of proposed wake-vortex solutions can be realistically achieved. Incorporated into this analysis will be the results of a review of current aircraft classification and separation standards. This review will determine the rationale for following aircraft spacings, and will demonstrate the relationship of wake-vortices to these spacings.

3. ***Parallel-Runway System.*** Development of a system for improving capacity at airports with closely spaced (<2500 feet) parallel runways.

4. ***Intersecting-Runway System.*** Development of an intersecting-runway system and modification of existing separation standards to increase capacity.

5. ***Single-Runway Separation Standards.*** Modification of existing separation standards to increase capacity.

6. ***Aircraft Vortex Spacing System (AVOSS).*** Comprehensive airport system for providing adaptive separation requirements to automated air traffic control.

3.2 FAA CAPACITY IMPROVEMENT PRODUCTS

The program is designed to provide one capacity improvement product in each program time frame (near term, mid-term and long term). Section 7 details the program products and milestones needed to achieve the capacity improvement products.

Near Term (1994-1996): Parallel-Runway System

A parallel-runway system can be implemented in the near term for three reasons:

1. Studies in this area are under way in Germany at this time with projected completion / implementation dates of 1995-1996. The program has initiated coordination with Germany in this area.

2. Vortex sensor development is under way at NASA and expected results from this work should allow for recommendations within 18 months.

3. The training program will be scheduled to follow the developments necessary for operations with the parallel-runway system.

Mid-Term (1997-1998): Single-Runway Separation Standards

The demonstration of improved single-runway separation standards will be coordinated with the development of sensors capable of detecting and measuring stalled vortices on runways. The evaluation of multiple sensor technologies will begin in mid-1994; preliminary reports will be available by early 1995. New separation standards, including vortex sensors for single-runway operations, will be validated at a demonstration airport during this time period.

Long Term (1998+): AVOSS

The AVOSS concept will perform the function of providing adaptive vortex-based separation criteria to the ATC system. The AVOSS concept will integrate knowledge of the state of the weather, sensor data, wake-vortex behavior, generating aircraft high-level characteristics, hazard definition, and FAA requirements and regulatory constraints. The AVOSS output to ATC will consist of separation constraints (at to-be-determined resolution and frequency), and time-critical information to indicate when previously predicted separation becomes inadequate (hazard warning). The FAA will participate in operational evaluation and readiness assessment of the AVOSS concept. The FAA will be responsible for the development of a prototype AVOSS for operational deployment.

3.3 AVOSS PERFORMANCE LEVELS

The FAA and NASA have agreed that a properly configured AVOSS structure will be capable of various levels of system performance. This capability will permit AVOSS to be implemented early and to take on additional capability as weather data become available, wake-vortex sensor performance is improved, and wake-vortex knowledge improves. Examples of levels of capability include:

1. Today's "AVOSS," consisting of current and historical separation rules. Update rate to ATC is now on the order of a change every 5 to 10 years.

2. AVOSS consisting of revised rules as historical rules are subjected to examination and contemporary wake-vortex studies produce results leading to recommended changes in separation rules. Update rate to ATC can be on the order of once per year.

3. AVOSS consisting of sensors for use in determining the length of time that wake vortices remain on approach or departure paths. Update rates to ATC may be achievable once per hour.

4. AVOSS integrating knowledge of the state of the weather, rules based on validated models of wake-vortex transport characteristics, and error limits on these predictions. This version would not include wake-vortex sensors, wake-vortex hazard definition, or wake-vortex location reporting capability. An update rate of once an hour to ATC may be achievable.

5. AVOSS in this version being the same as 4 above, with the improved performance of wake-vortex sensor verification of wake-vortex transport.

6. AVOSS in this version being the same as 5 above, with the added capability of integrating knowledge of wake-vortex decay and hazard definition.

7. This version of AVOSS being the same as 6 above, with the added capability of incorporating ITWS products for use in predicting separation criteria in 20-minute frames. The update rate to ATC is to be determined.

3.4 NASA WAKE VORTEX ACTIVITIES

While the NASA wake-vortex effort is a long-term program that will result in tools for an automation system to be deployed about the year 1998, the FAA and NASA have agreed that shorter term gains in levels of safety and capacity can be achieved as certain technological milestones (e.g., training and education, accurate 3D models, sensor development) are reached. The framework of the current program evolved during the development of the successful joint FAA / NASA Wind Shear Research Program. The basic structure of this interagency and industry cooperative research has remained intact throughout budget fluctuations in both agencies.

The NASA activity requires close cooperation with the FAA in providing support for:

1. Determining requirements and priorities
2. Sharing data in order to optimize results
3. Working with both the domestic and international communities to assure that knowledge and technology are widely distributed

3.4.1 NEAR TERM

For the near term (one to three years), NASA's program will focus on developing and validating basic vortex and hazard modeling technology. As the technology is developed, it will be applied to evaluate relative safety and potential capacity improvements. These improvements might result from changes in current procedures and separations. These changes will, in turn, require an evaluation of the number of classes and weight-class boundaries for determining separations necessary for minimizing wake-vortex hazards. In addition, the following three types of validation experiments will be conducted:

1. Wind-tunnel measurements will be taken using B-747 and DC-10 model aircraft as both leading and following aircraft in order to evaluate the wake characteristics of this aircraft pair. Results of these tests will be available in mid-1994.
2. Tunnel tests with powered flying models will be used to examine wake encounters behind a fixed wing in a NASA-LaRC wind tunnel. Preliminary results of these tests will be available by late 1994.
3. A heavily instrumented OV-10 aircraft (for which the roll inertia can be varied to simulate a wide range of commuter aircraft) will be used to evaluate large and commuter aircraft wake encounters and potential changes in weight class boundaries or number of aircraft classes in 1995.

3.4.2 MID-TERM

For the medium term (five years or less), the NASA program has four elements:

1. The development of a wake-vortex-encounter hazard algorithm and a simulation methodology for establishing a safe separation distance for any given pair of aircraft. The schedule for the completion of this effort is late 1995.
2. The development of a validated weather-related wake-vortex transport and decay model for use in determining when wake-vortex-imposed separations are not required. Validation of this effort is scheduled for late 1995.

3. The development of ground-based and / or airborne vortex detection technology to serve as a tactical safety net if needed for use with vortex forecasting. This work is scheduled for completion in 1996.

4. The design, fabrication, deployment, and performance evaluation of the AVOSS concept. This work is scheduled for completion by 1998-1999.

3.4.3 LONG TERM

Upon completion of operational evaluation and demonstration of the AVOSS concept, NASA, in cooperation with the FAA, will assess operational readiness, and provide design criteria and guidelines for FAA development of a prototype AVOSS.

In addition, NASA's Advanced Subsonic Technology Program includes a goal of developing wake prediction and high-lift flap system design methods which can be introduced into aircraft for maximum performance, low noise, and minimum wake hazard. The time frame for implementation of this technology is greater than 10 years. This is the only program goal of NASA which does not totally parallel the FAA goals for this program. This is reasonable, as the FAA, as well as the aviation community, has looked to NASA for development of alleviation techniques.

3.5 INDUSTRY WAKE-VORTEX PROGRAM ACTIVITIES

The major role of industry will be in the areas of training, data base analysis, design, and implementation. In the near term, emphasis will be in the areas of education and training, instrumentation, field testing, and database development. Longer term participation, through government partnership, will include prototype development for both semi-automatic and automatic systems, installation, and independent verification and validation procedures.

4. PROGRAM IMPLEMENTATION

4.1 REQUIREMENTS

The basic requirements and planning assumptions common to any wake-vortex system or changes to operational procedures are as follows:

1. ***User Involvement.*** The success of prior programs, such as the successful Wind Shear Program, was based on participation of the whole aviation community and a process of information exchange within the industry. This process will continue. Offices of Air Traffic and Flight Standards, and the Office of System Capacity have been participants in the formulation of this plan. Participation will be expanded to include other members of the aviation community.

2. ***Effectiveness.*** The product must provide a meaningful measurable improvement in airport and system capacity.

3. ***Performance.*** The current IFR level of integrity and safety must be maintained and is a part of the program goal. Vortex sensors will verify system performance in all demonstration activities and may become an integral part of some systems.

4. ***Workload.*** This program will consider controller and flight crew workloads with the intent of precluding any impact on these workloads. It is expected that results of this program will complement FAA automation programs and therefore support increased productivity.

5. ***International.*** U.S. citizens do not fly solely on U.S. airlines or aircraft, or solely in U.S. airspace. However, they are the most traveled passengers in the world. They fly on many different types of airplanes from, and in, many different countries. Therefore international acceptance of program results is necessary. Thus, this program will proceed in the same manner, internationally, as was done during the recently completed successful Wind Shear Program.

6. ***Operations and Maintenance.*** This program will develop such requirements as may be needed for operations and maintenance of any system, interfaces, or equipment developed in the course of the program. The program will also develop a recommended maintenance concept if required.

4.2 ACTIVITIES

4.2.1 Training and Education

One of the first tasks to be undertaken in the current program will be a review, analysis, and assessment of the various existing capacity studies and simulations to assess their validity for deriving realistic potential benefits of the program. If the existing capacity methodologies prove to be inadequate for predicting the effects of wake-vortex separation changes, they will be expanded to meet these requirements. In concert with these efforts, comprehensive education and training techniques will be developed to assure that current standards, procedures, and recommended practices are fully understood. This is an important aspect of the program. As changes are recommended, the training and education program will be modified to reflect these changes.

4.2.2 Capacity Analysis

In order to determine the potential benefit of any vortex capacity improvement concept, the expected capacity change must be quantified. A number of airport capacity studies have been conducted over the years. In addition, a number of simulations have been designed and implemented in order to determine the sensitivity of runway and airport capacity to a number of variables, such as longitudinal spacing between aircraft.

One of the capacity issues to be studied is the difference in capacity during IFR and VFR operations. Standards established for IFR will be reviewed from both safety and capacity standpoints. The difference in capacity under VFR and IFR is the driving force behind the overall program, where the goal is to achieve VRT capacity levels under IFR operations.

The airport capacity model selected will be validated by comparing its predictions with airport operations data. The Air Route Traffic System (ARTS) surveillance data tapes for selected airports will be analyzed to provide validated capacity data and to determine the differences in airport operations under IFR and VFR.

4.2.3 Parallel-Runway/Intersecting-Runway System

A Parallel-Runway System aimed at the reduction of longitudinal approach separations by means of parallel runways separated by less than 2500 feet is under evaluation in Frankfurt, Germany. The mode of operations will depend upon the magnitude and direction of crosswinds. This work will be assessed for contributions to this program.

This system may be adapted to increase capacity at airports with intersecting runways, such as La Guardia and St. Louis where the capacity of the landing runway is adversely affected by departing aircraft. The Converging Runway Display Aid (CRDA) is being operationally evaluated at St. Louis.

4.2.3.1 Parallel-Runway System Definition

Under current IFR procedures, parallel runways separated by less than 2500 feet must be treated as a single runway for wake-vortex longitudinal separation purposes. This is due to the possibility that the vortex from one runway might be transported to the other runway. Thus, a Large aircraft landing behind a Heavy aircraft must ordinarily maintain a five-mile separation, no matter on which runway the two aircraft land.

Germany is developing a Parallel-Runway System for application at Frankfurt Airport where the runways are separated by 1700 feet. The system will use measurements and predictions of the crosswind to reduce longitudinal separation. Studies indicate that a minimum time of 20 minutes is required for the prediction of crosswinds. The following three conditions apply:

1. ***Crosswind speeds so low that vortices will not travel from one runway to the other.*** Aircraft simply alternate runways.
2. ***Crosswind speeds so high that the vortices will leave the region of one runway before the next airplane arrives at 3-mile separation.*** Aircraft simply land in sequence on one runway.
3. ***Intermediate crosswind speed values.*** The Heavy aircraft land on the downwind runway and Large aircraft land on the upwind runway.

Where two modes of operation are possible, the system will be designed to provide preferred options to the controllers for selection of the mode that is most likely to persist. This will require consideration of both current and forecast meteorological conditions.

4.2.3.2 Intersecting-Runway System Definition

The cross-vortex encounter experienced for perpendicular runways is quite different from the axial-vortex encounter of concern for single and parallel runways. Calculations indicate that large vertical accelerations may be experienced. Since vortex transport will control the location of such vortex encounters, the parallel-runway system may be useful for preventing cross-vortex encounters in intersecting runway operations. Algorithms for predicting potential encounters will depend upon the detailed runway geometry. Validated transport and decay models (in and out of ground effect) will be critical for gains in this area. Full understanding of these transport and decay characteristics of vortices may be useful in the development of modified procedures to assure that the crossing aircraft is at least at or above the level of the vortex generating aircraft. This is an area where sensors may be useful.

4.2.3.3 Review of Existing Data

Available vortex lateral transport data will be reviewed and compared to assess whether the data and the algorithm(s) are consistent. The dependence of the algorithm on runway spacing will be determined and a tentative system algorithm will be defined. Work is already under way to consolidate and publish previously unpublished data. Previous work included a vortex encounter model for parallel runways that may be used as part of the safety analysis for the Parallel-Runway System.

4.2.3.4 System Implementation

The system concept will be validated for both safety and improved capacity by demonstration at an appropriate airport. The selected airport(s) should have parallel runways spaced at less than 2500 feet, be limited in capacity, and have enough terrain to locate vortex sensors in the approach region both between and outside the runway centerlines. The goal is to select an airport that is scheduled for CTAS installation.

As a part of the international coordination for the program, the forecast algorithm under development at Frankfurt, Germany will be used as a starting point. Using the Frankfurt algorithm as a basis, a 20-minute wind forecast algorithm will be developed by the program team for evaluation at the demonstration airport. The Low-Level Windshear Alert System (LLWAS) could be one source of data for this study.

Once the airport evaluation process is completed, and if the capacity analysis shows system feasibility, system installation will be initiated. When installation is completed, system test, evaluation, and demonstration will be conducted.

4.2.4 Single-Runway Separation Standards

Methods for improving single-runway capacity will be examined. Current separation standards consist of two parts: aircraft classifications (Heavy, Large, Small) and the separations required between classes for various operations; and the good practices recommended in the AIM. As the program progresses, different opportunities for changes will be examined. One example of such an opportunity would be a change in the number of weight classes, which may provide the opportunity for reduced separations between specific aircraft pairs.

In the long term, automated traffic control systems, for example, the Center TRACON Automated System (CTAS), will be able to define the arrival times of aircraft at the runway threshold to within a few seconds. In this environment, runway capacity can be increased by refining the wake-vortex separation requirements to specify required time separations (to the second) for each pair of aircraft types. Since current aircraft classes include a wide variety of aircraft sizes, the required separations must be conservative enough to apply to the largest leading aircraft of a class and the smallest following aircraft of a class. Runway time is therefore wasted for other members of the leading and following classes. Note that the separation times that will be used for CTAS are more in harmony with the nature of wake-vortex decay than the distance separations used for manual air traffic control (ATC). In this effort, the goal is to achieve VFR capacity under IFR operations.

4.2.5 Separation Consideration

4.2.5.1 Manual Air Traffic Control Separations

Various schemes such as development of alternative weight classifications that may be required for Heavy aircraft and new large aircraft now on the drawing board are under evaluation. Reducing separations for lighter-weight categories would allow some capacity gains. Improved models and quantification of the wake-vortex hazard should provide the means for determining new separation standards to achieve these gains while maintaining the current high levels of safety. Emphasis must be placed on the recommended flying practices of the AIM and on the support of flight crews in meeting wake-vortex procedures.

4.2.5.2 Automated Air Traffic Control Time Separations

Automated ATC systems (e.g., CTAS) will permit aircraft time separations to be individually tailored for each aircraft pair. As the automated systems are ready for implementation, fully developed and validated transport and decay models will permit sophisticated separation matrices to be introduced. This should result in increased capacity under IFR operations and increased safety under VFR operations.

4.2.5.3 Takeoff Separations

Previous studies have emphasized landing operations. Takeoff separation standards that may be required will also be evaluated. The newly developed models will be used to evaluate separations of departing pairs. For example, the U.K. is currently permitting departures of a B-747 following a B-747 to be one minute apart. Takeoff operations may permit the use of pair separations defined to the second without ATC automation. This may be accomplished by allowing flight crews to time their departures according to the preceding aircraft type.

4.2.5.4 Safety Analysis

The safety analysis, Section 5.2, used to analyze separation standards is strongly dependent upon the validity of the vortex hazard and decay models that are used. A number of improvements have been made in the models; some of these will require additional vortex decay data. The safety analyses will be repeated whenever the models are updated. The following work can be carried out without additional vortex data:

1. The NASA effort on vortex hazard will lead to more realistic vortex-hazard models and play a more integral part in achieving a wake-vortex prediction capability.
2. The existing databases of landing and takeoff vortices (measured with an acoustic sensor and laser doppler velocimeters) will be further processed to improve existing vortex decay models.
3. Recently collected data and new data on aircraft types will be analyzed and compared with earlier data and theoretical predictions to validate the prediction model. This validated model will be used to assess the classification of existing and new aircraft types.

4.2.6 Wake Vortex/Meteorological Sensors

4.2.6.1 Vortex Sensors

The requirement for sensors and their development, where necessary, is carefully planned in the wake-vortex portion of the NASA TAP Program. The selection of required sensors is scheduled to be complete in 1996. The emphasis of the TAP Program is on continued development of the sensors that were developed during the windshear program (lidar and doppler radar). In addition, sensors suitable for detection of wake vortices during the final mile of approach will be evaluated. Lidar studies have already determined the ability of lidar to detect vortices. Certain program goals and requirements, such as the detecting, locating, tracking, and quantifying of wake vortices, require a degree of maturity not yet demonstrated by existing sensors.

4.2.6.2 Meteorological Sensors

The transport and decay of wake vortices are believed to be primarily functions of wind, vertical wind shear, turbulence, and stratification of the atmosphere along and under the path of the generating aircraft. The requirements for and development of meteorological sensors to adequately measure these meteorological phenomena are currently under way with a schedule consistent with vortex sensor development and vortex transport and decay modelling efforts.

4.2.7 Aircraft Vortex Spacing System (AVOSS)

The AVOSS concept will provide adaptive separation requirements in the automated ATC environment of CTAS. AVOSS will be designed as a total airport system including single-, parallel-, and intersecting-runway operations. Deployment of candidate technology resulting from this program will be based on criteria developed from a cost-benefit analysis.

The AVOSS concept will use real-time meteorological data from meteorological sensors and the Integrated Terminal Weather System (ITWS) and real-time vortex measurements to reduce the required time separations, when permitted by meteorological conditions, for both parallel-runway and single-runway operations. In the AVOSS time frame, variable separations can be provided to the automated control systems (e.g., CTAS). The AVOSS concept is thus a more general version of the Parallel-Runway System that will be designed to operate in an automated ATC environment. A version of the AVOSS concept for manual ATC or current weather systems will be defined in the event that CTAS or ITWS is not available when AVOSS is ready for demonstration.

4.2.7.1 System Definition

4.2.7.1.1 Parallel Runway/Intersecting Runway

The parallel-runway application of the AVOSS concept will interface with CTAS and use real-time vortex measurements and/or predictive models along with meteorological measurements as required to improve vortex behavior predictions. More sophisticated separation algorithms will go beyond the simple effects of the ambient wind on vortex transport effects, and will include the effects of other weather parameters on vortex-decay. Refined algorithms for dealing with specific aircraft pairs will also be developed.

4.2.7.1.2 Single Runway

The single-runway separation algorithm will adjust separations according to both weather data obtained from meteorological sensors and the ITWS and vortex sensor measurements. The data required to develop and justify adaptive separation algorithms will be collected at the single-runway demonstration airport.

4.2.7.2 Meteorological Effects and Parameter Forecast

An analysis of the existing U.S. databases on vortex decay to assess meteorological effects is currently under way. This analysis includes the data and results of a previous analysis of O'Hare landing data which showed little change in vortex lifetime during normal working hours (0800-1600 hours). In contrast, longer lifetimes were noted early in the morning and at night in the Idaho Falls and DFW data collected in 1990 and 1991. One of the results of this analysis is the justification of additional data collection to improve our understanding of the variations in wake-vortex lifetime at specific high-density traffic airports under a variety of meteorological conditions.

Data will be collected from the selected parallel-runway and single-runway test airports to improve our understanding of how meteorological parameters affect wake vortices. The primary improvements of this effort will be in obtaining this data around the clock and the collection of data from new aircraft types for which there is no data.

Use of meteorological parameters for predicting separation requirements is an area that will be addressed. Certain site-specific data may be required and any special instrumentation needed for this data would become a part of the AVOSS.

4.2.7.3 Implementation

The AVOSS concept is part of the automation package to be used in an adaptive separation system and as such will be implemented towards the end of this joint program. The potential requirements for interfacing with other programs such as ITWS and CTAS need to be ascertained as early as possible in order that tasks can be assigned / modified.

5. PROGRAM SPECIAL CONSIDERATIONS

5.1 AUTOMATIC DATA COLLECTION AND ANALYSIS

All past wake-vortex studies have been labor intensive in both the data collection and the data reduction phases. This limitation has resulted in the following problems:

1. Data were collected only at certain times of the day or for limited periods of time. Existing databases therefore do not contain data acquired under rare conditions (e.g., fog) or at inconvenient times (e.g., night). Data on rare aircraft types are also limited.

2. Statistically significant results of data reduction have not been available until long after the data collection had been completed.

3. Some data reduction procedures were so arduous that the measurements were simply never processed.

Efforts will be made to develop both automated data collection and a near real-time data reduction and analysis capability. Therefore, statistics of the data collection will be available in near real-time and proper decisions can be made about the data collection process. Moreover, this automation is required for an operational system. This will prepare the way for the automatic data processing required for the final vortex system. The only possible loss associated with real-time processing is that improved processing algorithms may be developed by a later date. To avoid this problem, selected raw data will be saved for subsequent off-line processing. The automated data collection will be augmented through use of information gained from questionnaires and data sheets for users (i.e., flight crews and controllers).

5.2 SAFETY ANALYSIS

Changes in vortex procedures must be justified by a safety analysis that is convincing to the public as well as the users of the system. Increases in separations have been relatively easily justified on the basis of perceived increased safety. Decreases in separations are more difficult to justify since they may be perceived to result in reduced levels of safety. Four rather different approaches have been proposed for evaluation of reduced IFR separations. The first two apply only to weather-dependent separation standards and allow no vortex encounters, while the second two can be applied to either fixed or weather-dependent separation standards and maintain the existing level of vortex encounters:

1. Perhaps the most convincing is the demonstration and calculation that the ambient wind will consistently remove wake vortices from the path of the following aircraft (single runway), or will not cause vortices to drift into the path of the following aircraft (parallel runways). While it is well known and understood that vortices can be transported by winds, little is known of the impact of this knowledge when applied to an operational system.

2. Vortex decay is less well understood than vortex transport due to winds. Therefore, if a vortex is not removed from the path of the following aircraft by winds, only decay can eliminate the vortex. This safety analysis method identifies the weather conditions which result in the absence of hazardous vortices remaining at the time of arrival of the next aircraft.

3. The probability of wake vortices remaining hazardous at the time of arrival of the following aircraft under the existing separation standards is quantifiable once a hazard criterion is developed. Since no accidents have occurred when existing standards and recommended practices were followed, the level of “hazard probability” must have been operationally safe. This safe level can then be used as a first estimate to assess the vortex safety of other separation standards. The method to be used is based on vortex decay models derived from vortex measurements and on current vortex hazard models. Improvements and validation for these models will increase user confidence in the results of the safety analysis.

4. A method used by air traffic for justifying a reduction in IFR separations is a comparison with the actual aircraft separations used by pilots under Visual Flight Rules (VFR) operations. Air Traffic developed a formal demonstration method for validating the safety of such reduced separations and used it to justify the adoption of 2.5-mile separations on the final approach within 10 miles of the airport for certain aircraft types at airports where the runway occupancy time is 50 seconds or less (reference 10). Heavy aircraft and the Boeing B-757 are permitted to participate only as the trailing aircraft. The wake-vortex safety of such operations was originally demonstrated at several airports by conducting 500 landings at 2.5-mile separations by volunteer pilots. The test was to be stopped in the event of any reported wake-vortex encounters. Wake-vortex sensors and video monitoring will be used in future demonstration programs involving reduced separations to provide objective information relating to any reported encounter.

The combination of more than one safety approach is worthwhile. For example, the separation model of item 3 was used to evaluate the 2.5-mile separations that were primarily justified by demonstration (item4). The program tests and demonstrations at test airports will include wake-vortex sensors. Such sensors, however, may or may not become part of the final system.

A demonstrated wake-vortex detection and avoidance system must maintain existing safety levels that have been achieved under IFR, approach the goal of capacity levels of VFR under IFR, and produce fewer wake-vortex incidents under VFR than currently experienced by flight crews. This result will be independent of planned MLS curved approaches and / or precision Global Positioning System (GPS) approaches which will require separate evaluation for wake vortex considerations.

5.3 WORKLOAD ANALYSIS (HUMAN FACTORS)

Two basic approaches are available for developing the procedures associated with a new system and determining their workload impact:

1. If recommended changes are perceived as incremental to existing operations, then the procedures and impacts can be assessed through evaluation by the operational personnel involved. The system can then be installed and operated off-line to train the operational personnel in the use of the system and later operated on-line as a demonstration of system performance. This approach is advantageous since the time and cost is much less than that of the second approach, which follows.

2. The most complete method of assessing the impact of a new system requires that training personnel evaluate it in a complete ATC simulation where both controllers and pilots use the new system. This approach will be necessary if the proposed changes are not perceived as incremental.

6. SYSTEM INTERFACES

6.1 WEATHER SYSTEMS

In the near term, vortex systems must interface with individual existing weather systems (e.g., LLWAS) using additional meteorological sensors to augment the required meteorological data. In the long term, integrated airport weather data will likely be required (e.g., ITWS).

6.2 AIR TRAFFIC CONTROL SYSTEMS (E.G., CTAS, ETMS, AERA)

Conservative adjustments in separation standards expected as intermediate products of this joint effort will be recommended as procedural changes with the express intent of maintaining controller workload at current levels. The end goal of this activity is the inclusion of these products in the final results of the TAP program and an automation system maximizing operating efficiencies.

6.3 COCKPIT TECHNOLOGY

Provisions will be provided for crew training, airborne sensors (if required), data link interfaces, FMS interfaces, operations procedure development, and human factors considerations in the same manner as was done for the Wind Shear Program.

7. PROGRAM PRODUCTS

The following sections list the program products according to the time frame. Capacity improvements are presented in boldface.

7.1 NEAR TERM (1994-1996)

1. A training program that will be developed in 1994, based upon the present air traffic procedures and upon the recommended practices of the Airman's Information Manual. The training program will be coordinated with users, industry, flight crews, and the appropriate flight standards and air traffic control offices of the FAA. Training will be modified as required by developments of the program.

2. Validated methodology for:

   a. Quantification of the difference between VFR and IFR capacity

   b. Quantification of the capacity gains from wake-vortex solutions

3. Exploration of interim enhancements for the air traffic control system. These include identification of wind levels suitable for reduced separations consistent with wake vortex considerations for both single- and parallel-runway operations. In addition, reduction in separation standards as a result of modified classification of aircraft will be assessed. Suitable wind levels for single- and parallel-runway operations and modified aircraft classifications along with modified separation standards will be recommended by mid-1994.

4. Development of a relational data base of all applicable wake-vortex data already gathered for use by the program team members and the scientific community.

5. Selection of parallel-runway, converging-runway, and single-runway demonstration airport with baseline definitions of VFR and IFR capacity for each and predictions of the performance of baseline wake-vortex solutions.

6. **Implementation of parallel-runway system at demonstration airport.**

7. Report on separation standards methodology.

8. Establishment of new single-runway separation standards.

   a. Manual air traffic control

   b. Automated air traffic control

9. Report on how meteorological conditions affect duration of vortex hazard.

   a. O'Hare data

   b. Idaho Falls, DFW data

   c. NASA-MIT/LL tests performed in 1994

10. AVOSS System Requirements.

11. Vortex sensing technology assessment

    a. Status of current sensors

    b. Recommendations for parallel-runway and single-runway vortex sensors

    c. Recommendations for development leading to AVOSS vortex sensors

12. Meteorological sensing technology assessment
    a. Status of current sensors
    b. Recommendations for support of parallel-runway and single-runway operational system concepts
    c. Recommendations for support of AVOSS

7.2 MID-TERM (1997-1998)

1. Evaluation of capacity gains relative to predictions for a parallel-runway system and new single-runway separation standards. Assessment of capacity gains at all other airports where these methods may be deployed.
2. **Demonstration of new separation standards at the single-runway demonstration airport, including single-runway vortex sensor for validation.**
3. Predicted capacity gains of AVOSS at parallel-runway and single-runway demonstration airports.
4. System specification for parallel-runway system (if decision to deploy).
5. AVOSS baseline system definition.
    a. Separation algorithm
    b. Vortex sensor requirements
    c. Meteorological data requirements / forecast algorithm
6. Development of AVOSS vortex sensors.
7. Development of AVOSS meteorological sensors

7.3 LONG TERM (1998 +)

1. **AVOSS implementation at parallel-runway and/or single-runway demonstration airports.**
2. AVOSS demonstration.
3. Evaluation of capacity gain relative to predictions for complete AVOSS demonstration systems.
4. Assessment of capacity gains at all other airports where complete / partial AVOSS systems may be deployed.

8. MILESTONES TO ACHIEVE PRODUCTS

1994

- Benefit analysis (parallel / converging-runway reduced separation distances), early 1994
- Training Program initiation, early 1994
- Interim recommendations for revised aircraft classification and separation standards, mid-1994
- Recommendation of interim wind level / reduced aircraft separations for single- and closely spaced parallel-runway operations, mid-1994
- Assessment of current separation / classification criteria (U.S., U.K., Germany, ICAO), mid-1994
- Rationale for current separation standards (VFR & IFR), mid-1994
- Initiation of development of wake-vortex database, mid-1994
- Measurement of wakes during final mile of approach, mid-1994
- Application of anemometry to collect wind data during final mile of approach, mid-1994
- Evaluation of ARTS data, mid-1994
- Re-assessment of NOAA Idaho Falls data, mid-1994
- Validation of airport selection criteria and confirmation of airport selection, mid-1994
- Operational readiness of field facility for measurements of effects of meteorological conditions on wake-vortices, late 1994
- Scattering mechanisms for microwave and laser illumination of wakes, late 1994
- Updated empirical wake-vortex decay model, late 1994
- Initial AVOSS functional requirements, late 1994
- Close-spaced parallel runway safety analysis, late 1994
- Workshop to exchange information, mid-1994
- *Wake-Vortex Program review, late 1994*

1995

- Wake Vortex Sensor requirements, early 1995
- Meteorological sensor requirements, early 1995
- Determination of current controller / pilot workload criteria, early 1995
- Report documenting measurements describing meteorological effects on wake vortices, mid-1995
- Revised aircraft spacing / classification recommendations, mid-1995
- AVOSS functional requirements defined, mid-1995
- Wake-vortex hazard criteria based on sensor measurables, mid-1995
- Wake-vortex transport and decay model in ground effects (3D), mid-1995
- Initial revised approach procedures consistent with AVOSS requirements, late 1995
- Candidate wake-vortex prediction algorithm defined, late 1995
- Initial adaptive separation criteria, late 1995
- Sensor technology selection, late 1995
- Meteorological sensor technology selection, late 1995
- Determination of feasibility of modifying existing separation standard for single-runway configuration, late 1995
- Development of demonstration plan for single- and parallel-runway concepts, late 1995
- Simulation of independent parallel-runway concept, e.g., using St. Louis airport data, late 1995
- International user conference to exchange information, mid-1995
- Wake-Vortex Program review, late 1995
- Continuation of field measurements program, throughout 1995

1996

- Adaptive separation algorithm defined, early 1996
- Wake-vortex detection hardware/software final design and initiation of sensor build, mid-1996
- Adaptive separation criteria for CTAS automation, mid-1996
- Implementation of parallel runway system at demonstration airport, mid-1996
- Demonstration of modified separation standards for single-runway operations, mid-1996
- System concept simulation to evaluate adaptive separation procedures and quantify capacity impact, late 1996
- User conference, late 1996
- Wake-Vortex Program review, late 1996
- *Continuation of field measurements program, throughout 1996*

1997

- Completion of take-off separation standards criteria, mid-1997
- Wake Vortex transport, decay, and hazard prediction subsystem validation, mid-1997
- Wake-vortex detection system operational, late 1997
- Initial wake-vortex detection system field experiments, late 1997
- User conference, late 1997
- Wake-Vortex Program review, late 1997
- *Continuation of field measurements program, throughout 1997*

1998

- Validation of wake-vortex integrated detection and prediction system, late 1998
- User conferences, late 1998
- *Wake-Vortex Program review, late 1998*

1999

- Demonstration of operational feasibility of AVOSS concept (linked to A-109), mid-1999
- Release of AVOSS system design guidelines for operational implementation, late 1999
- *User conference, late 1999*
- Wake-Vortex Program review, late 1999

9. SCHEDULE

The schedule of activities is shown in Figure 4. The primary key decision point is shown to occur in 1994. The milestone schedule by financial year (FY) is shown in Figure 5.

10. WAKE-VORTEX PROGRAM MATRIX TEAM

The Wake Vortex Program will proceed in the same manner as that of the completed windshear program. The organization will be that of a matrix team. The members of this team are FAA, NASA, John A.Volpe National Transportation Systems Center, MIT Lincoln Laboratory, and industry. This matrix team is illustrated in Figure 6.

11. MILESTONE INTERRELATIONSHIPS

The interrelationships of the Wake-Vortex Program Plan milestones are illustrated in Figure 7. In addition to the interrelationships, this figure illustrates the relationship of the FAA Wake-Vortex Program Steering Committee to the technical elements of the program. Note that the Memphis (MEM) field measurements are indicated both by a solid block and a dotted block. This indicates that the MEM (or other airport) field measurements will continue throughout the development phases of the program.

APPENDIX A

SUMMARY OF PROGRAM GOAL AND OBJECTIVES

GOAL:

- To support increased system capacity

OVERALL OBJECTIVE:

- To remove wake vortices from the separation “equation”

SPECIFIC OBJECTIVES:

- To identify and validate aircraft classification requirements
- To reduce separation standards
  - Single-runway operations
  - Parallel-runway operations
  - Converging-runway operations

APPENDIX B

REFERENCES

1. Airman's Information Manual.
2. "NASA Wake-Vortex Research," AIAA Paper 93-4004, by H. Paul Stough, III, et al., presented at the AIAA Aircraft Design, Systems, and Operations Meeting, August 11-13, 1993, Monterey, California.
3. Memorandum of Agreement between DOT/FAA and NASA Concerning Wake-Vortex Systems Research.
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9. Hallock, J. N. *Aircraft Wake Vortices: An Annotated Bibliography (1923-1990).* Report No. DOT-FAA-RD-90-30 or DOT-VNTSC-FAA-90-7, U. S. Dept. of Transportation, January 1991.
10. 7110.65H Air Traffic Control (CHG 1), paragraph 5.72f., page 5-5-2. Also see 7210.3K, Facility Operation and Administration (CHG-1), Paragraph 12-46, pages 12-4-3 and 12-4-4.

APPENDIX C

ILLUSTRATIONS

1. Calculated Inital Vortex Strength
2. Wake-Vortex Program Planning Methodology
3. Aircraft Vortex Spacing System (AVOSS) Concept
4. Program Schedule
5. Program Milestones
6. Wake-Vortex Program Matrix Organization
7. Wake-Vortex Program Plan Milestone Interrelationships

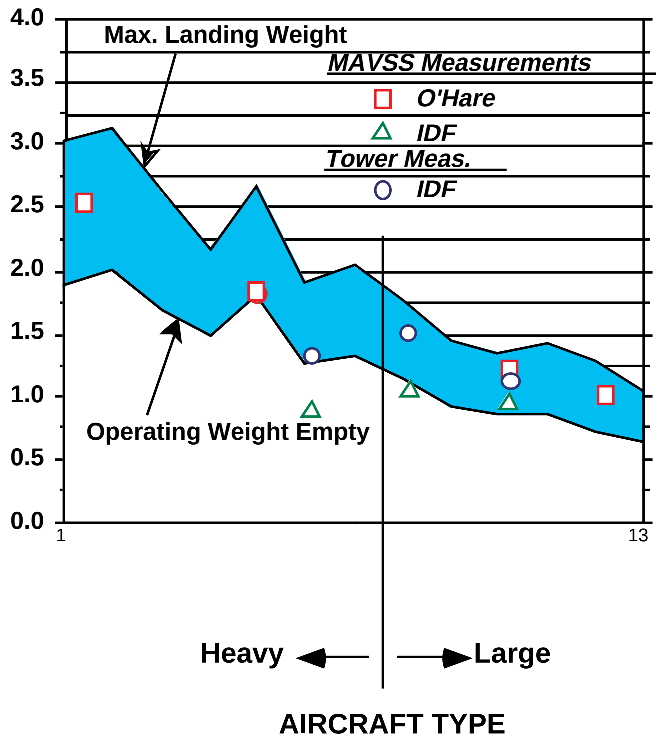


FIGURE 1. CALCULATED INITIAL VORTEX STRENGTH

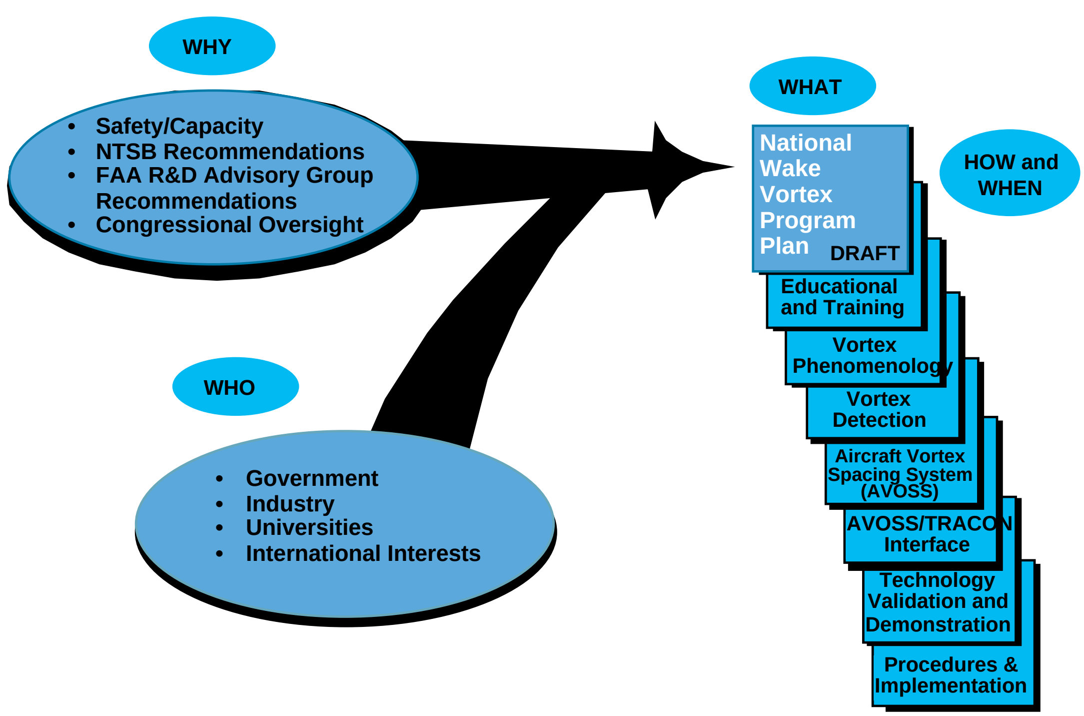


FIGURE 2. WAKE-VORTEX PROGRAM PLANNING METHODOLOGY

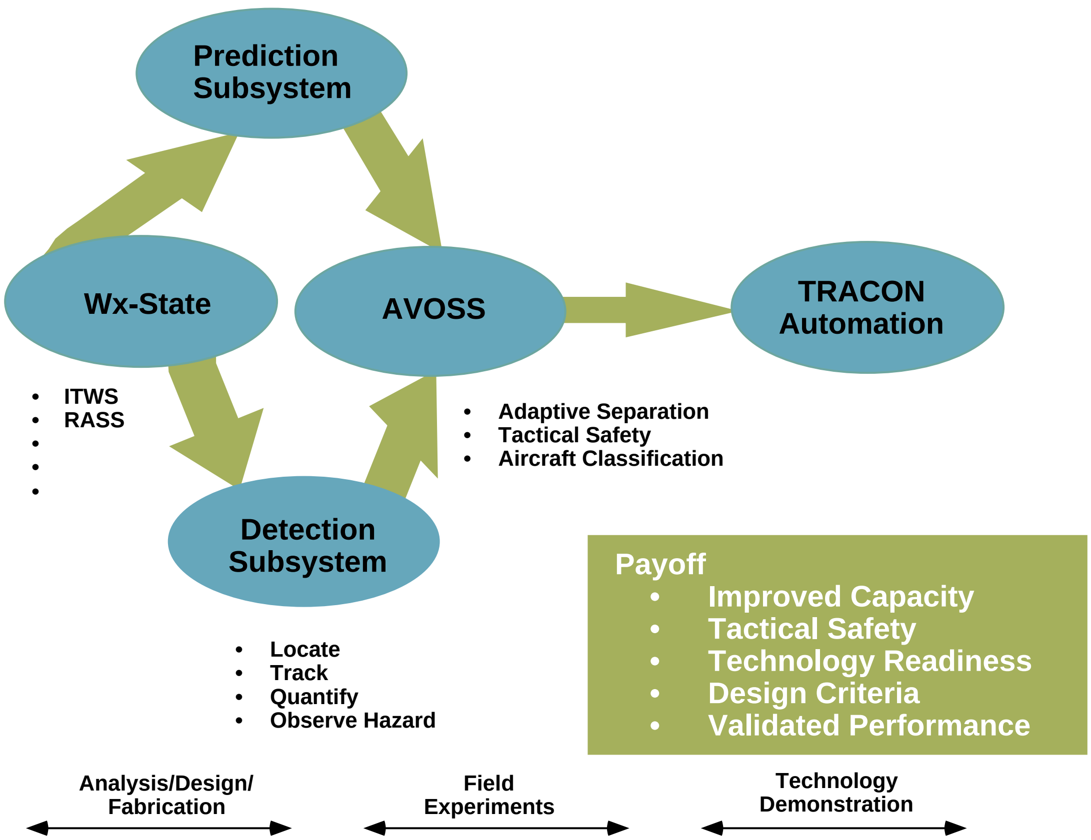


FIGURE 3. AIRCRAFT VORTEX SPACING SYSTEM (AVOSS) CONCEPT

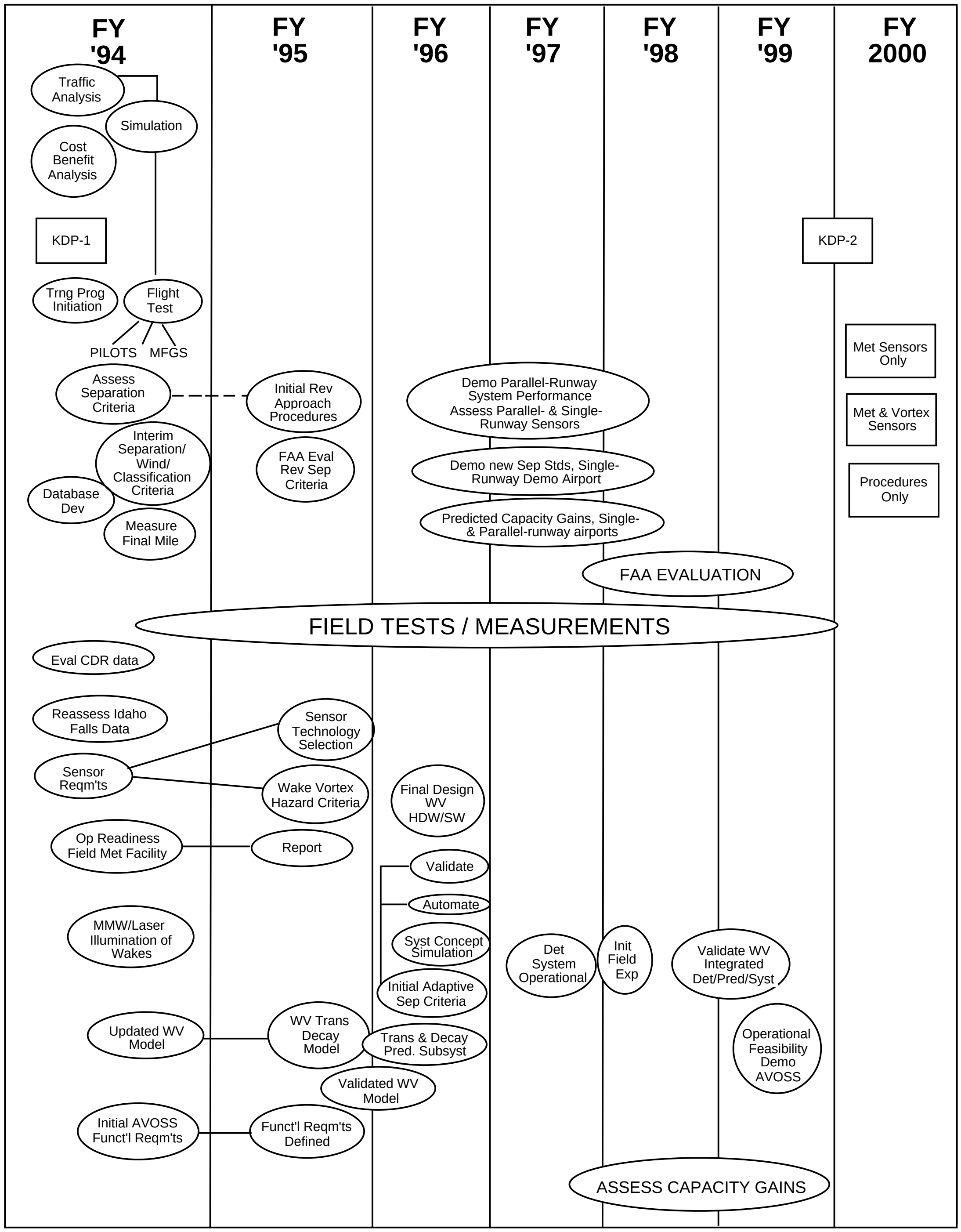


FIGURE 4. PROGRAM SCHEDULE

MILESTONES	1994	1995	1996	1997	1998	1999
Benefit Analysis	▼					
Training Program Initiation	▼					
Interim Revised Aircraft Classification/Separation	▼					
Wind Level/Reduced Separation, Single/Parallel Runway	▼					
Assess Current Separation/Classification Criteria (US, UK, ICAO, Others)	▼					
Rationale for Current Separation Standards (VFR & IFR)	▼					
Initiate Wake-Vortex Database	▼					
Wake Measurement Final Mile of Approach	▼					
Apply Anemometry Final Mile of Approach	▼					
Evaluate ARTS Data	▼					
Re-Assess NOAA Data	▼					
Demo Airport Selection	▼					
Meteorological Field Measurements Program	▼	—	—	▼		
Updated Empirical Wake Vortex Decay Model	▼					
Initial AVOSS Functional Requirements	▼					
Close-Spaced Parallel Runway Safety Analysis	▼					
User Conference	▼	▼	▼	▼	▼	▼
Wake Vortex Program Review	▼	▼	▼	▼	▼	▼
Wake Vortex Sensor Requirements		▼				
Meteorological Sensor Requirements		▼				
Controller/Pilot Workload Criteria		▼				
Report Meteorological Effects		▼				
Revised Aircraft Spacing/Classification Recommendation		▼				
AVOSS Functional Requirements		▼				
Wake-Vortex Hazard Criteria (Based on Sensors)		▼				
Wake-Vortex Transport/Decay Model in Ground Effect		▼				
Initial Revised Approach Procedures		▼				
Candidate Wake Vortex Predictive Algorithm		▼				
Initial Adaptive Separation Criteria		▼				
Sensor Technology Selection		▼				
Meteorological Sensor Technology Selection		▼				
Feasibility of Separation Standard, Single R/W		▼				
Develop Plan for Single- & Parallel-Runway Concepts		▼				
Simulation of Parallel R/W Concept		▼				
Adaptive Separation Algorithm			▼			
Wake-Vortex Detection Hardware/Software Design and Initiate Sensor Build			▼			
Adaptive Separation Criteria for CTAS			▼			
Parallel R/W System at Demo Airport			▼			
Demo Modified Separation Standards Single R/W			▼			
Systems Concept Simulation, Evaluate Adaptive Separation (Quantify Capacity Impact)			▼			
Complete T/O Separation Standards Criteria				▼		
Wake Vortex Transport, Decay, Hazard Prediction Validation				▼		
Wake Vortex Detection System Operational				▼		
Initial Wake Vortex Detection System Field Experiments				▼		
Validation of Wake Vortex Integrated Detection & Prediction System					▼	
Demo Operational Feasibility of AVOSS						▼
Release AVOSS System Design for Operational Implementation						▼

FIGURE 5. PROGRAM MILESTONES

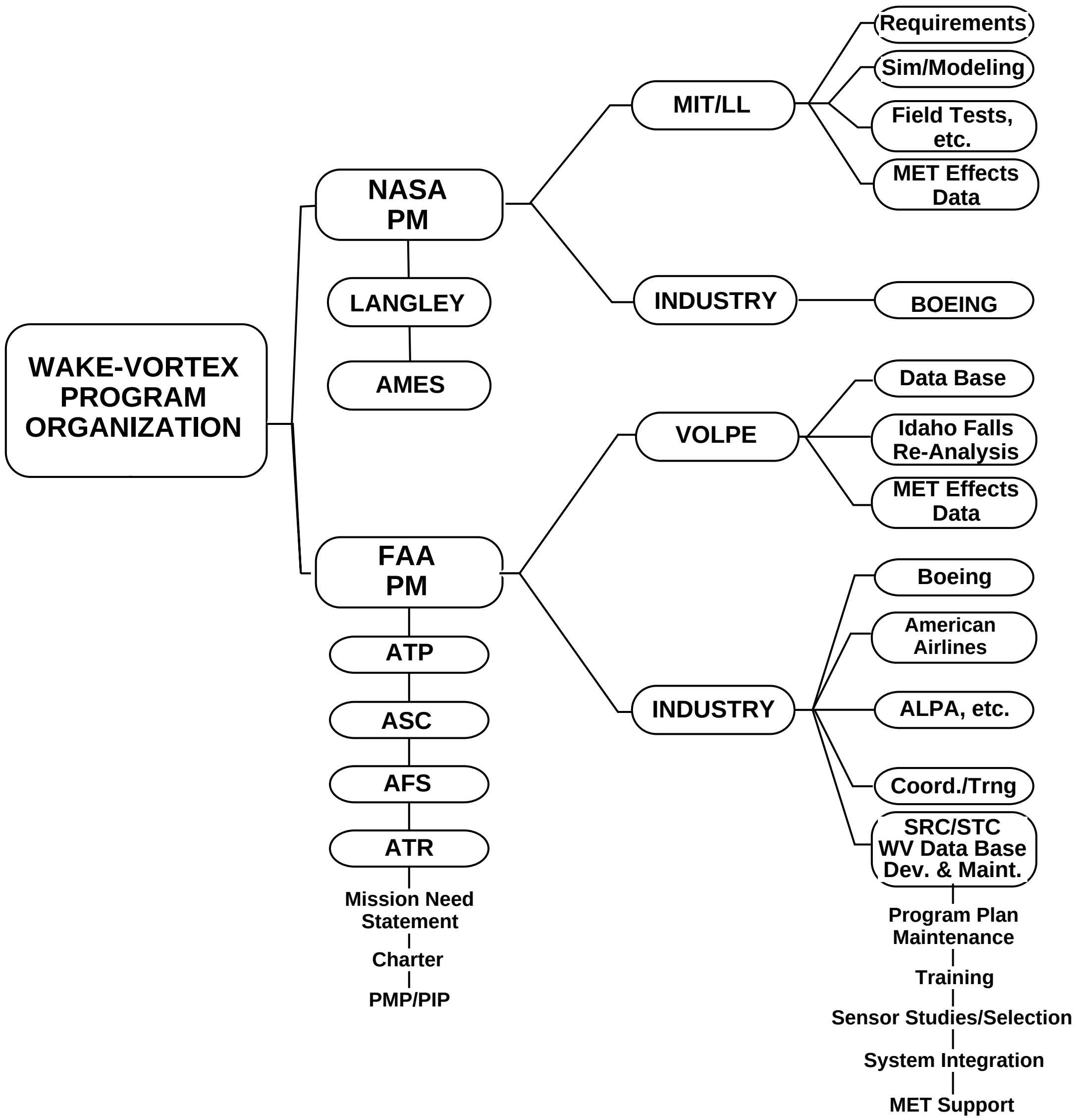
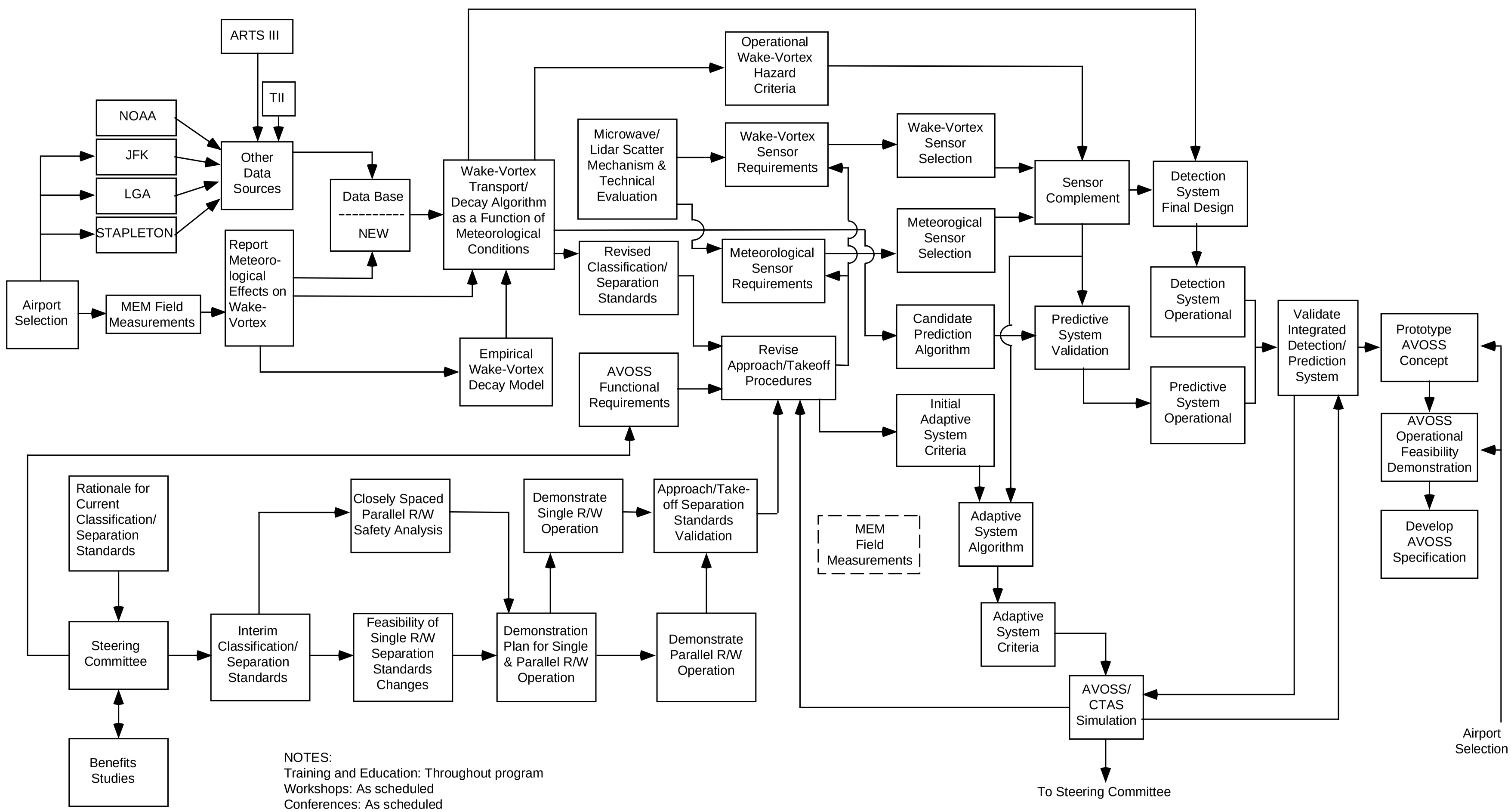


FIGURE 6. WAKE-VORTEX PROGRAM MATRIX ORGANIZATION



NOTES:
Training and Education: Throughout program
Workshops: As scheduled
Conferences: As scheduled
Program Reviews: As scheduled

FIGURE 7. WAKE-VORTEX PROGRAM PLAN MILESTONE INTERRELATIONSHIPS

APPENDIX D

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AERA	-	Automated En Route Air Traffic Control
AFS	-	Flight Standards Service
AIM	-	Airmen's Information Manual
ALPA	-	Airline Pilots Association
App	-	Approach
ARTS	-	Air Route Traffic System
ASC	-	Office of System Capacity and Requirements
ASTA	-	Airport Surface Traffic Automation
ATC	-	Air Traffic Control
ATP	-	Air Traffic Rules and Procedures Service
ATR	-	Air Traffic Plans and Requirements Service
AVOSS	-	Aircraft Vortex Spacing System
CDR	-	Computer Data Recording
CRDA	-	Converging Runway Display Aid
CTAS	-	Center TRACON Automated System
CY	-	Calendar Year
Det	-	Detection
Dev	-	Development
DFW	-	Dallas-Fort Worth Airport
ETMS	-	Enhanced Traffic Management System
Eval	-	Evaluate
Exp	-	Experiment
FAA	-	Federal Aviation Administration
FMS	-	Flight Management System
FY	-	Fiscal Year
GPS	-	Global Positioning System
HDW	-	Hardware
ICAO	-	International Civil Aviation Organization
IDF	-	Idaho Falls Airport
IFR	-	Instrument Flight Rules
Init	-	Initial
ITWS	-	Integrated Terminal Weather System
KDP	-	Key Decision Point
LaRC	-	Langley Research Center
LDA	-	Localizer Directional Aid
LIDAR	-	Light Detection and Ranging
LLWAS	-	Low-Level Windshear Alert System
MAVSS	-	Monostatic Acoustic Vortex Sensing System
Met	-	Meteorological

MFGS	-	Manufacturers
MGT	-	Management
MIT/LL	-	Massachusetts Institute of Technology, Lincoln Laboratory
MLS	-	Microwave Landing System
MMW	-	Millimeter Wave
MOA	-	Memorandum of Agreement
NASA HQ	-	NASA Headquarters
NASA	-	National Aeronautics and Space Administration
NOAA	-	National Oceanic Atmospheric Administration
NTSB	-	National Transportation Safety Board
OMB	-	Office of Management and Budget
Op	-	Operational
PIP	-	Program Implementation Plan
PM	-	Program Manager
PMP	-	Program Master Plan
Pred	-	Prediction
Procs	-	Procedures
Prog	-	Program
RASS	-	Radar Acoustic Sounding System
Reqmts	-	Requirements
Rev	-	Revised
ROT	-	Runway Occupancy Time
SEP	-	Separation
SIM	-	Simulation
SRC	-	Systems Resources Corporation
STC	-	Science and Technology Corporation
Stds	-	Standards
SW	-	Software
Syst	-	System
TAP	-	Terminal Area Productivity
TATCA	-	Terminal ATC Automation
TR	-	Technical Representative
TRACON	-	Terminal Radar Approach Control
Trans	-	Transport
Trng	-	Training
UK	-	United Kingdom
US	-	United States
VAS	-	Vortex Advisory System
VFR	-	Visual Flight Rules
WV	-	Wake Vortex
Wx	-	Weather

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