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OVERVIEW OF 1994 MEMPHIS WAKE VORTEX TESTING PROGRAM*

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1. INTRODUCTION

Significant restrictions currently exist in the air traffic control system due to wake vortex considerations. Eliminating or reducing these restrictions would yield increased capacity, decreased delays and significant cost savings (Evans & Welch, 1991). These improvements would be especially desirable at high traffic airports which cannot expand (e.g., Boston, JFK, LaGuardia, Newark, Washington National, O'Hare, etc.).

However, scientific uncertainty about wake vortex behavior under various weather conditions is a major concern. The current wake vortex restrictions are normally very conservative but could be insufficient under certain transient atmospheric conditions. A successful adaptive wake vortex advisory system must be able to: 1) monitor for unsafe conditions, 2) predict wake vortex behavior over 20–30 minutes in the future and 3) provide an interface to air traffic controllers. Operational implementation of such a system will involve synergism between the Wake Vortex (WV), Integrated Terminal Weather System (ITWS) and Terminal Air Traffic Control Automation (TATCA) programs.

The Wake Vortex program is a new effort at Lincoln Laboratory sponsored by NASA Langley Research Center in cooperation with the FAA. The joint NASA/FAA/Lincoln program seeks to aid in resolving wake vortex behavior issues as a function of the weather environment with a series of field measurements. The field measurements will include obtaining aircraft, meteorological and wake vortex data in an operational airport environment. The data collected will support efforts at NASA and elsewhere to validate wake vortex behavior models, aircraft/vortex interaction and atmospheric diagnosis/prognosis methods. The first of these field measurements is scheduled for the fall of 1994 at the Memphis International Airport.

2. FIELD MEASUREMENTS

The elements of the Memphis field measurement program for the first year are summarized in Figure 1. These elements include wake vortex measurements, atmospheric measurements and aircraft data collection.

2.1. *Wake Vortex Measurement System*

A van–mounted 10.6 μm CO_2 CW (Continuous Wave) lidar will measure line–of–sight velocities in a plane perpendicular to the flight path in order to measure vortices generated by approaching or departing aircraft (Heinrichs et al., 1991). Various lidar scanning strategies will be employed to study wake vortices generated in and out of ground effect. An algorithm will be developed to allow the lidar to automatically recognize, track and characterize wake vortices.

The design of the wake vortex measurement system is summarized in Figure 2. The lidar design is similar to those used in previous work, but with some significant improvements. First, the master oscillator is heterodyned with a local oscillator offset in frequency to prevent

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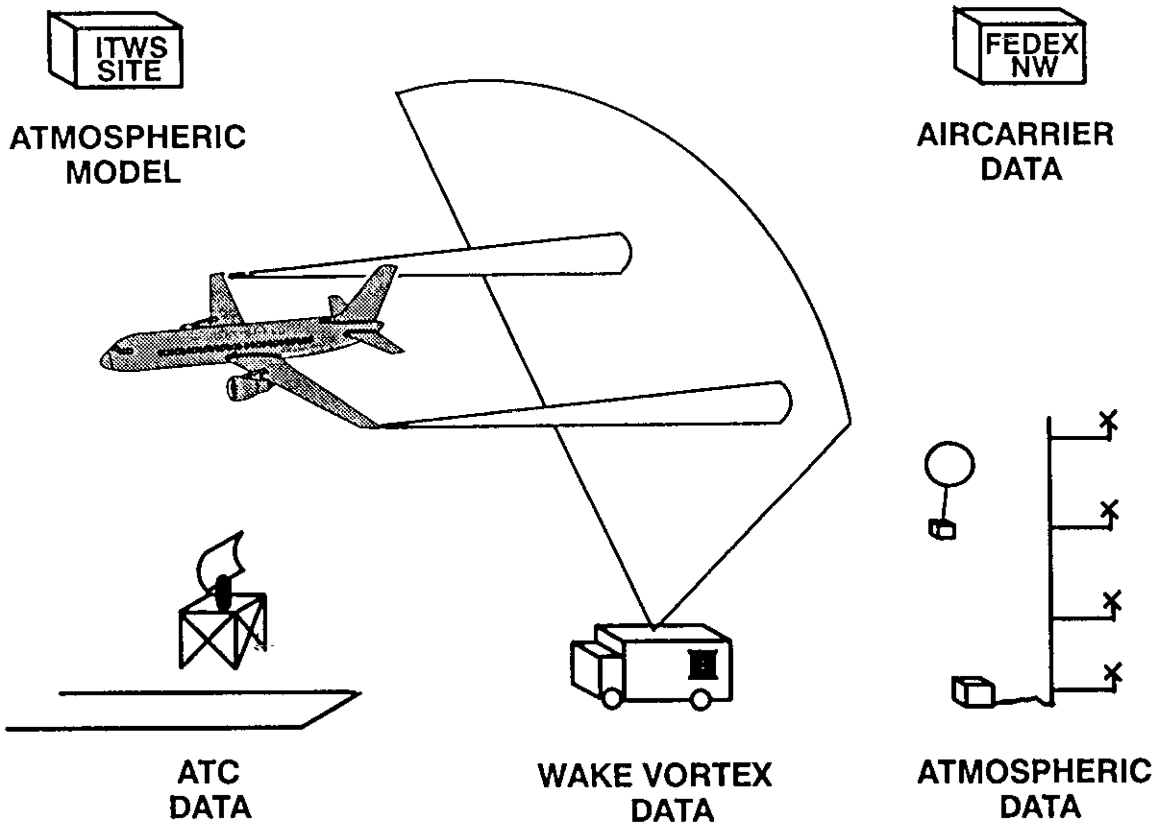

Figure 1.Memphis Wake Vortex Field Measurement Program.

the aliasing of positive and negative Doppler frequencies that occurs in homodyne lidars. Second, the design features a fully digital signal processing system which offers greater flexibility than the analog techniques previously used.

The lidar utilizes a 33 cm aperture with a downrange resolution of 6 m at 100 m range, which increases as the square of the distance. The maximum measurement range is expected to be roughly 300 m. The maximum sweep rate is 180°/s, which allows a 50° sweep in 1 s (including acceleration and deceleration).

The lidar data is sampled at a 40 MHz rate with for an effective 100 m/s velocity bandwidth. FFT (Fast Fourier Transform) processing is performed on the raw data using a Valley Technologies Ultra Digital Signal Processor board. A typical FFT might consist of 512 velocity data points and correspond to a velocity resolution of 0.2 m/s. The FFTs are accumulated to generate averaged velocity spectra at initially a 50 Hz rate (to be upgraded later) and sent to a Sun workstation for archiving and further processing.

The Sun workstation carries out the task of recognizing, tracking and characterizing wake vortices from the lidar data. The first step in this process is to perform feature extraction on the averaged spectra, such as peak finding. The extracted spectral features are then used to locate vortex cores, which are then tracked. The vortex tracking data is fed back to the lidar scan and focus control circuits. Once the core location is determined, the core radius and circulation can be estimated

Figure 3 summarizes the scan strategies to be employed in making wake vortex measurements. The three main strategies are out–of–ground effect (OGE), near ground effect (NGE) and in ground effect (IGE). The onset of

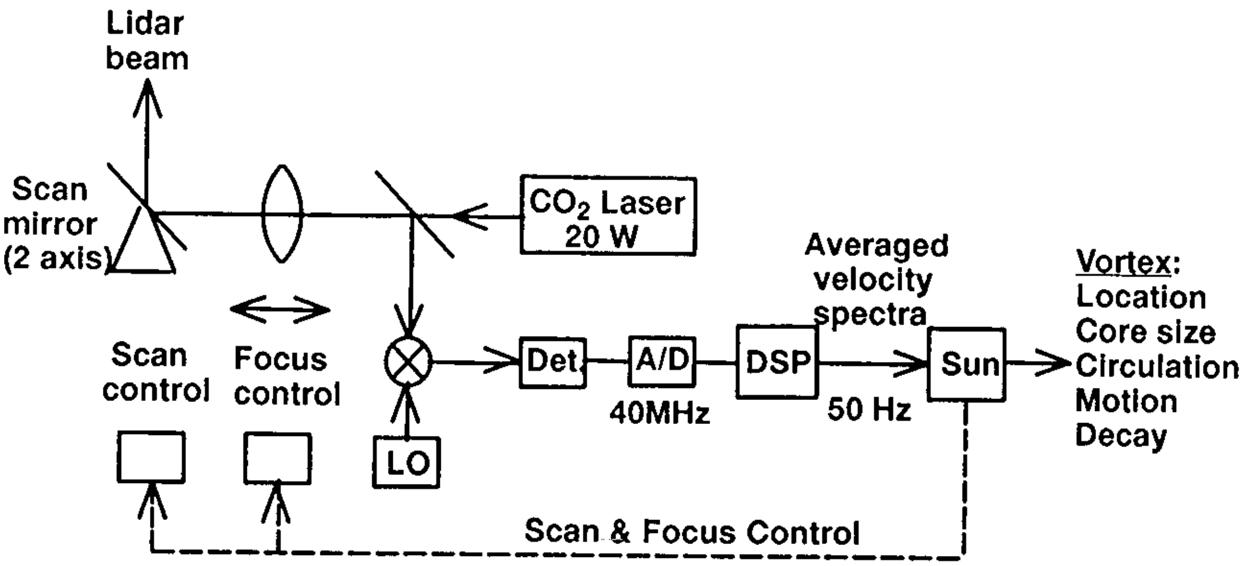

Figure 2.Wake vortex measurement system

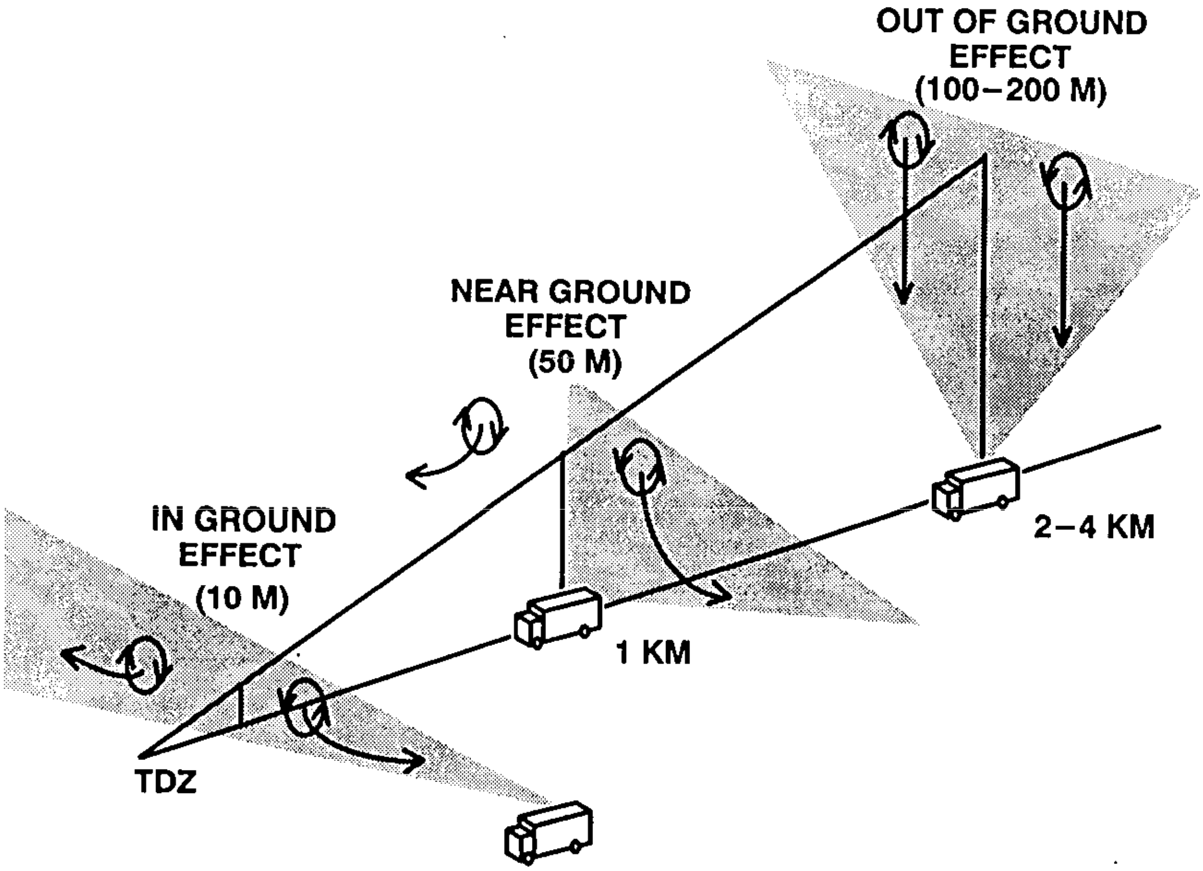

Figure 3.Lidar Scanning Strategies.

ground effect occurs at an altitude of approximately half the generating aircraft wingspan. As illustrated in the figure, vortices tend to descend downwards above this level and to diverge horizontally below it. The three scan strategies will allow the behavior of vortices generated above, near and in ground effect to be studied. Scan strategies will also be designed for obtaining wind and turbulence measurements from the lidar data.

2.2. *Atmospheric Measurement System*

Atmospheric data will be obtained from several sources. An instrumented tower will be erected on the airport to collect temperature, humidity, winds and other data needed to characterize the atmosphere near the surface. Balloon soundings will be made to collect this data above the tower level. A profiler/RASS and sodar are also planned to be installed. Atmospheric model data, plus ACARS downlinked data, surface observations and weather radar data, will be obtained from the ITWS testbed.

Figure 4 illustrates the atmospheric measurement system. A 150' tower will be erected on the airport between the two main runways. This tower will have two types of sensor packages: SAVPAKs and FLUXPAKs. Five SAVPAKs will be used to collect temperature, humidity and 2D (horizontal) winds at a 1 Hz rate. Two FLUXPAKs will be used to measure temperature, humidity and 3D (horizontal & vertical) winds at a 20 Hz rate at the base and top of the tower.

Additional instruments near the tower base include a total net radiometer, barometer and soil temperature/moisture probes. The data from the tower and other sensors will be collected by an ASTER Data Acquisition Module (ADAM) box developed by the National Cen-

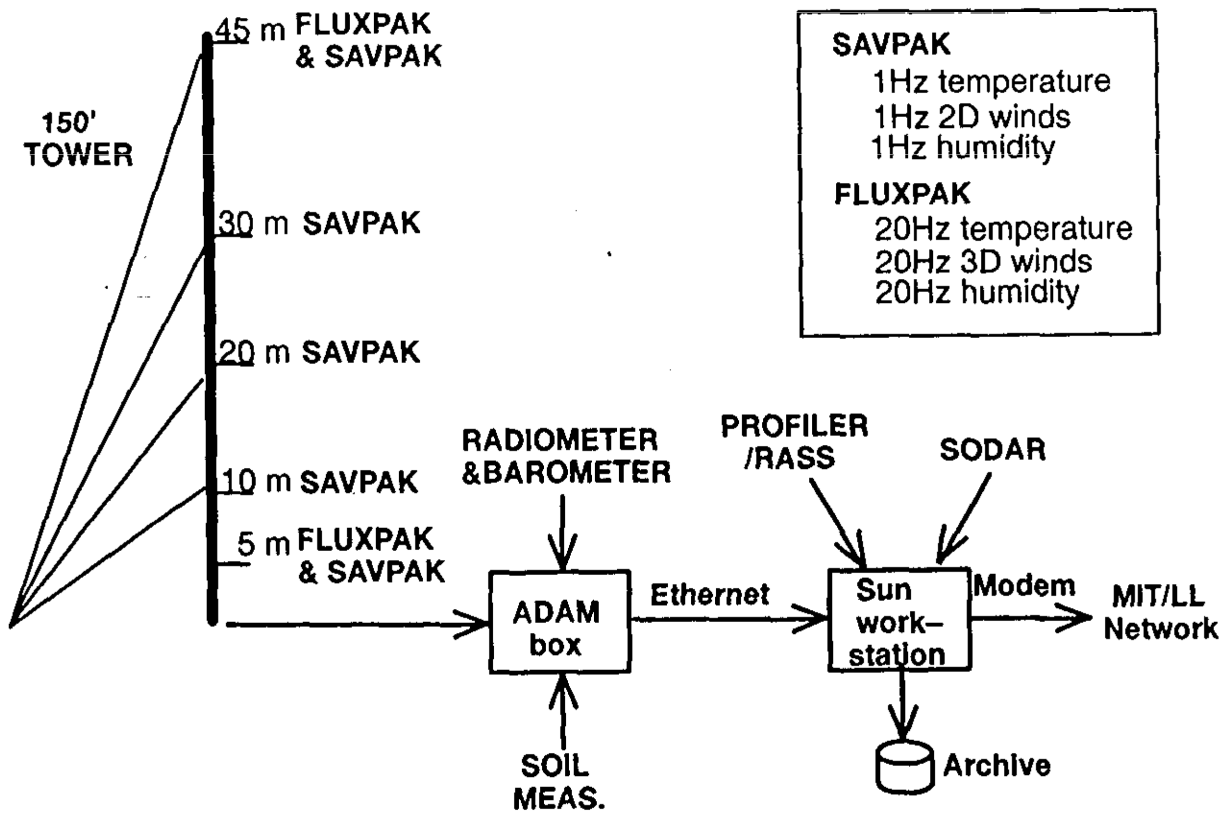

Figure 4.Atmospheric measurement system

ter for Atmospheric Research (NCAR). The ADAM communicates via Ethernet with a Sun workstation located in a shed some 500' south of the tower location.

The Sun workstation will perform processing on the data from the ADAM, such as computing temperature, moisture and momentum fluxes from the FLUXPAK data. Besides communicating with the ADAM, the Sun workstation will also interface to a Radian Profiler/RASS and a Remtek Sodar. The Sun will archive the atmospheric data to a large disk and provide communication with the main Lincoln Laboratory network via a modem connection. The communications capability will also be used to remotely access the data and monitor sensor health.

2.3. *Aircraft Data Collection*

Air traffic control (ATC) data will be obtained to determine the aircraft type, position and speed. This data will be in the form of aircraft beacon reports and flight plans. Additional data will be acquired from air carriers to determine the weight of the aircraft on takeoff or landing. Information will also be obtained from the air carriers about nominal flap settings and other aircraft configuration items.

3. DATA PROCESSING

The wake vortex data processing system is outlined in Figure 5. Due to the diverse nature of the data sources, extensive post–processing will be required to analyze and correlate the data. To the extent possible, the lidar data processing (e.g., computing vortex circulation,

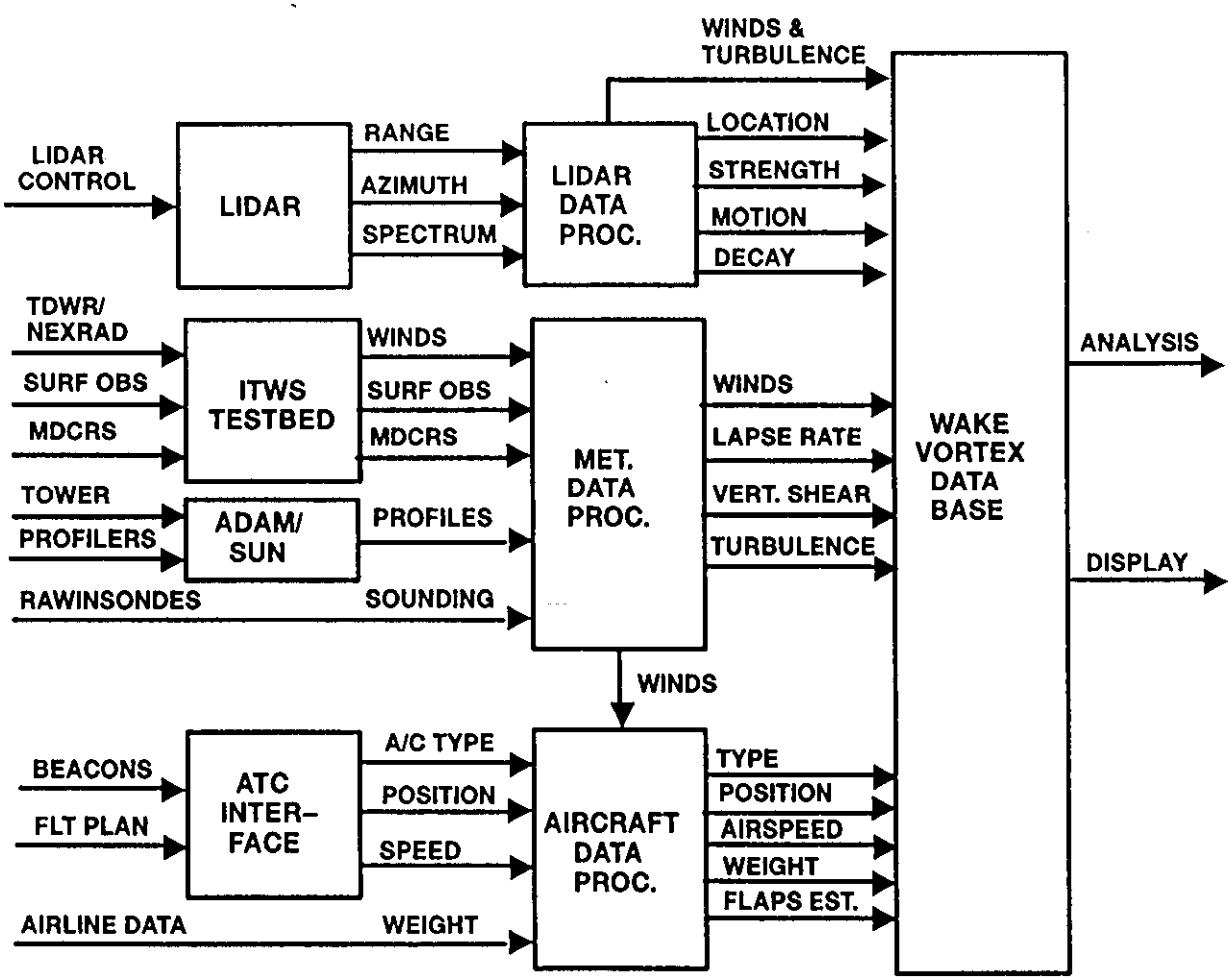

Figure 5.Data processing system

core motion, etc.) will be performed during real–time data gathering. Other processing, such as determining wind and turbulence profiles will probably be performed in post–processing.

The meteorological processing will combine data from the tower, profilers, rawinsondes, surface observations and other data to generate atmospheric profiles. These profiles will include the temperature, winds and turbulence vs altitude. A filtering, weighting and interpolation scheme will be developed to generate a composite profile from the diverse sources of atmospheric data. These profiles will then be used to compute the lapse rate, vertical wind shear and turbulence levels for each lidar measurement.

The aircraft beacon and flight plan data will be processed to determine the aircraft type, ground speed, glideslope and position with respect to the runway. Winds data from the meteorological processing will be combined with the ground speed to determine the airspeed of the generating aircraft. Weight data from airlines will be combined with this information and flap position estimates made based on airline procedures.

All of this information will be combined in a wake vortex data base which draws together the wake vortex, atmospheric and aircraft data for each event. This data base will be analyzed using the IDL interactive data language. The data processing will be designed to facilitate rapid turnaround processing and dissemination of the wake vortex data set.

The data base will be organized into several levels. The topmost level will provide a one–line summary of the important information about each event, such as date, time, aircraft type, runway, airspeed, glideslope, initial vortex circulation, radius and separation, vortex descent and decay rate, lapse rate, vertical shear and turbulence level. The second level will provide additional information, such as the vortex circulation vs time and the third level will provide detailed information such as vortex velocity vs distance from the core. Finally, the fourth level will include raw sensor data.

4. FUTURE WORK

The field measurement program is planned as a multi–year effort. A three month field test is planned for the summer of 1995 at Memphis and long term plans include field measurements to support testing of a prototype NASA/FAA Automated Vortex Spacing System (AVOSS) concept.

5. SUMMARY

This paper outlined a comprehensive field measurement program for automated collection of wake vortex, atmospheric and aircraft data in an operational airport environment. These measurements will provide a valuable data base to aid in the validation of wake vortex behavior models and techniques for atmospheric diagnosis/prognosis.

6. ACKNOWLEDGEMENTS

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