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MEASUREMENT OF AIRCRAFT WAKES AT 250-METER ALTITUDE WITH A 10.6-MICRON CW LASER DOPPLER VELOCIMETER

by

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Introduction

The use of a CW laser Doppler velocimeter (LDV) to study aircraft wake vortices began in 1969 (Ref. 1). This early development of the techniques culminated in measurements on wakes of landing aircraft at the John F. Kennedy International Airport in 1974 and 1975 (Ref. 2). These measurements involved aircraft at altitudes below 100 meters. In late 1975, a similar LDV system was used to measure wake velocity profiles from aircraft at altitudes up to 250 meters (Ref. 3). Based on this work, the Transportation Systems Center (TSC), under the sponsorship of the Federal Aviation Administration, developed a new scan pattern (Ref. 4) which yields good high-altitude vortex data, and is being used to collect data on the wakes of aircraft landing at Chicago's O'Hare International Airport.

Principles of Operation

The LDV makes a remote measurement of atmospheric wind by focusing CW 10.6-micron laser radiation into a small volume in space. Naturally occurring aerosols within the focal volume scatter a small fraction of the incident radiation back to the LDV. The backscattered radiation is Doppler shifted by the line-of-sight velocity of the aerosols which move with the wind. The magnitude of the Doppler shift, but not its direction, is determined by mixing with a portion of the transmitted signal.

A profile of the line-of-sight wind in a plane can be obtained by scanning the focal volume of the laser beam in range and angle. The focal volume is narrow in the direction transverse to the beam but is long in the beam direction (needle-shaped). Since the length of the response increases as the square of the range R(the 3dB length in meters is $R^2/1000$ for our LDV), little range resolution exists beyond some limiting range.

Range resolution is poor in another sense; the response decreases very slowly with distance from the focal point (Ref. 5). The response is down only 20 dB at a point that is ten times the displacement giving a 3-dB drop in response. This effect leads to interesting results for measurements on wake vortices; it is difficult to measure the range to the vortex, but it is easy to measure the tangential vortex-velocity profile. The region where the vortex tangential velocity is tangent to the LDV beam will give a peak in the Doppler spectrum even when the beam is focused far from the vortex (Ref. 4). This peak will also be the largest Doppler shift observed along the beam. Vortex data are therefore processed by setting a spectral-intensity threshold at a level well above the noise and then assigning the vortex tangential velocity to the largest observed Doppler shift.

The focal-point scan pattern used to search for high altitude vortices is shown in Figure 1. The elevation angle is scanned back and forth at a rate of one scan per second. At the end of each scan, the range is stepped to a new value. Eight ranges are scanned from the highest range to the lowest range providing a scan through the vortices every eight seconds. A complete scan through all the ranges is called a data frame. This scan pattern gives high resolution velocity profiles of the vortices and makes optimum use of the inherent fast range response and slow angle response of the scanner. When the vortices are located directly above the LDV, the vortex velocity measurements have minimum contamination by the ambient wind; the wind is horizontal and therefore has little line-of-sight component.

The LDV van is positioned under the approach path to a runway. The pair of trailing vortices from landing aircraft are therefore generated in the region of optimum measurement. When there is little crosswind, the vortices can be monitored for as long as two minutes as they descend toward the ground. A strong crosswind will rapidly blow the vortices out of the scan region and will also distort the vortex signature when the vortices are no longer above the LDV.

System Description

The TSC/FAA mobile LDV system is housed in a 7.3-meter van and was designed for two modes of operation: a mobile test vehicle in which the LDV system can be set up and operated for short periods of time at various locations, and as a fixed base of operation where the enclosure is removed from the truck chassis and placed on a permanent foundation. The laser system is contained within the enclosure and is configured as shown in Figure 2.

A horizontally polarized, 20 watt, continuous wave CO_2 laser, emitting at a single wavelength, single mode (P20, TEM_{00}) is deflected 90° by a 70% beamsplitter and a total reflecting mirror. The approximately 6-mm diameter beam then passes through a Brewster beamsplitter and a CdS quarter-wave plate which converts the beam to circular polarization. The beam impinges on the secondary mirror (range scanner) of the Cassegrainian telescope, is expanded and is back-reflected onto the 30-cm diameter primary mirror, deflected 90° to the azimuth-elevation scanner, and focused out into the atmosphere. Beam energy scattered by aerosols, at the focal volume, is collected by the telescope and passed through the quarter-wave plate. The quarter-wave plate changes the polarization of the backscattered radiation from circular to vertical. The vertically polarized beam is approximately 78% reflected off the Brewster beamsplitter and directed to the detector beamsplitter where is is combined with a low-power reference beam (local oscillator beam). After passing through the focusing lens, the two beams are photomixed on a Pb-Sn-Te photovoltak infrared detector. Heterodyne or homodyne operation is obtained when the acousto-optic frequency translator is on or off, respectively.

The electrical output of the detector is amplified with a high-gain, broadband preamplier and put into a spectrum analyzer which generates the spectral amplitude in 80 frequency bins, each 100 KHz wide. The spectra are averaged digitally for 8 milliseconds and then input to a minicomputer along with information on the scanner range and angles. In addition, the spectra are processed with hardware that compares each spectral component with a selected threshold and finds the largest Doppler frequency with amplitude above the threshold. This hardware determination of the spectral feature directly related to vortex tangential velocity serves to reduce the computer overhead.

Data Processing

The minicomputer software performs the following functions:

a) Accept data from the spectrum analyzer and hardware processor.
b) Display the current wake velocity profiles on a refresh graphics CRT.
c) Select data and output the data to a digital tape recorder.

The real-time graphics display is similar to that in Figure 3 which was generated on the playback processing system. The hardware-determined vortex tangential velocity is plotted as a function of scan angle (actually versus sample number with about 0.5° per sample) for each of the eight arc scans in one data frame. The velocity is plotted downward from the zero velocity line for each range. The range (in meters) is labeled at the left edge of each line. The negative sign for alternate ranges indicates the ranges where the scan was actually done from right to left. The system operator uses the real-time display to make sure that the scan covers the trajectories of the vortices and that data are recorded until the vortices have disappeared from view. The display also allows the operator to set the optimum spectral threshold; i.e., just high enough to eliminate noise from the velocity plots.

The data tapes are processed off line to obtain vortex trajectories ánd strength as a function elapsed time. Attempts to automate this process always led to a data base which required substantial editing. Consequently, an interactive graphics program was developed to allow visual determination of the tricky part of the procedure, namely, locating the center of the vortices. The vortex center is usually marked by a velocity dip where the line-of-sight velocity drops to zero. The centers of the two vortices are marked with a light pen and the vortex strengths are calculated using corrections for the ambient wind, measured at an angle selected by the light pen. The range to the vortices is selected by noting the range with the highest vortex velocities or the highest calculated vortex strength.

Status of Data Collection

The LDV was initially set up beneath the flight path for aircraft landing on runway 27R at O'Hare. The nominal altitudes of the aircraft were 250 meters. Procedural changes and the overall wind pattern during the summer months prompted moving the LDV to the approach region of runway 14R, where the system is presently (August 1978) located.

Vortices from over 2500 aircraft have been monitored with the LDV. The data tapes recorded at O'Hare are shipped to TSC for detailed offline processing. The objectives of the analyses are to determine vortex-descent rates and distances, vortex-decay rates, and the time required for vortices to exit a defined corridor. The behavior of the vortices will be correlated with a number of concurrent measurements/observations: aircraft type, ambient meteorology (winds, atmospheric stability, inversion heights, etc.), and theodolite-determined location of the aircraft above the LDV.

Conclusions

The novel scan mode, which takes advantage of the relative speeds of range and angle scanning in a focusing CW LDV, is proving to be valuable. Without the LDV, however, there would be no way to study aircraft wake vortices at these altitudes (between 150 and 300 meters) on a non-interfering basis.

References

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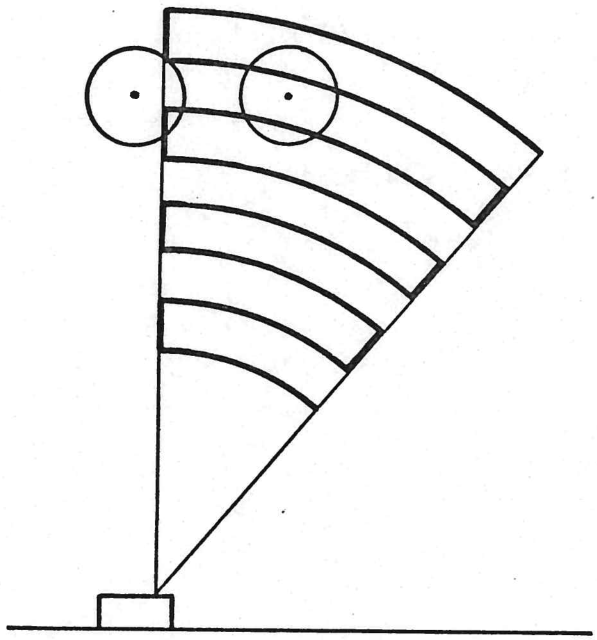

FIGURE 1. STEPPED ARC SCAN MODE FOR PROBING TRAILING VORTEX PAIRS

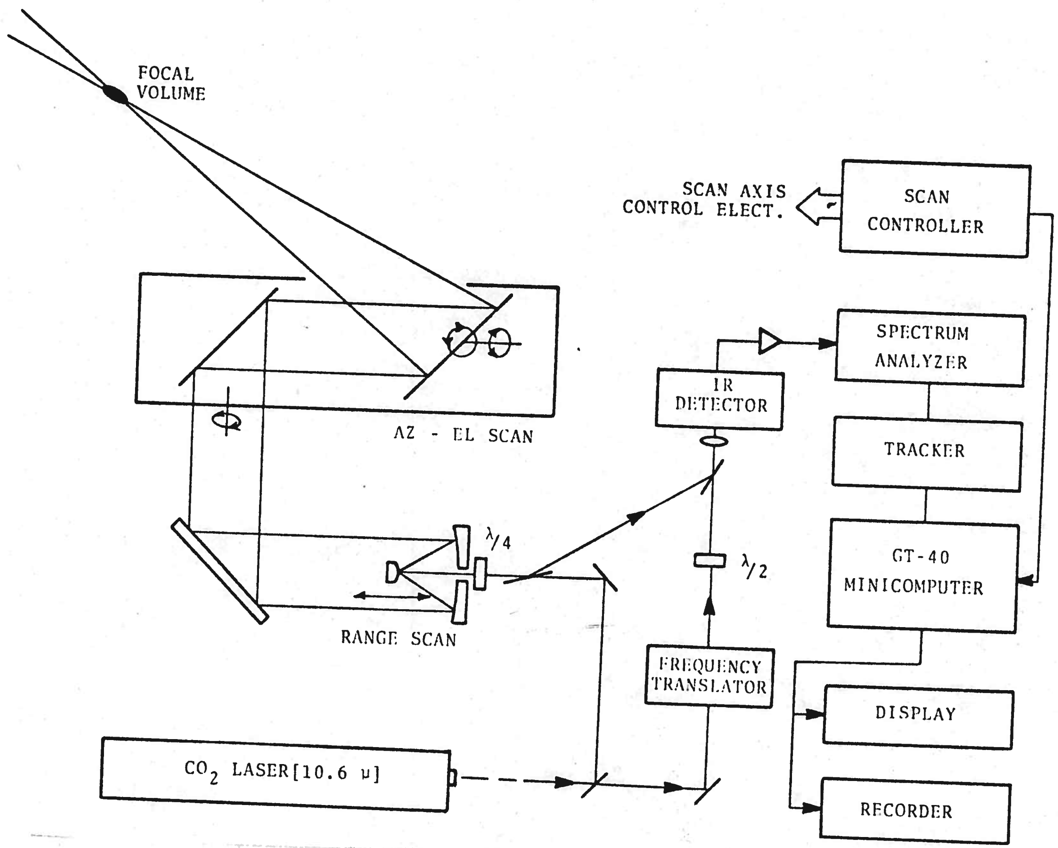

FIGURE 2. LDV CONFIGURATION

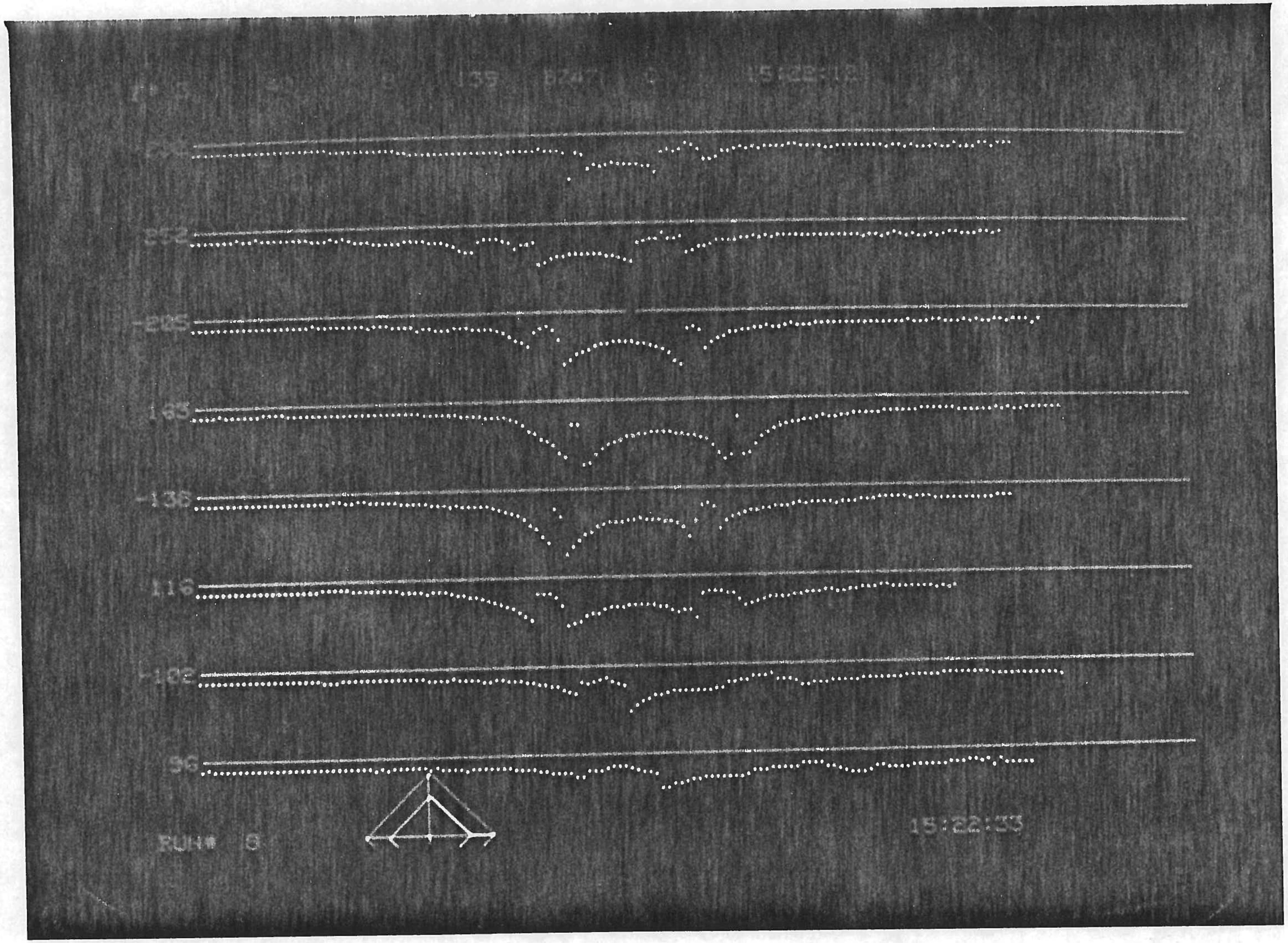

FIGURE 3. CRT DISPLAY OF AIRCRAFT WAKE VELOCITY FIELD