Table 1 Fitting technique evaluation

Coefficient	Simulation Input	Fit	% Difference	Experimental fit
$C_{m\alpha_0}$	-60.0	-60.0	0.	-57.2
$C_{m\alpha_2}$	0.1	0.1	0.	0.03
$[C_{m_q} + C_{m\dot{\alpha}}]_0$	-1500.0	-1500.3	0.02	-2120.0
$[C_{m_q} + C_{m\dot{\alpha}}]_2$	-2.5	-2.1	16.0	3.1
$C_{n\beta_0}$	40.0	40.0	0.	33.2
$C_{n\beta_2}$	0.05	0.05	0.	-0.01
$[C_{n_r} - C_{n\dot{\beta}}]_0$	-1500.0	-1500.7	0.04	-1620.0
$[C_{n_r} - C_{n\dot{\beta}}]_2$	7.	8.4	16.6	1.8

type aircraft. The aspect ratio of the lifting surfaces is 1.0 and 1.5 in the pitch and yaw plane, respectively, as shown in Fig. 1. The wind-tunnel support system utilized sapphire jewel bearings which have proven to minimize the effects of nonaerodynamic friction.[5] The tests were conducted at a tunnel speed of 50 fps in the open circuit low-turbulence tunnel (Fig. 2). The model was displaced to $\alpha = 40°$ then released while its motion was being recorded by a high-speed motion picture camera. The camera was focused through a mirror oriented 45° to the flow and mounted downstream of the model. Projecting the film on an optical comparator and then utilizing the reference marks shown in a sample data frame (Fig. 3), the angle of attack and angle of sideslip vs time records for the model were determined. A sample α-β motion is given in Fig. 4. This motion is characteristic of the aircraft Lissajous patterns resulting from the configuration having different frequencies in the pitch and yaw planes.

Experimental Test Results

The numerical integration fitting technique was then applied to the experimental wind-tunnel data to determine the aerodynamic stability coefficients for the test configuration. The results of the fitting procedure, Table 1, yield the expected results for this configuration. $C_{m_{\alpha 0}}$ and $[C_{m_q} + C_{m_{\dot{\alpha}}}]_0$, the terms effected by the larger lifting surfaces, were definitely larger than their respective terms in the yaw plane, $C_{n_{\beta_0}}$ and $[C_{n_r} - C_{n_{\dot{\beta}}}]_0$. The fitting procedure also yielded definite results for the nonlinear aerodynamic restoring moments $C_{m_{\alpha 2}}$, $C_{n_{\beta_2}}$ and damping moments $(C_{m_q} + C_{m_{\dot{\alpha}}}]_2$ and $[C_{n_r} - C_{n_{\dot{\beta}}}]_2$. Since the static moments were of the soft spring type, that is, decreasing stability with increasing α and β, this indicates the possibility of instability at high α, and demonstrates the importance of considering nonlinear aerodynamics in aircraft stability studies.

Conclusion

The analytical and experimental work presented in this Note has indicated that the aerodynamic stability coefficients can be extracted from the angular motion of aircraft configurations. Using the numerical integration fitting technique applied to the differential equations of motion, it is possible to determine values for the stability coefficients without imposing limiting assumptions on the configuration or its motion. The fitting technique demonstrated a high degree of accuracy as well as establishing the nonlinearity of the stability coefficients. Application of this technique is now being made to the complete pitch, yaw and roll of an aircraft configuration with primary interest in extracting the cross-coupling stability coefficients.

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Acoustics: A New Approach for Monitoring the Environment near Airports

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THE introduction of much larger aircraft to commercial and military fleets has focused attention on the need for more complete coverage of the meteorological environment at airports. Of immediate concern to those responsible for flight safety, and indeed to every pilot who may encounter one, are the intense vortices shed from the wings of large aircraft. This problem is especially critical near the ground where momentary loss of control could prove fatal. Concern over this new safety aspect has lead to a concerted effort by the FAA to learn more about the nature of vortices and their effect on other aircraft, and to a search for ways of reducing their residence time in the atmosphere or of determining their location in order that other aircraft can be advised of the potential hazard.

This effort has lead to a potpourri of suggested methods for monitoring the affected airspace, ranging from pulsed lidar to various acoustic devices. A common weakness found in most of the proposed monitoring systems is that they concentrate only on vortex detection and overlook other equally important, if less spectacular, environmental factors which affect low-level aircraft operation. For example, the effect on a planned glide slope of strong low-level wind shear or of turbulence produced by strong thermal activity can be of great importance to aircraft safety. This Note describes a relatively new device, an acoustic echo sounder, which has the potential to not only indicate the presence or absence of wake vortices, but to act as a continuous monitor of other important meteorological parameters.

In 1962, Monin[1] following contributions from many others, formulated the basic relationship describing the scatter of sound waves by turbulent wind and temperature fluctuations. More recently following a summary of this work, Little[2] outlined the potential applications of this principle which has been applied in the development of acoustic echo sounders used in remote sensing of low-level atmospheric phenomena.[2–4]

Because an acoustic wave is dependent on the medium being measured (the atmosphere) for its transmission, its

Received August 12, 1971. Taken from a talk given by the author at the FAA Sponsored Symposium on Turbulence held in Washington, D. C. during March of 1971.

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interaction with changes in structure are far stronger than for other types of waves (radio or light) used for remote sensing.[2] This strong interaction also limits the useful range of the echo sounder to regions within the Earth's boundary layer. For these reasons, an acoustic echo sounder is ideally suited for minitoring the immediate environment of an airport.

The mode of operation which has been successfully used in sounders designed for research purposes consists of sending a sound pulse, on the order of 50 msec long, into the atmosphere and then monitoring the acoustic power scattered from atmospheric inhomogenities along the path traversed by the pulse. This has been done for both colocated and separated transmitters and receivers, an important consideration because of the different scattering intensity for the two modes.

The sounder is sensitive to turbulent eddies on a scale which is equal to one half the wavelength of the acoustic wave, i.e., at a carrier frequency of 2000 Hz, eddies having dimensions of about 0.08 m produce the strongest scatter. While this portion of the turbulence spectra is of little aeronautical interest, information relevant to larger scale motions can be inferred. Assuming a Kolmogorov turbulence spectrum, having a well defined energy cascade rate, the intensity of the fluctuations at the smaller scale are directly related to the intensity of the eddies at all other scales within the inertial subrange. Perhaps more important, however, is the influence of much larger motions on regions or layers of strong, small scale, turbulence.

The regions of intense scatter are displaced by the larger scale flow and serve as tracers of phenomenon which are large enough to affect the flight of aircraft. This influence of large scale motion on smaller tracer is clearly shown in Fig. 1, a typical example of the output from an acoustic sounder reproduced on a facsimile recorder. Each vertical trace of the facsimile corresponds with a single pulse from the sounder, the dark line along the bottom of the record showing the end of each active pulse and the remaining portion, above this level, the period of time when the sounder was in a passive mode, "listening" for the scattered returns. The single vertically pointing antenna used during this field test provided the data necessary for monitoring a temperature inversion surface, the dark oscillating line between 200 and 450 m. This inversion marked the boundary between clear air and a low-level stratus deck, a valuable input to ILS operations. The ability to continually monitor the height of such low-level inversions would be of value also in regions where visibility reducing air pollution might accumulate.

The evolution from stable horizontally stratified structures to vertically oriented unstable structure (thermal plumes) after the breakup of a low-level inversion is equally vivid in acoustic sounder records and can also be monitored with a single antenna. A typical record produced by a thermal plume is shown on the left side of Fig. 2, where the ascending portion of the plume creates the dark vertically oriented structure.[5]

The actual vertical velocities within the plume can be determined from the Doppler frequency shift of the scattered

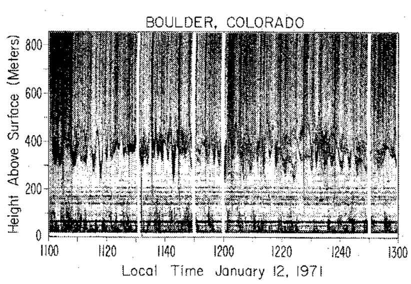

Fig. 1 Facsimile recording of the backscatter from an inversion surface.

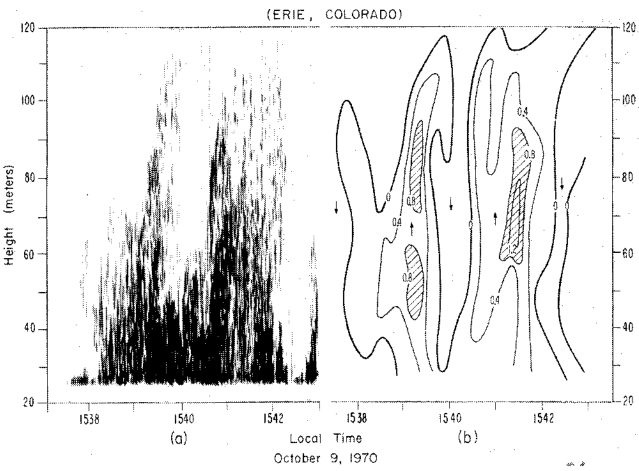

Fig. 2 Acoustic echoes (left) and Doppler derived vertical velocity field during thermal plume activity. Contour interval is 0.4 $msec^{-1}$; regions of vertical velocity >0.8 $msec^{-1}$ are shaded; arrows indicate direction of vertical component.

signal. This was done for the plume shown in Fig. 2 and resulted in the vertical velocity field shown on the right side of the figure.

By adding a second antenna separated from the first, but pointing at a volume common to both antenna beams, a second wind component in the plane formed by the two beams can be measured. This type of measurement has also been carried out successfully,[6] demonstrating the feasibility of adding a third antenna orthogonal to the plane of the first two in order to resolve the total wind vector at the intersection of the three beams.

From here, it should be a relatively simple matter to incorporate phased steerable antennas capable of sweeping up and down the vertically pointing beam and to process the information in a small on-line computer for real time display of a vertical profile of the total wind vector up to heights of about 1 km. This technique could then be incorporated into a complete monitoring system, such as that shown in Fig. 3, where a terminal forecaster or air controller would have a display of the vertical wind profile, inversion height, and information on the ambient turbulence intensity. This amount of continually updated detail wind information would certainly improve the air controllers ability to advise aircraft, considering that present information at airports at best consists of a constant output of surface wind and a vertical sounding every 6 hr.

It should be noted that the information discussed above is derived entirely from the ambient background scattering of sound in the atmosphere, no additional tracer is required. Very high velocities found in wake vortices coupled with entrained engine heat result in an increase of scatter from both velocity and temperature fluctuations. The scattering strengths associated with this increased activity should be orders of magnitude greater than those which result from ambient turbulence. The presence of a wake vortex will be readily detectable by the increased signal amplitude and its range or height above the ground can be fixed by the delay time between each pulse and the return signal. Methods of vortex detection similar to this are already being tested,[7,8] and preliminary results support the speculation that scatter from a vortex is much stronger than that from the ambient atmosphere. In addition, these tests have demonstrated that an acoustic sounder can be successfully operated in an environment containing extremely high-intensity noise sources, such as would be present at an airport.

Other characteristics of the interaction of sound waves with vortices may also prove useful as detectable phenomenon. One of these is the ray bending which results as a sound wave passes through a strong vortex. Georges,[9] has demon-

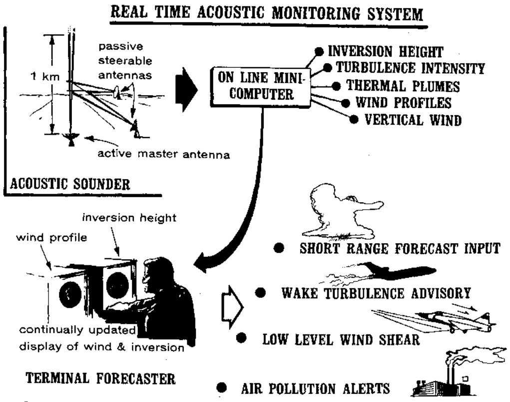

Fig. 3 Schematic of monitoring system which could provide real time information about meteorological conditions near an airport.

strated that this bending can be of very large magnitude and can result in high concentrations of sound pressure or complete nulls depending on the locations of the receivers. Because of the requirement that the transmitter and receiver must be located at just the right spot to receive the enhanced signal this approach would appear to have limited operational value. A better understanding of the phenomenon, however, will certainly aid in the interpretation of data collected by the scattering method.

A second approach, as yet untested, might be to interpret the amplitude or phase scintillation of the received signal as a measure of the turbulence intensity along the path of the sound wave. It is known that the intensity of such scintillations is a function of the turbulence intensity and eddy size[10,11] and a real time analysis of this parameter could provide information on the intensity of both the ambient background turbulence and the turbulence when a vortex is present. While more theoretical study and experimentation are needed to establish the functional relationship between sound wave scintillation and a vortex or ambient turbulence this approach would seem to provide exactly the type of information that a pilot making an approach would be interested in knowing. It would also be possible to make this type of measurement with the same equipment used for measuring the wind profile.

With any operational monitoring system the question of cost must certainly be considered, and it is here that acoustics has a decided advantage over the use of other types of waves. Thanks to the high level of interest in providing quality sound eqipment for the general public, many of the components needed for an acoustic sounder have already been developed and are being mass produced. This factor alone reduces the over-all cost of the system to a level which would allow the building and installation of sounders at most major airports. This, added to the versatility of a system which can monitor not only wake vortices but also provide real time information on the ambient environment, makes the acoustic sounder an attractive prospect.

To summarize, recent studies have shown that the strong interaction of acoustic waves with the atmosphere can be used to remotely sense a variety of details about the structure and motions within the boundary layer. The need for more complete information on both the ambient and man induced structure of the environment near airports can be fulfilled by the practical application of this relatively new monitoring technique. Based on confirmed measurements and an extension of these ideas one can envision systems similar to that shown in Fig. 3. Here a fixed, vertically pointing antenna, in conjunction with two orthogonally positioned scanning antennas could provide a continual real time record of the inversion height, the turbulent intensity, an indication of the presence of wing tip vortices, and the vertical profile of the total wind vector.

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Human Factors Study of Keyboards for Cockpit Data Entry

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Introduction

ANTICIPATING the use of keyboards for cockpit data entry, the Human Factors Group at Collins Radio Company has been collecting data on features of keyboards that are important for air-borne applications. The general nature of the studies and conclusions influencing control design of the CDU (area navigation control and display unit) are discussed below.

The standardized operator task in each study involved entering a sequence of vhf communication frequencies taken from sequences used in actual cross-country flights. Response time was measured from the time a start tone sounded

Table 1 Study I error data

	Proportion of Erroneous Entries		
Control box	Cleared	Total insert	Undetected insert
Keyset (16 oz)	0.0154	0.0046	0.0013
Dual knob	n/a	0.0043	0.0024
Concentric knob	n/a	0.0024	0.0006
Total number of trials represented: 16,200			

Received June 1, 1971.
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