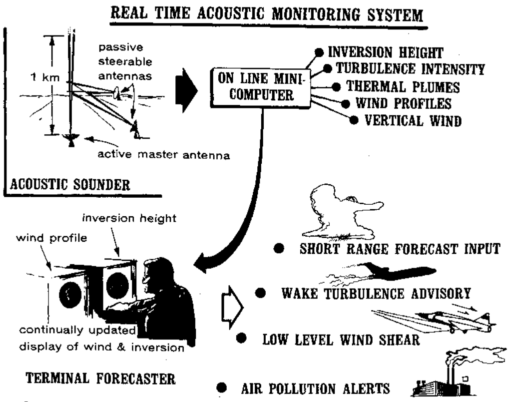

Fig. 3 Schematic of monitoring system which could provide real time information about meteorological conditions near an airport.

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.

References

[1] Monin, A. S., "Characteristics of the Scattering of Sound in a Turbulent Atmosphere," *Akusticheskii Zhural*, Vol. 7, pp. 457–461; also *Soviet Physics Practice*, Vol. 7, April 1962, pp. 370–373.

[2] Little, C. G., "Acoustic Methods for the Remote Probing of the Lower Atmosphere," *Proceedings of IEEE*, Vol. 57, 1969, pp. 571–578.

[3] McAllister, L. G., Pollard, J. R., Mahoney, A. R., and Shaw, P. J. R., "Acoustic Sounding—A New Approach to the Study of Atmospheric Structure," *Proceedings of IEEE*, Vol. 57, 1969, pp. 579–587.

[4] Beran, D. W., "Project EAR (Environmental Acoustic Research)," Rept. 17, March, 1970, Meteorology Dept., Univ. of Melbourne, Melbourne, Australia.

[5] Beran, D. W., Little, C. G., and Willmarth, B. C., "Acoustic Doppler Measurements of Vertical Velocities in the Atmosphere," *Nature*, Vol. 230, 1971, pp. 160–162.

[6] Beran, D. W. and Willmarth, B. C., "Doppler Winds from a Bistatic Acoustic Sounder," *Proceedings of the Seventh International Symposium*, Univ. of Michigan, 1971.

[7] Kodis, R. D., *FAA Sponsored Symposium on Turbulence*, Washington, D. C., March 1971.

[8] Proudian, A., private communication, Xonics Inc., Van Nuys, Calif. March 1971.

[9] Georges, T. M., "Acoustic Ray Paths Through a Model Vortex with a Viscous Core," to be published, *Journal of the Acoustical Society of America*, Nov. 1971.

[10] Clifford, S. F. and Brown, E. H., "Propagation of Sound in a Turbulent Atmosphere," *Journal of the Acoustical Society of America*, Vol. 48, Nov. 1970, pp. 1123–1127.

[11] Mandics, P. A., "Line-of-Sight Acoustical Probing of Atmospheric Turbulence," TR 4502-1, 1971, Stanford Electronics Laboratories, Stanford Univ., Stanford, Calif.

Human Factors Study of Keyboards for Cockpit Data Entry

C. A. Fenwick* and H. M. Schweighofer†
Collins Radio Company, Cedar Rapids, Iowa

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.
* Head, Human Factors Engineering.
† Technical Staff, Avionics Systems Division.

and the desired frequency was presented on a 7-bar incandescent display until an insert key was pushed. Each trial ended with the operator pushing a key indicating that he thought the frequency he inserted was either a correct insert, an error insert, or an error corrected (an error entry on the keyset that was cleared from the local verification display and followed by a correct frequency insert).

Study I

The first study compared operation of a dual knob vhf control box, a dual concentric-knob control box, and a 10-key keyset with the same numeral arrangement as the touch-tone telephone. Each of nine operators entered a sequence of 90 frequencies in each control box in each of five locations (see Fig. 1): 1) aisle stand aft (immediately aft of the throttle quadrant), right-hand operation; 2) aisle stand forward (immediately forward of the throttle quadrant), right hand; 3) light shield, right hand; 4) control wheel hub, both right-hand and left-hand operation. 5) outboard console, left hand.

In each of the locations the 10-key keyset was significantly faster than either of the knob type control boxes by 2–3 sec at the 90th percentile. There were no significant differences in response times among locations within any given control box. The very small differences in response times between left- and right-hand operation were also of no practical significance. The error data for each control box are shown in Table 1.

"Cleared" errors are all errors that were corrected by pushing the clear key and then making a new entry before pushing insert. "Total insert" errors are all errors that existed at the time the insert key was pushed, regardless of the explanation given. "Undetected insert" errors are the subset of the total insert errors for which the explanation "correct insert" was given. Thus, the undetected insert errors were considered by the subject to be correct entries. The differences shown are not statistically significant; however, the fact that the error rates are so small makes it very difficult to detect significant differences without taking an inordinate number of measurements.

Study II

The second study compared operation of the same concentric knob and 10-key keyset control boxes and a thumb wheel control box over a period of 9 days. There were nine operators for each control box. Each day each operator entered 100 vhf communication frequencies in the same control box in the aft aisle stand location. The differences in response times between the concentric knob control and the 10-key keyset were very similar to the differences in the first study. The thumb wheels were even slower than the concentric control, as might be anticipated. The differences among the boxes remained constant across the 9 days of operation with approximately 1 sec decrease in 90th percentile response times for all control boxes. The error rate data from this study have been only partially analyzed, but the results are very similar to the results of the first study.

Table 2 Study III error data

Key pressure	Proportion of Trials Containing Errors: Cleared	Total insert	Undetected insert
8 oz	0.0346	0.0067	0.0033
16 oz	0.0158	0.0038	0.0017
24 oz	0.0088	0	0
Total number of trials represented: 7,200			

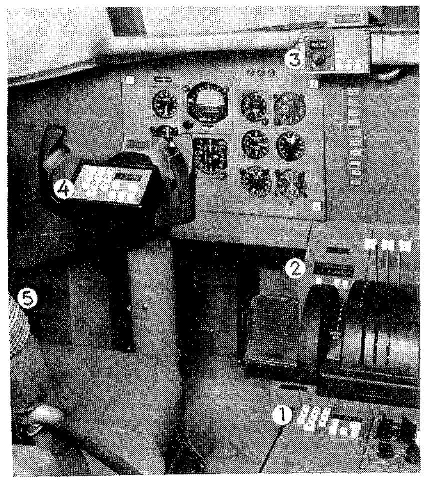

Fig. 1 Cockpit simulator showing locations of control boxes: 1) aisle stand aft; 2) aisle stand forward; 3) light shield; 4) control wheel, right-hand or left-hand operation; 5) outboard console, left hand operation.

Study III

The third study introduced the important variable of turbulence. A mechanism was constructed to shake the control boxes to simulate the relative motion between a pilot's hand and the control boxes in turbulence. From consideration of the nature of the keyset task and the characteristics of turbulence in transport aircraft it was concluded that the greatest effects on keyset operation would occur with the relatively high amplitude movement near the resonant frequency of the total airframe. Based on airframe data, a combination of three sine waves at nonintegral multiples with a maximum frequency of 1.5 Hz and an amplitude of ± 1 in. were selected for driving the turbulence simulation mechanism. Simultaneous motion in the lateral and vertical axes was provided by independent signal generators. The turbulence simulation mechanism is shown in Fig. 2. Control boxes with key pressures of 8, 16, and 24 oz were operated in the aft aisle stand and in the light shield locations. Each of 4 operators entered a sequence of 100 vhf communication frequencies 3 times with each of the key pressures in each of the locations. There were no significant differences between response times with the different key pressures. However, there were significant differences in the percent error data that are shown in Table 2. The definitions of cleared errors, total insert errors, and undetected insert errors are the same as for the first study. The differences in percent cleared errors among different key pres-

Fig. 2 Turbulence simulation mechanism.

sures were statistically significant. The heavier key pressures were effective in limiting the detrimental effects of motion.

It may appear to the reader that 24 oz is an unreasonable amount of pressure, which might lead to fatigued fingers and disgruntled pilots. Our subjects regularly entered 500 digits over a span of 30–40 min. without complaints.

Study IV

A fourth study has been completed recently and data are being analyzed. Operation with and without simulated turbulence is being compared. The concentric knob control box, the 24 oz 10-key keyset, and a thumb wheel control box were operated in the forward aisle stand and in the aft aisle stand locations. A comparison of operation by laboratory technicians and by commercial pilots is also included.

Study V

A fifth study is currently under way to evaluate detailed design features of alphabetic key modules. This is expected to be especially valuable in view of the critical importance of packaging so many keys in a small area.

Based on the results of the above studies, combined with analyses of the control tasks required for area navigation, we have concluded that a keyset control provides saving in entry time over a traditional knob-type control. This holds true for all locations considered, and, more specifically, the location forward of the throttles is acceptable for a keyset-type control. Finally, by selecting a key pressure significantly heavier than would be recommended for stationary operation, the detrimental effects of turbulence on error rates with keysets can be held within current limits.