AMBIENT NOISE IN THE COCKPIT/FLIGHTDECK COMMUNICATION ENVIRONMENT OF AUSTRALIAN CIVIL AVIATION AIRCRAFT

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ABSTRACT - A recent survey of ambient sound pressure levels and noise spectra occurring in the cockpit/flightdeck of various categories and classes of civil aviation aircraft is described. Variations in the cockpit noise between aircraft classes and during different flight operations indicate that cockpit speech technology should be evaluated under a range of conditions, although conditions within aircraft of the same category or class are similar enough to allow construction of an 'average' noise environment for a specified flight condition.

INTRODUCTION

Speech communication, whether it take the form of a ground-air, intercrew, or increasingly, man-machine interaction, forms a large and vital part of aircrew workload. The growing application of speech technology systems in aviation has gained much of its impetus from military aircraft requirements, particularly high-performance tactical aircraft where the workload is rapidly approaching the limit of pilot capability. The U.S. Air Force, for example, is conducting a number of programs investigating voice-actuated systems and voice synthesis systems as a means for inputting data to the cockpit management system (Porubcansky, 1985). Undoubtedly, however, there have been and will continue to be flow-ons of such technology to civil aviation aircraft. For example, the use of rudimentary voice warning messages to signal emergencies has now existed for 25 years (Wheale, 1983).

Civil aviation aircraft cockpits are considerably less homogeneous than those of modern jet fighters and present ambient noise environments which differ greatly in their adversity to speech communication. Designers of advanced speech technology systems for these aircraft must take into account the fact that their systems, whether for speech synthesis or recognition, will not only be operating in far from optimal noise conditions, but also that these conditions are not constant. User confidence in cockpit speech systems demands that they function reliably under all operational conditions.

Evaluation of speech systems for accuracy, optimal intelligibility and general effectiveness should be performed under realistic airborne conditions. This will entail the on-ground simulation of the cockpit noise environment using spectrally accurate acoustic envelopes produced at in-flight sound pressure levels. As an example of possible inadequacies in current evaluation procedures, recently published research (Wheale, 1983) concerned with the evaluation of voice messages produced by a Votrax synthesizer involved the use of simulated jet-engine noise at a level of 71 dB(A) as a masker. Even at this level, pilots had difficulty understanding the synthesized messages. By contrast, results obtained by the authors from jet aircraft indicate average levels on climb, cruise and descent of about 77 or 78 dB(A), which would require a higher speech presentation level to preserve the same signal-to-noise ratio used in Wheale's study. These differences are likely to impact heavily on the results of such an evaluation. High levels of ambient noise decrease the intelligibility of synthesis systems and tend to increase the error rate of speech-recognition devices. Fortunately, communication difficulty is somewhat reduced, and the potential for speech technology applications increased, by other linguistic and situational constraints on messages. This aspect of the cockpit communication environment is discussed in a companion paper.

A recent research project, (Clark, Kennedy and Koob, 1988), provided a large database relating to cockpit noise and communications within forty-four aircraft commonly used in Australian civil aviation. This database includes overall cockpit sound levels and the associated noise spectra at selected points during the operation of these aircraft.

This data would allow the accurate simulation of the ambient noise experienced by the pilot of a particular aircraft during specified operational conditions. The data also makes it possible to quantify fairly accurately the extent of variation in both noise level and frequency distribution which exists both as a function of a) an aircraft's operational status, and b) its particular classification in the range of aircraft types being used in Australian aviation.

METHOD

Inflight noise measurement and recording procedures

A Technics RD-686DS cassette recorder was used to obtain calibrated, high fidelity audio recordings of cockpit environmental noise, recorded via a Bruel and Kjaer sound pressure level (SPL) meter (type 2209). The sound level meter, with its free-field omnidirectional microphone, was used to make direct observations of cockpit noise levels during the actual time of aircraft operation. With the aid of a flexible extension rod, and consistent with cockpit seating layout and operational requirements, the microphone was located within 30 cm of the pilot's ear near the cockpit centreline. On some flights the microphone was also positioned adjacent to a side and/or front window for short periods. This was to give indications of the variability of noise levels within the cockpit, and also the difference in levels heard by each ear. An elastic suspension cage helped to protect the microphone from vibration. Sound levels were estimated in flight to validate levels calculated later by computer-based spectral analysis of the aircraft noise recordings. Often the time-varying characteristics of the cockpit noise, especially notable in aircraft having out of phase turbo-prop engines, made in-flight sound level estimations fairly subjective, although the difference between the estimations and the computer-calculated level was rarely more than 2dB. An external bandpass filter, designed and built in the S.H.L.R.C., was used to constrain the response of the SPL meter so that it matched the frequency range of the recording and analysing equipment.

The entire recording apparatus was compactly located in a specially designed padded box. This unit could then be unobtrusively situated on the Operator's lap, securely strapped to his seat belt. Located in this position, the microphone was well protected from vibration transmission through the body of the aircraft.

The Operator recorded on a running sheet various aircraft parameters (observed noise level, altitude, RPM, horizontal and vertical speed, barometric pressure) as well as the sound level meter attenuation and the appropriate tape counter numbers. Occasional announcements were also made on to the tape as a further check to avoid confusion when analysing the recordings. Measurements were made during taxiing, take-off, on climb, cruising, on descent and landing. Any other factors likely to influence noise levels (external precipitation, open vents etc.) were also noted.

Computer analysis of cockpit noise recordings

The portions of audio tape to be analysed were selected with reference to notes of in-flight events together with related tape counter numbers which had been made on a running sheet during the aircraft's operations. A comprehensive set of samples was analysed for each aircraft, including, where appropriate; engine tests, taxiing prior to takeoff, waiting for takeoff clearance, takeoff, various altitudes on climb, on cruise, various altitudes on descent, on approach, landing, and taxiing after landing.

The long term spectra of the right (environmental noise) channel of the aircraft recordings were determined in the following manner. The same stereo tape recorder that had been used to make the recordings was used for the playback of the tapes. The multifilter divided the pre-recorded signals into twenty-eight 1/3 -octave bands, channels 14 to 41 (centre frequencies 25 to 12500Hz). Filter levels were preset so that a sample of pink noise on the tape would be analysed at equal levels (tolerance of 1dB) for each band. Each channel was connected to a true root mean square (RMS) convertor which gave out a DC level proportional to the RMS of the input signal. The output was then averaged using the Macquarie University SHLRC Long Term Spectrum Program (V.6.8) with a sampling period of 125ms (see Robinson, 1986). The correct sound level of the recordings was determined with reference to the pre-recorded calibration tone, which had a known level of 124dB when coupled to the B & K 4145 microphone and which was recorded with the SPL meter input attenuator set to 120dB.

Aircraft classification and categorisation

The forty-four aircraft surveyed during the project were divided into three broad classes which subsumed a total of eight categories (see list below). This division was justified on the basis that aircraft within these classes and categories were similar in function and design, made similar operational demands upon their aircrew, and after preliminary inspection of the individual aircraft data, were considered to possess quite similar cockpit noise environments.

Class 1. General Aviation
    Categories
    1. single piston-engined monoplanes (SPEM)
    2. twin piston-engined monoplanes (TPEM)
    3. turbo-prop twin engined monoplanes (TPTEM)

Class 2. Regular Passenger Transport
    4. tail/fuselage mounted turbo-jets (TFMTJ)
    5. wing mounted turbo-jets (WMTJ)

Class 3. Rotary-Wing
    6. light single piston-engine rotary wing (LSPERW)
    7. light single turbo-engine rotary wing (LSTERW)
    8. heavy turbo-shaft rotary wing (HTSRW)

Determination of representative noise levels and spectra for aircraft classes and categories

It was expected that aircraft having similar size, shape, type and number of power-plants would generate similar noise spectra. If this is indeed so, then it would be desirable for speech technology evaluation purposes to know what noise levels and spectra would be representative of all these similar aircraft, and to know to what categories of aircraft such a representation might reasonably be applied. The overall noise level and noise frequency distribution for a group of individual aircraft was thus derived using a facility in the LTS program which enabled the averaging together of the 1/3 octave band level information for a specified flight operation from all surveyed aircraft in the category. A potential problem with this approach is that the averaging of data over a number of aircraft might increasingly smear any distinctive properties in their spectral shape. Peaks of noise within a small frequency range that may be quite distinctive in each individual aircraft become somewhat less distinct when the long term average spectra is calculated for several aircraft, simply because while the spectral shape may be similar, the peak noise levels occur in slightly different frequency bands. This could result in reduced realism for the cockpit environmental noise spectrum. Obviously the more disparate the spectra of individual aircraft the more uniform will be the resulting average noise intensity distribution for the entire class of aircraft.

To examine the extent of this problem, the long term spectra during cruise of 1) an individual aircraft; 2) the category (e.g. single piston - engined monoplanes), and 3) the class (e.g. general aviation) to which the aircraft belongs, were plotted on the same set of axes. This was done for three aircraft (one from each class), which were chosen for the similarity of their overall S.P.L. to the average overall levels for the category and class (less than 2dB difference). Inspection of the graphs, an example of which is shown as Figure 1 (over), revealed that there was good preservation of the spectral shape from individual aircraft through to the class average. Other data demonstrated that when all the surveyed aircraft were ranked according to their overall sound pressure level under cruise conditions, fairly tight groupings of the various categories and classes resulted. In view of this evidence, the averaging of aircraft data from an entire category or class was deemed an acceptable procedure. The desirability of ensuring the representative long term spectrum contained frequency information from all aircraft in the class or category derives from the fact that results of speech technology evaluation under such conditions might then be generalised to a wider number of aircraft.

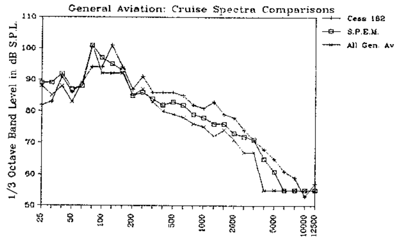
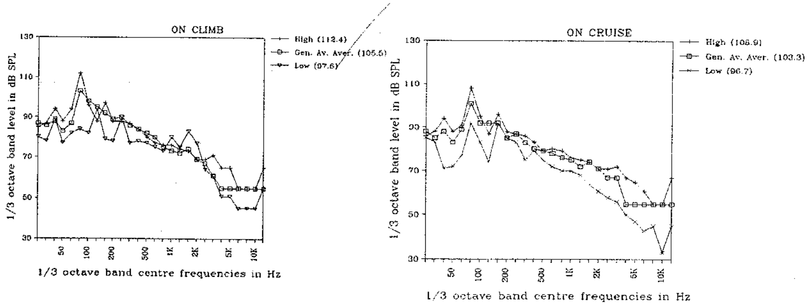


Figure 1. Individual aircraft, category and aviation class spectral comparison for general aviation.

RESULTS OF FLIGHTDECK/COCKPIT NOISE ANALYSES

Long term spectra for aircraft classes and categories

Significant spectral variations occurred in the cockpit noise both between aircraft of different classes, and in the same aircraft during different times of flight. Following are 1/3 octave band level by band centre frequency plots for the aircraft classes during on climb, on cruise and on descent conditions. It can be observed that the frequency distribution of the noise is quite distinct for each class. Also shown are the cockpit noise spectra of the two aircraft in each class which had the highest and lowest overall levels for that particular operational condition. The LTS of these aircraft demonstrate what spectral differences are associated with the maximum sound level differences occurring across an entire aviation class.



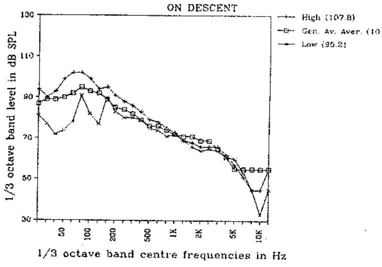


Figure 2. Noise level & spectral variations within general aviation aircraft (clockwise from top left)

a) on climb;

b) on cruise;

c) on descent.

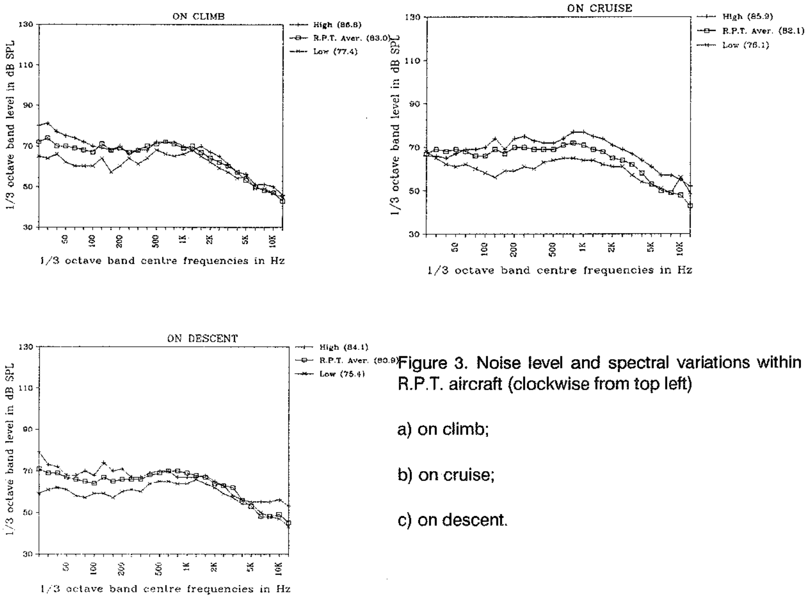


Figure 3. Noise level and spectral variations within R.P.T. aircraft (clockwise from top left)

a) on climb;

b) on cruise;

c) on descent.

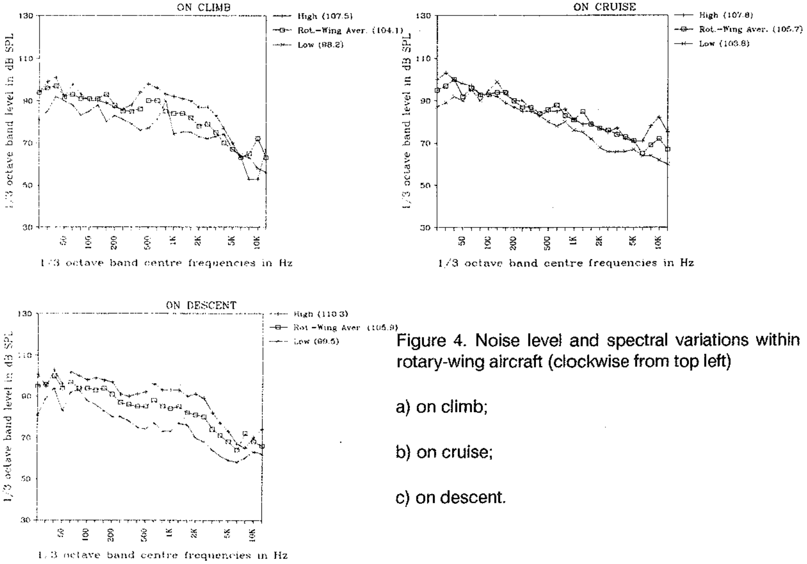


Figure 4. Noise level and spectral variations within rotary-wing aircraft (clockwise from top left)

a) on climb;

b) on cruise;

c) on descent.

Average overall sound levels for selected operational conditions

Overall noise levels were obtained for the eight aircraft categorisations listed previously. Category averages were determined for several distinct aircraft operational conditions. These category results were also averaged together to produce representative data on a number of operational conditions for the aviation class divisions. The aircraft operational conditions and the average dB SPL obtained from the averaging process for the aviation classes are presented below in the form of cockpit noise flight profiles. Category and more detailed individual aircraft flight profiles were shown in a recent report (Clark, Kennedy and Koob, 1988). These profiles plot the overall cockpit noise level against successive operational conditions. Obviously, the operational labels do not convey the length of time at which a particular sound pressure level prevailed, although some attempt was made to indicate the predominance of cruise noise levels by extending their representation on the horizontal axis. These plots indicate when peak noise levels occur, and the extent of variation (excluding transient noise events) in noise levels during a flight.

The flight profile of the three major aircraft classes - R.P.T., rotary-wing and general aviation -highlights the pronounced overall level differences between the noise heard by turbo-jet aircrew and crew of other aircraft, quite apart from consideration of frequency distribution variations in the ambient noise. The profiles for rotary-winged and general aviation aircraft are also quite distinct, although closer in overall levels.

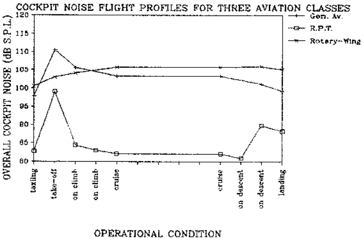


Figure 5. Noise flight profiles - 3 aviation classes.

CONCLUSIONS

This paper has provided acoustical data indicative of the nature of civil aviation aircraft cockpit/flightdeck environments, recourse to which would be of benefit in the design and evaluation of aviation speech technology systems. Speech synthesis, recognition and interactive voice systems must function reliably in a complex noise environment and under wide-ranging operational conditions, and so it is essential that such systems be adequately evaluated. However, there appears to be reasonable justification for the construction of average noise spectrums to represent an aviation class during a particular operation e.g. turbo-jet aircraft on climb. Judging user acceptability and success in the integration of speech systems into the cockpit through on-ground trials depends greatly on accurate simulation of in-flight conditions, the parameters of which need to be derived from a comprehensive acoustical database.

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