COCKPIT NOISE INTENSITY: FIFTEEN SINGLE-ENGINE LIGHT AIRCRAFT

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In the history of measurements of aircraft noise, nearly all of the published work has been devoted to noise under the flight path of large planes, to the exposures received by flight-line personnel, and to the noise in and around military aircraft. Almost nothing has been done about recording noise levels inside civil aircraft. The few reports on airline pilots are equivocal, although the one study[3] that compared cockpit-noise exposures in air transport planes with the latest DRC (damage-risk criterion) curves of Kryter, Ward, Miller, and Eldredge[2] found levels that are potentially damaging. Only two papers have been written on the noise problems in light aircraft (aircraft weighing less than 12,500 pounds). One of these[6] covered some of the same territory that the present paper will; the other[4] dealt only with the specialized kinds of civil aircraft that are used for aerial-application (crop-dusting) work. Because of the vast numbers of light planes presently in use and the large number of people flying in them—there are now nearly two-thirds of a million active civilian pilots—a program of careful measurement and analysis of cockpit noise was undertaken.

In cooperation with the major manufacturers of light, general-aviation aircraft, measurements were taken of the noise levels in the cockpits of fifteen representative models of the most popular, currently manufactured, single-engine light airplanes in the country. The planes tested were essentially similar in their interior configurations—except for one six-place plane, all had four seats. Some had fixed landing gears; some had retractable. Some had fixed-pitch propellers; some had constant-speed (variable-pitch) propellers.

I. Method.

Preliminary measurements suggested that the measured noise in the cockpits of these planes might change as a function of the cruising altitude. Meaningful variations were expected to appear for altitude increments of 4000 feet; if smaller values were selected, time would be wasted, and if larger values were selected, something might be missed. For the part of the country in which the tests were made, 2000 feet MSL (mean sea level) was the lowest indicated altitude that would still keep the planes out of trees and houses. Therefore, measurements were made at 2000, 6000, and 10,000 feet MSL. Most single-engine planes such as were tested here, although they can operate at higher altitudes, usually do not because of the need for supplemental oxygen.

At each of the three altitudes, noise recordings were made at normal cruise power, or if the engine was incapable of maintaining that power—usually 75%—at the higher altitudes, then the highest possible power setting was used.

Because air rushing through the ventilating systems made a meaningful subjective difference, recordings were made at each altitude with all vents open, and also with all vents closed.

In addition to the two recordings made at each of the three altitudes (2000, 6000, and 10,000 feet MSL), recordings were made at takeoff and landing. However, because the objective of this report is to indicate the kinds of continuing noise exposure that the pilots and passengers in light aircraft receive, the levels measured during these short-duration parts of the flight are not reported here. It is worth nothing, though, that the takeoff and landing measurements indicate only slight changes in spectrum, and almost no change in overall level.

II. Apparatus.

The recording and analyzing systems used are illustrated in Figure 1. A Bruel & Kjaer sound-level meter, model 2203, was used both for the specification of levels and as an input transducer. The meter's microphone was held at the height of the pilot's ear, but a minimum of 6 inches from his head. The output of the meter was led to a

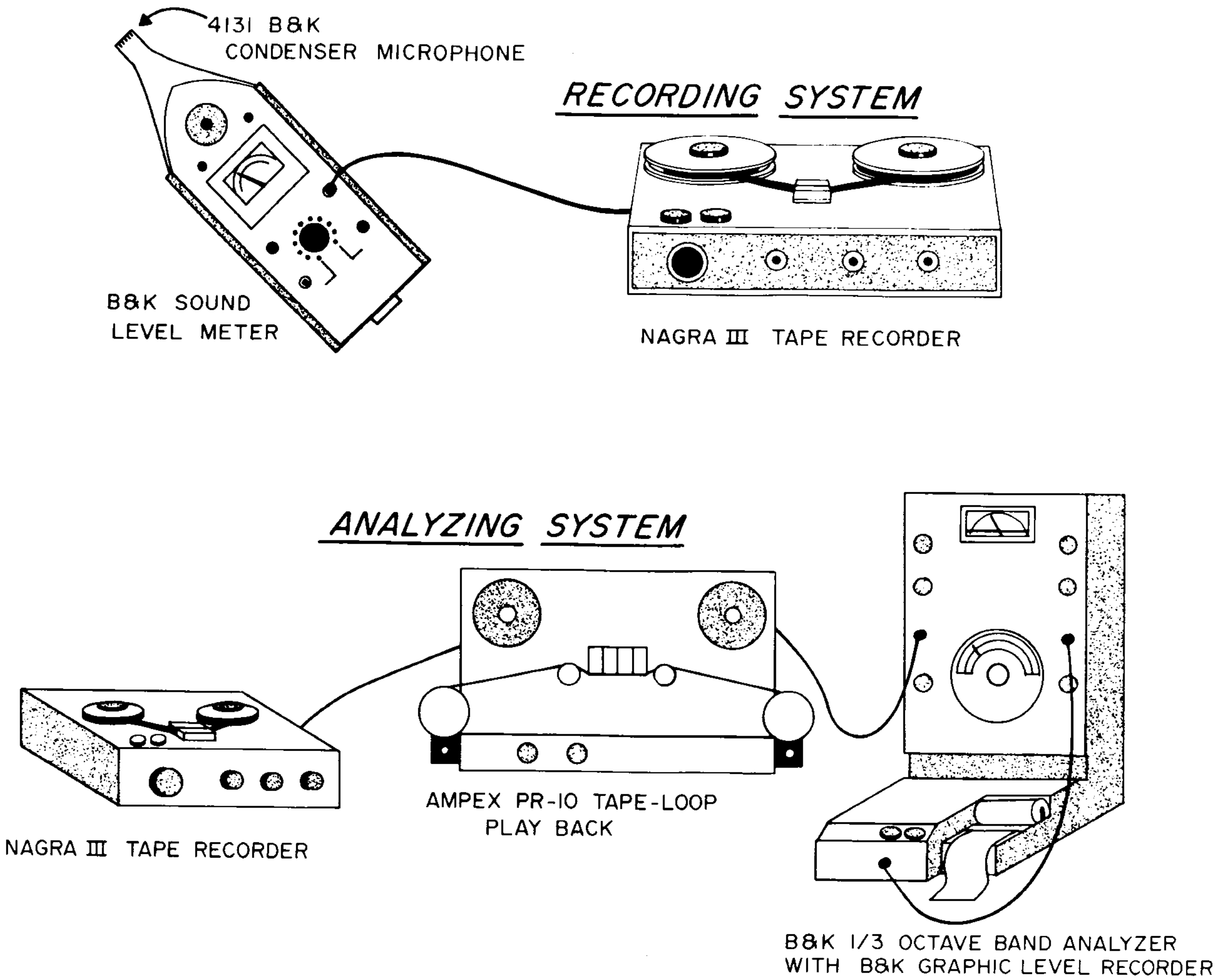

FIGURE 1. Diagrams of the recording and analyzing systems used.

Nagra III tape recorder. The system was calibrated before and after each flight with a Bruel & Kjaer pistonphone, model 4220. This calibration was used not only for the sound-level meter, but also for the amplifiers in the tape recorder. In addition, the tone produced by the pistonphone was recorded as the first 30 seconds of tape so that it was always possible to return to precisely the value of the noise being recorded. Whenever changes were made in the meter's settings, the operator reported the change into the microphone. In that way, all the information necessary for a complete reconstruction of the cockpit noise environment was available once the tape was returned to the laboratory.*

The analyzing system used the same Nagra III tape recorder, but as a playback. The amplified recording was first played into a Bruel & Kjaer graphic level recorder, model 2305, for a continuous record of the overall level throughout the tape. This chart was used in the selection of representative segments for complete analysis. These selected segments were rerecorded on an Ampex PR–10 tape recorder that was modified to handle loops. Ten-second tape loops were then played from the PR–10 into a Bruel & Kjaer, model 2111, third-octave-band analyzer, and from there into the graphic recorder. Third-octave-band analysis was used rather than octave-band analysis in order to produce more accurate profiles of the noise levels, in order to show any

*For those interested in doing similar work, but who are unfamiliar with the physical measurement of acoustic signals, please note that any reliable, wide-range, stable-speed, portable magnetic recorder will do. Even more important is the fact that any sound-level meter that is built in accordance with the American or the International standard is comparable in performance to any other. Thus, data collected with two meters made by two manufacturers will differ no more than data collected with two instruments made by the same company.

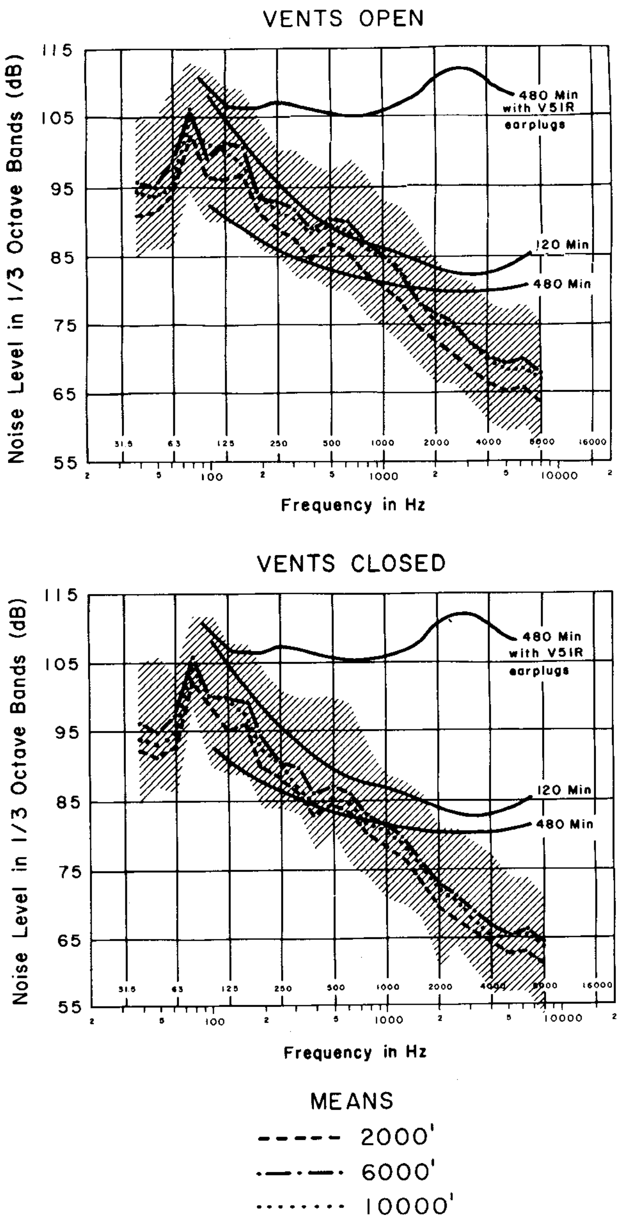

FIGURE 2. Effects of altitude on cockpit noise. 2a shows the mean values for each altitude when the vents were open. 2b shows the values when the vents were closed. The solid lines represent DRC curves.

narrow-band or single-frequency components, and in order to approximate certain critical-band values (the human ear's analysis of complex sounds is similar to that of a third-octave filter through most of the audible range).

III. Results.

In order to illustrate the range of results in the various planes, and in order to protect against misinterpretation of high or low points that occurred in a given plane but might not be totally representative of that model, data from all the analyses were combined. In each figure, then, the hatched area represents the whole range of noise levels (in third-octave bands) measured under the specified conditions for all the aircraft tested.

Thus, all the data collected are presented in Fig. 2. It shows the effect of altitude on cockpit noise. Figure 2a shows all the data taken with open vents; Fig. 2b shows all the data taken with closed vents. The mean values for each of the three altitudes are plotted as dashed and dotted lines. In each case, the level appears just slightly decreased with each increase in altitude; the maximum changes occur at frequencies above 250 Hz. Each 4000-foot increment produces at most a change of 2 dB—somewhat less at most frequencies.

The data are replotted to produce Fig. 3. It shows the effects of ventilation on cockpit noise. Figure 3a shows all the data recorded at 2000 feet MSL; 3b shows the data at 6000 feet; and 3c shows the data at 10,000 feet. The mean values for each of the two vent conditions are plotted as dashed and dotted lines. In each case, the level is somewhat increased when the vents are opened, and again, the maximum changes occur at frequencies above 250 Hz. The maximum change is about 4 dB; the change is somewhat less at most frequencies.

The effect of the type of landing gear is also small. A comparison of fixed- and retractable-gear planes shows the retractable to be quieter—as one would predict—but by only 4 dB at the most. No consistent difference at all can be sensibly attributed to the propeller type (fixed- or variable-pitch).

Through all of these data, the major peaks of intensity remain at about the same frequencies. (There is no evidence of hazardous single-frequency components, however.) This low-frequency similarity results from the fact that the two major noise sources (the engine and the exhaust resonance) have their maximum effects in the same general range: from 50–250 Hz. Changes in air movement, either *in* the cockpit or *around* it are relatively small compared to the constant engine and exhaust noises.

Finally, it is useful to know that the noise levels were similar from plane to plane. No single tested plane could be called quietest or noisiest. In fact, the high limit of noise shown

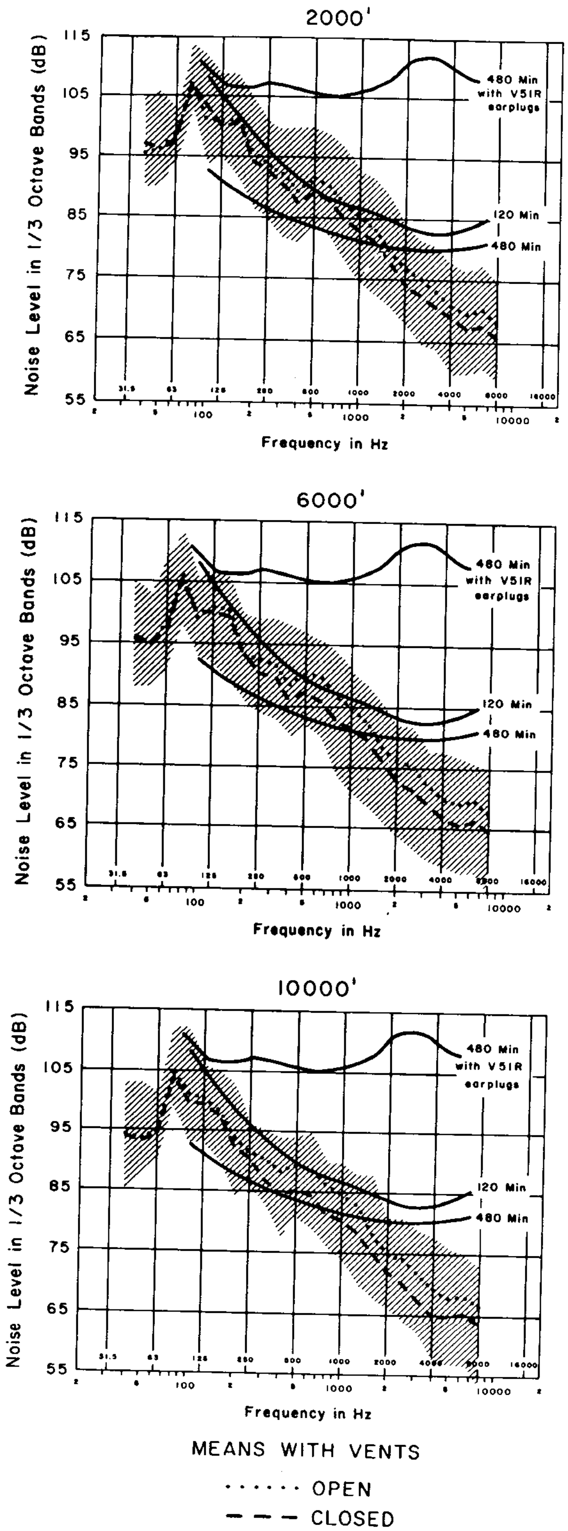

FIGURE 3. Effects of ventilation on cockpit noise. 3a shows the mean values for each condition of ventilation at 2000 feet MSL; 3b shows the same information at 6000 feet; and 3c shows it at 10,000 feet. The solid lines represent DRC curves.

in the figures represents measurements, not from one, but from eight different models. Similarly, the low limit represents measurements from six different planes.

IV. Risk of Damage.

Audiological experience suggests that pilots generally have hearing losses, but evidence to this point is lacking. FAA medical records do not furnish adequate information because so few audiograms are included; a whisper test for hearing is still accepted by the FAA for medical certification. The conclusions drawn here, then, are based in theory, and in the finding[4] that *every* aerial-application pilot tested had some degree of hearing loss.

In Figs. 2 and 3, each of the graphs includes, in addition to the noise-measurement data, three solid lines. They are "damage-risk criterion" (DRC) curves.[2] Each one shows the maximum amount of steady, complex noise that a human observer can listen to once a day, for the time indicated, without incurring permanent damage to his hearing. A noise that exceeds a DRC curve at any point is considered damaging if the listener is exposed for longer each day than the time indicated on the curve.* The DRC

Note that the measured noise levels are excessive. In fact, someone who exposes himself unprotected to such noise intensities for more than 3 or 4 hours a week can expect to experience some irreversible hearing loss in a few years.

The simplest and cheapest solution to this problem is the use of well fitted earplugs. They decrease the damaging effect of noise until it is almost negligible. And earplugs have no adverse effect on the speech-to-noise ratio in the cockpit—not for face-to-face communication, not for loudspeaker communication, and not for communica-

curves are one for noise exposures of eight hours per day, one for exposures of two hours per day, and one for eight-hour exposures when the listener is wearing standard earplugs.**

tion under a headset. Indeed, at the noise levels

*Exposure to a sound whose intensity corresponds *anywhere* with a given DRC curve will produce some permanent hearing loss, but the loss will not have a significant effect on the perception of speech—which is the criterion for determining whether a loss of hearing is "damaging."

**The V–51R is only one of many earplugs available; it is used in this illustration only because data on it are more readily available than on the other popular varieties.

found in this study, the use of earplugs is likely to produce an *improvement* in speech intelligibility.[1] And they may lessen the susceptibility to fatigue from other sources.

Wernick and Tobias[5] found a positive correlation between the amount of auditory fatigue one experiences, and the intensity of mental activity going on during noise exposure. It is possible, then, that pilots, because of the kind of mental effort that flying requires, are even more susceptible to noise than these DRC curves predict. So there is still another reason to protect fliers. The noise emergency never ceases, but earplugs protect against it continuously.

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