EFFECT OF NOISE AND VIBRATION ON MAN

THE prefix, bio-, attached to the names of various disciplines among the physical sciences, is becoming increasingly familiar to workers outside the biological field as the specialties in applied biology increase and multiply. One of the sessions in Section G (Engineering) of the recent British Association Cardiff meeting was entitled "Bio-mechanics" and was devoted to two topics in the field of what the Americans are now calling 'bio-acoustics'. Prof. E. J. Richards, of the Department of Aeronautics and Astronautics, University of Southampton, spoke on "Noise Annoyance and its Assessment", and Flight-Lieut. J. C. Guignard, Royal Air Force Institute of Aviation Medicine, delivered a paper on "Some Effects of Low-Frequency Vibration on Man" under the co-authorship of himself and Mr. A. Irving, who holds a research fellowship at the same Institute. Both papers dealt specifically with aircraft noise and vibration.

Prof. Richards began by emphasizing that the primary function of the human ear is communication, and he defined 'noise' as everything which is heard and which hinders communication. He allowed a fairly wide definition of communication and illustrated with several amusing examples how the labelling of a given sound pattern as 'noise' (that is, 'annoying') depends very largely on circumstances and will vary greatly from one individual or community to another. The annoyance caused by jet aircraft noise is, he said, virtually impossible to establish in scientific units and can only be assessed by the reactions of the population in areas irradiated by the noise. He described the establishment of empirical limits of acceptable noise around airports, based on the incidence of complaints by individuals and organized groups living nearby, and cited American surveys of aircraft noise and public reaction to it during operation of piston-engined aircraft from Idlewild Airport, New York (before the introduction of jet traffic). These surveys were used to establish a figure of 107 decibels as the maximum tolerable overall noise-level, measured at ground-level in the open air.

However, Prof. Richards continued, when jet aeroplanes began to fly overhead producing 107 decibels of noise on the ground, it was soon obvious that this figure was no longer acceptable—owing to the different quality of the noise from jet engines. Prof. Richards then digressed to explain the decibel scale of sound pressure measurement—related to the logarithmic response of the human ear to mean square sound pressure—and went on to stress the fact that the disturbance produced by noise depends very much on the frequency distribution of the sound. This is partly due to the non-linear frequency-response of the human ear, and, in practice, it is found that noises of high pitch are considerably more annoying than equally intense noises of relatively low pitch. Prof. Richards showed the meeting curves of equal subjective loudness, together with curves of equal 'noisiness' (annoyance) for pure tones, obtained by American workers in laboratory studies, and he pointed out that the latter curves were, in effect, weighted against the higher frequencies.

The reason for the greater annoyance produced by the jet aircraft (at a given overall sound pressure-level) lies in its emitting a higher proportion of its

total noise at high frequencies. For example, jet aircraft noise spectra show the highest levels in the frequency-band 600–2,400 c./sec., as against the band 75–300 c./sec. for the propeller aircraft. Prof. Richards described the concept of the 'perceived noise-level' (quoted in *PN* decibels) and its derivation using the subjective 'equal noisiness' data to transform physical sound pressure measurements. The determination of perceived noise-level allows comparisons between noises of differing spectral quality. A criterion of acceptability can therefore be established for jet noise, based on information regarding other types of noise from industrial sources and piston-engined aircraft. It turns out that the acceptable 107 decibels for propeller aircraft at Idlewild is equivalent to 111 *PN* decibels, which is now the standard accepted by the American authorities and to which jet aircraft must conform in populated areas around that aerodrome.

Prof. Richards then described the probable need for revision and modification of currently accepted *PN*-levels as jet operations became more extensive and the characteristics of jet aircraft and their flight envelopes altered. Present methods of minimizing jet noise include the fitting of noise suppressors and the practice of throttling back the engines when passing over built-up areas during the climb. This of course lengthens the climb and, while reducing the intensity of the local noise nuisance, spreads it over a wider area. Prof. Richards recalled that the current standards of acceptable noise were based on reactions to the worst quartile of propeller aircraft operating over a fairly narrow zone, and that jets would cause a more widespread disturbance. (At the present time, however, the worst annoyance is caused by jet airliners frequently breaking the rules for noise reduction on take-off.)

It is anticipated that the number of jet aeroplane movements at London Airport will increase some eight-fold over the next decade or so, involving not only a very high frequency of take-off during the day but also the introduction of more night operations. Prof. Richards considered some of the implications of these trends for the 111 *PN* decibels-limit. It has been found that, when the incidence of complaints from the surrounding population is related to the number of take-offs at different times of day, proportionally more annoyance is caused by noise during the evening hours of wireless and television entertainment and bed-going. It has been suggested, therefore, that a 10 *PN* decibels reduction in allowable noise must be specified for night operations. It will also be necessary to consider the duration and frequency of occurrence of aircraft noises, and some further reduction in the day-time standard may become obligatory as jet traffic grows heavier.

It appears that quite a high proportion of complaints arise from the landing of jet airliners rather than their taking-off and that in many cases (80 per cent in one survey) people who expressed annoyance revealed, directly or indirectly, some element of fear of aircraft crashes. The pattern of noise on landing is different from that on take-off and is probably more alarming, since the aircraft passes lower over the house-tops, the onset of noise is sharper and the sound spectrum often contains discrete

frequency spikes due to compressor whine. A typical jet aircraft throttled back for landing might show a spike of some 15 *PN* decibels amplitude superimposed on the random noise spectrum at about 2,000 c./sec. It is found that noise containing discrete frequency spikes is more disturbing and would require a lower *PN* decibel figure as the maximum acceptable. The 'annoyance penalty' in the example cited would be of the order of 6 *PN* decibels; but Prof. Richards recommended caution in interpreting such figures, since the estimates of penalty due to discrete frequencies are based on laboratory experiments using 'white' noise, whereas the practical *PN* decibel limit is based on studies of propeller aircraft noise which is itself made up of discrete frequency sounds.

Prof. Richards amplified some of the above points in replying to questions asked in discussion, during which a number of speakers expressed alarm at the prospect of the worsening noise nuisance brought about by jet operations. He agreed that what is urgently needed are extensive and well-controlled social surveys of the noise problem. Speaking on the threat of sonic bangs produced by supersonic transport aircraft, Prof. Richards said that, during a typical supersonic flight, free air pressure jumps of the order of 1 lb./sq. ft. must occur over the majority of the flight path. The nuisance value of such bangs was not at all certain but may be great, affecting large populations if supersonic airliners were to fly overland as well as overseas routes. The problem, again, was one of annoyance and its assessment. Individual reactions to impulsive noise were likely to be very variable. The approach was to determine experimentally the limiting tolerable amplitudes of pressure jump, using realistic samples of people in rather the same way that thresholds of annoyance by continuous noise can be determined in the laboratory and in the field. Prof. Richards felt that, while the aeronautical engineer and the acoustician can do much to minimize aircraft noise at source and in transmission, there is still an urgent need for human data which must be provided by the experimental psychologist and the social scientist.

Aircraft noise disturbs a large population outside the aircraft, whereas mechanical vibration as an environmental factor concerns only the people inside it. Published work on the physiological actions of vibration is accordingly much smaller in quantity, less well known, and of less general interest than that on noise and hearing. The paper by Flight-Lieut. J. C. Guignard and Mr. A. Irving described current research at the Royal Air Force Institute of Aviation Medicine, Farnborough, on the effects of very low-frequency vibrations on man. This is, in the first instance, a problem of military aviation. Aircrew can be violently jostled in high-speed flight through turbulence and, again, disturbing intensities of more or less periodic vibration can occur in some types of aircraft—notably helicopters. In civil aviation, it has been predicted that vibration will be a potential nuisance to the passengers and crew in supersonic airliners. These aircraft may have natural modes of oscillation at very low frequencies, easily excited by gusts and being poorly damped at the great altitudes at which supersonic flight is to be made.

After reviewing briefly the biological actions of mechanical vibration (which are in many cases fairly narrowly frequency-dependent), the authors went on to explain the approach they have adopted in their present field. Although in-flight studies of reactions

to turbulence and experiments using dynamic flight simulation have their attractions, the authors favoured the study of human frequency-response to simple sinusoidal vibration. Some reasons were given for this approach, including ease of interpretation and generality of application of the results. The frequency band selected for study was the infra-sonic region (that is, below about 20 c./sec.) in which are excited major aircraft structural modes of vibration, as well as physical resonances in the human body. The lower limit of the band studied was 2 c./sec.

A method of conducting resonance search tests on the human body was described in some detail. One feature which had not been adopted in previous work was careful standardization and control of the subjects' posture (as well as other conditions of vibration) during the tests. Acceleration resonance was measured in seated men at forcing frequencies of approximately 2.4, 4.8 (the dominant response) and 13 c./sec., the latter being detected only as a phase resonance between seat and head. So far, the results showed fair agreement with those of other workers, but the investigation was taken a step further by examining the influence of some physical variables in the conditions of vibration on the resonant response of the body. The influence on resonance of body size, force of vibration (that is, acceleration-amplitude) and muscular tensing were examined and it was found that, while the effects of the first two named were small, tensing modified considerably the man's dynamic response. The tensing manoeuvre, in effect, increased both the damping and the stiffness of the body, reducing the dynamic amplification at resonance and increasing the dominant resonant frequency to nearly 6 c./sec.

The paper ended with an account of a simple experiment of more direct practical interest concerning the degradation of visual and visuo-motor performance by whole-body vibration. Performance was measured in four subjects doing two simple tasks during vertical sinusoidal vibration applied through the seat, the test material remaining at rest. The measure of performance used was the time taken to complete a number of replicates of each task. Five frequencies of vibration were applied, in half-octave increments from 2.4 to 9.5 c./sec. at a constant acceleration-amplitude of 0.25*g*. The presentation of conditions was randomized and performance during vibration was compared with that at rest. Vibration hindered the subjects, and the worst performance in each task was measured at 3.4 c./sec. (which is a rather lower frequency than that of the dominant physical resonance in the body). The authors concluded—very tentatively—that the degradation of visual performance in this experiment was related to the velocity-amplitude of vibration at the subject's head. It was incidentally pointed out that breaking down of fixation of a static target by the eyes during whole-body vibration occurs at about 2 c./sec.

Flight-Lieut. Guignard agreed with comments made in discussion to the effect that vertical vibration was only one component of the acceleration pattern of an aircraft in flight, and also stated that different patterns of resonance could be elicited in the body by, for example, transverse excitation. Most work has been done on vertical vibrators as a matter of custom and convenience, and because the vertical components of low-frequency aircraft vibration were considered to be particularly important.

J. C. GUIGNARD