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Noise at Airports†

by

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Discussion

Mr C. H. Jackson (Assistant Chief Engineer (SD), British Overseas Airways Corporation) said that those concerned with air transport had been very conscious of their social obligations in regard to the problem of noise. As early as 1952 their first draft specifications for an aircraft to succeed the *Comet* had included the reduction of air-to-ground noise as one of the leading criteria. Knowledge of the problem at that time had not been sufficient to enable them to tell the designers what were the criteria of public acceptance, nor could the designers tell them what would be the effects on economics and performance of any attempt to meet hypothetical standards. This had been a difficult position for operators and designers who had then been planning for the late 1950s and early 1960s.

57. In the last five or six years, that position had changed a great deal because of the work of various authorities, including in Britain the Author himself and Lighthill, Greatrex, Bell and others. Operators now felt that they could say that the limits of their social obligations had been defined and that they could comply with them even with aircraft and operations which had been designed and planned before that knowledge had been available.

58. Their problem was to comply with them in safety and with economy. He mentioned safety because the greatest reduction in noise in the neighbourhood of airports came from getting the aircraft as high as possible before passing over residential areas and then reducing engine power as much as possible while over them. That introduced new operational techniques which were neither operationally easy nor popular.

59. The cost of complying with their obligations arose directly from the need on some aircraft to carry the so-called exhaust sound suppressors and also occasionally to restrict aircraft weight by reduction of fuel or payload. They did not often reduce the payload; it was most uneconomic, because the exchange rate between aircraft weight and height and, therefore, noise levels, was poor, so that the practice was employed only in exceptional operational circumstances. Cost considerations could also arise from curfew restrictions on departures and arrivals and from the noise abatement provisions for engine run-ups on maintenance.

60. They did not, of course, quibble about the cost of noise abatement, any more than they would question the cost of safety margins on aircraft structural strength and performance; it was all part of the total job. It was, however, worth noting that the performance and weight costs of noise suppressors on the *Boeing 707* over the life of a fleet was probably equal to the price of one aircraft, and that sort of margin had to be reflected in direct costs and fares.

61. It might be that in embarking on the development of suppressors they had adopted an unnecessarily expensive approach, and perhaps the Author would comment on that? They worsened the take-off and climb performance and they added to the weight of fuel and aircraft for a given payload or journey. The regulatory or safety requirements, however, necessitated take-off and initial climb performance and procedures approaching those now used to lessen the noise over communities. They might have done better

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by obtaining extra margins on aircraft weight and on take-off performance and climb, avoiding the carrying of suppressors. They were not really suppressors; he thought that the Author would call them frequency-shifters rather than noise-suppressors. The discussion of that point led straight to the problem of the quality of noise rather than its intensity, and perhaps the Author would say a little more about this?

62. Mr Jackson had already referred to curfew restrictions. Their task as long-haul operators did not often call for late night or very early morning operations through main or terminal airports, where in general they were able to avoid very severe noise-abatement requirements, though they would appreciate a little more flexibility than they were at present allowed. On long routes, however, they could not avoid night operations through some stations, and if they had to face rigorous noise-abatement requirements such as 100 PNdB the economic penalties could be severe, because of the effects on aircraft utilization or diversion of traffic. They had not so far encountered this problem, probably because residential communities did not yet exist in all potentially critical areas. Nevertheless he welcomed the Author's attention to this point, because there was a tendency to build up residential communities near airports and it was important that such developments should be carefully zoned. It was to be hoped that local authorities would heed the advice of authorities such as the Author, to ensure that as, inevitably, local demands for building development arose they would be zoned in respect of existing and protected airports.

63. Looking to the future, with supersonic aircraft, if ever they arrived, it might be possible, strangely enough, to avoid the worst of the noise problems over communities beyond the airport, partly because of their good climb performance and partly because they might make it possible to dispense with night operations altogether; some operational studies indicated that this was possible. They would, however, produce a bigger problem on the airport and for communities near the airport. If supersonic transport was not introduced it would be necessary to face the problem of very large subsonic aeroplanes with more powerful engines. But there again the safeguard would be that compliance with the airworthiness requirements for take-off and climb, and the procedures now available would safeguard the position of communities beyond the airport if there was proper planning, but there might be a bigger problem on the airport and for people living immediately alongside.

64. It was possible that the worst had been heard of the noise problem over communities beyond the airport, and it might well diminish in importance. The fact must be accepted, however, that future developments might make more difficult the easement of the problems of those who lived immediately alongside the airport, and this pointed also to the importance of the Author's views on airport buildings.

65. A further reservation to be made about the impact of future long-haul aircraft was the likely increase in cargo operations, for which late night departures from the main terminals seemed preferable. This would lead to night operations through commercial transits near industrialized or built-up areas. Designs for new cargo aircraft, however, might cater for this possibility in ways not open to passenger transports, and in any case it was difficult to believe that any new designs could not offer improvements on some of the older piston-engined cargo aircraft that sometimes seemed to grind away over our heads for interminable periods in the night hours.

66. The short-haul operators might have somewhat different problems and he could not speak for them. If they had aircraft designed to take off from the smaller airports in Britain and on the Continent they might be far better placed than the long-haul operators on night operations when using the airports which catered also for inter-continental aircraft.

67. The Author discussed the problems of the maintenance area. Here again as operators they could say that reducing night running or the noise of night running to socially tolerable levels had not introduced operational difficulties, but they had had to accept the cost of mufflers and of earth banks to reduce the noise for nearby communities.

The mufflers were probably the more effective of the two. The costs of such measures should, however, be recognized; air transport seemed destined to aid the growth of the wealth of nations without acquiring much of a profit margin for itself; any extra costs, therefore, were significant, even if only a small proportion of total expenditure.

68. Looking to the future and accepting that there would be more powerfully-engined subsonic aircraft and very powerfully-engined supersonic aeroplanes, they could see a worsening of problems only for the airport itself and for residential communities immediately alongside; but, looking ten years ahead at the possibility of economic developments, new routes and a density of traffic necessitating additional airports, it was timely to emphasize that planning should curb such residential development.

69. The remarks he had made were not intended to infer that noise was no longer a major consideration for the operator. He was saying only that the operators were better placed now that some standards had been defined. The operators still did not like the operational procedures which were made necessary and could only hope that compliance would be easier with future aircraft. The Author suggested planning for more rigorous noise abatement requirements, if only because of the future flow of traffic, but the interpretation of current experience did not necessarily indicate such a need. The increasing traffic could indicate increasing community acceptance of all that the aircraft offered for personal pleasure, as on holidays, for the expansion of commercial activities, and for affairs of State. Such acceptance might well be balanced against any trend to set more rigorous standards than were apparently now acceptable.

Mr P. B. Edwards (Senior Engineer, Scott & Wilson, Kirkpatrick & Partners) was with consulting engineers who had been associated with the problems arising from the development of a new office block for British European Airways at London Airport. He thought it might be of interest if he were briefly to outline the tests which they had carried out, in conjunction with their clients and with the Building Research Station, in 1957 to determine the effects of noise—how much would arrive at the site, how much could be tolerated inside the building, and, therefore, how much would have to be excluded by the fabric of the building.

71. The new office block was sited about 1,100 ft from the eastern end of Runway 5 at London Airport and was therefore within the PNdb 120 contour. The building was also close to the maintenance apron of the adjoining hangars, where engine tests were carried out from time to time. The initial object of the test had been, first using a turbo-prop aircraft and then a turbo-jet aircraft, to produce a variable scale of noise so as to subject observers to noise conditions which would vary from an acceptable level to an intolerable level. But it had been felt that the position of the aircraft relative to the observation point was of little significance; all that mattered was that enough noise could be obtained to achieve the desired conditions. For the same reason, the nature of the building used for the observations was unimportant.

72. In a room next to the observation point, an observer received through a normal G.P.O. telephone a succession of suitably selected words, unconnected in meaning, which he recorded. It had been found that the syllabic articulation deteriorated very steeply at a point at which the observers judged the noise to be no longer acceptable. Immediately before that, 80–90% correct results had been achieved and if sentences had been used the percentage might have been higher.

73. Some general comments on the observers' reactions might be of interest. Apart from the more severe judgement recorded against turbo-jet aircraft (the *Comet 2* in this instance), remarks such as "appalling" and "terrifying" had been made even with the aircraft 1,100 ft away from the observation place. The general verbal comment suggested that it was the low-frequency vibrations which produced this sort of reaction. Parts of the building, the windows, the heating installation and so on vibrated in sympathy and added to the general effect.

74. It had been decided that the phon scale should be used to record the results,

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because it seemed to correlate as satisfactorily with the subjective ratings as any single scale that could have been used, and indicated true loudness as well. Loudness levels of 70, 80 and 90 phons seemed to be the approximate dividing lines between the four ratings of disturbance, as could be seen from Fig. 23.

75. Double glazing had been adopted, because it was felt that by the time the limit of the noise which was acceptable (80 phons) had been reached, any noise above that level would probably be only of short duration and not so detrimental to the staff working in the building.

FIG. 23.—RESULTS OF TESTS AT LONDON AIRPORT IN 1957, ORGANIZED BY SCOTT & WILSON, KIRKPATRICK & PARTNERS, AND THE D.S.I.R. BUILDING RESEARCH STATION

76. In fact the conditions in the building were much more satisfactory than had been expected when the tests were carried out. With 9-in. solid precast concrete external walls, with the joints caulked and sealed with mastic, and with double windows with two $\frac{3}{4}$ -in. panes of glass in metal frames, the conditions in the offices were such that the ambient noise level of the unoccupied office was 43 db and the occupied noise level when the building was in use was approximately 55 db. The building was air-conditioned, and the plant provided a noise level of 55 db, equivalent to the normal occupied level of noise. An interesting fact was that the ambient noise level being so low, the internal inter-office noise became predominant. If the unoccupied noise level had been brought up from 43 to 55 db the inter-office noise would not have been so noticeable.

77. All this served to point out that the technique of providing insulation for buildings against external noise was not a simple one of keeping it out as much as possible but of deciding upon a balance between the noise level created by the occupation of the building and the external noise which could be satisfactorily admitted through the cladding.

Dr G. E. Bell (sometime Head of Operational Research at the Ministry of Aviation) pointed out that airports presented very difficult problems as regards noise. The airport had to be located near the city to be served, and this meant that there were almost inevitably residential areas near. Often, with suitable planning, it was possible to mitigate the effects to some extent; for example, in Britain, with the prevailing wind in a westerly direction, it was a distinct advantage to have the airport to the north or south

of the city, so as to minimize over-flying. This was in fact so at Gatwick Airport, where also there was advantageous zoning that put an industrial area between the airport and the main residential areas, thus reducing substantially the trouble due to noise at the engineering base.

79. The human aspects of noise were by no means fully understood, and there was consequently great difficulty in defining noise limits. Prof. Richards had mentioned most of the particular troubles, but it was by no means certain that the same criteria were applicable to every individual. At airports in the United Kingdom a criterion of 110 db of perceived noise had been adopted as a reasonable limit, comparable to the maximum noises experienced just before the introduction of heavy turbo-jet aircraft: it was not, however, held that this was an acceptable standard of noise—in fact it was almost certainly too high—but it did represent about the best that could be done at the moment, and did ensure that the position would not continue to get worse. At U.K. airports there were also many regulations concerning, for example, the times and conditions at which engines might be run for non-operational purposes that collectively did do much to reduce the troubles.

80. With regard to schools and the like, there was the fundamental difficulty that good natural light and ventilation were inconsistent with good sound-reducing properties, a problem that was not by any means restricted to aircraft noise.

Mr N. Fleming (formerly of the National Physical Laboratory) commented on two points out of the large number that the Author had covered. In connexion with ground mufflers, he said in § 53 that “The financial return for successful research into ground mufflers has not been realized as yet, either by government or industry.” Mr Fleming was ignorant of the financial return, but would agree with the Author if the implication was that more development work was needed. That was not to say, however, that a great deal of development work had not already been done. In the latter half of the 1940s and in the early 1950s, when jet engines were growing in size and in numbers, and the need for silencing of jet engine test-houses was becoming increasingly important, a certain amount of *ad hoc* experimentation had been sponsored by, he thought, the Ministry of Aircraft Production, as it then was, and he had been concerned at that time at the National Physical Laboratory with noise measurements made at various sites on the devices which had been developed.

82. From those experiments the general principles which were embodied in the Author's muffler, shown in Fig. 14, had become evident, namely, the need for diffusion and final discharge at a low velocity, the need for absorption of the noises produced both by the mixing of the jet with the air and the passage of the gases through the muffler, and the need for special precautions to suppress noise coming through the walls of the muffler.

83. One of the major differences between the Author's muffler and the ground mufflers which were perhaps most commonly used in this country was in the shape of the final orifice, a long rectangular orifice in the Author's muffler as compared with a circular or square orifice. The rectangular shape of the orifice should give improved performance at the low frequencies, both because it would limit the production of low-frequency noise at the orifice and because it provided an orifice of lower efficiency of radiation of the noise which had already been produced inside. Mr Fleming recalled only one test-house silencing device which incorporated such a shape of orifice. It had certainly been good at low frequencies, but the design had not been proceeded with, possibly because it had not been satisfactory in other respects and also because at that period the low-frequency noise had not been so important as it had become with the increasing size of jet engines. With increasing mass flow the size of the muffler had had to be increased, the final orifice had become bigger and more low-frequency noise was produced. In at least one case, where the muffler had a square orifice of something like 10 ft side, the noise from the muffler at sub-audible frequencies had been greater than the noise without the muffler. These sub-audible frequencies did not, of course,

add to the loudness of the noise, the effect of the noise on the ear, but they could be a source of complaints of vibration in structures at a distance from the silencer.

84. He was interested, therefore, in the effect of this rectangular shape of orifice and would like to ask what was the scale of the model for which the test results were given in Fig. 16 and whether or not a full-scale muffler of this form had been tested, and if so, with what results?

85. His second point was a small one in connexion with sound insulation and the statement in § 33 that a single $\frac{1}{4}$ -in. glass wall would suffice to give 30 db attenuation in the 150–300 cycles/sec frequency range. That was rather misleading. Fig. 9, with the curve of sound insulation against weight per unit area, which showed a figure of 30 db for $\frac{1}{4}$ -in. glass, referred (though this was not stated in the text of the Paper, and it was even difficult to find it in the original reference from which the Author had taken it) to average sound insulation for a frequency range from 125 to 4,000 cycles/sec, and, since the sound insulation increased with increase in frequency, that average value was considerably higher than the value at about 200 cycles/sec. In fact $\frac{1}{4}$ -in. glass at 200 cycles/sec would have a transmission loss of about 22 db and it would require something like $\frac{3}{8}$ -in. glass to give a figure of 30 db.

Wing-Commander T. R. Cave-Browne-Cave (Consultant, Expanded Metal Co. Ltd, and Professor Emeritus of Southampton University) also referring to ground mufflers, said that the Author referred in the Paper to the results achieved by a model of the silencer in which he was interested. It was important to know whether the model/full-scale relationship was comparatively simple and satisfactory, because the difficulty and delays of dealing with ground muffler development on full scale were great. If it was possible to carry out many of the basic experiments on a model scale it would be very useful. He would be grateful, therefore, if the Author would describe how this relationship could be established.

87. The Author was inclined to reject the ground muffler on the argument that the noise which came out of the jet pipe exceeded the noise which came forward from the compressor intake only by 20 db or so, and therefore, provided the muffler would take 25 db out of the jet discharge, that was all that was wanted. That seemed to be an over-simplification. The noise which came from the compressor was high-frequency and the noise which came from the jet discharge had a very much larger low-frequency content. High-frequency noise was very objectionable, but it could be very effectively dealt with by ear muffs and by building construction and did not travel so far as low-frequency noise.

88. It was the low frequency which mattered because it reached the greater number of sufferers. He would be glad to have the Author's view on this, because it was extremely important to know what wavelength it was most important to reduce. The most important and difficult wavelength from the ground muffler point of view was that below, say, 1,000 cycles/sec.

89. In the development of ground mufflers, the most difficult factor was, he thought, the temperature of the gas. That did not appear, at all, on the model. Many people did not realize that the temperature achieved in the discharge gas of a normal jet developing full thrust was what the visual scale described as "bright red". Going further on to the re-heat condition, where additional fuel was burned in the jet discharge and there was still higher velocity, the temperature achieved was "bright white". The visual scale went no higher than "bright white". The difficulty of devising any form of equipment which would stand up to those very high temperatures was great. The way in which it was normally done was to admit a considerable amount of dilution air round the outside of the jet as it came from the jet mouth and went into the mouth of the muffler. In order to produce a considerable reduction of temperature it was necessary to introduce a large amount of air, that necessitated a large annular clearance; and, of course, the amount of noise that came back through that gap was very large. If the orifice was made as some form of Venturi, with a very high speed in the throat of the

Venturi, the static pressure beyond it was less than atmospheric and that was unduly favourable to the engine under test.

90. There was another way of avoiding high temperature and that was to use water. As a cooling agent, air was not very good because it occupied a large volume and had low specific heat; but water had high latent heat, and therefore absorbed a large amount of heat for a given volume of steam formed. The amount of water necessary to reduce the temperature of the jet gas from its "bright red" or "bright white" temperature down to, say, 100°C, was not unreasonably great. They had carried out experiments in which they had succeeded in reducing the temperature of a full-scale jet down to 100°C, and the amount of water involved was not prohibitive. Everything depended on the way in which the water was introduced; it had to be introduced in a carefully-thought-out and intelligent way. If that were done, however, it was possible to cool the gas down very greatly in apparatus of reasonable size and with a reasonable amount of water.

91. A figure which could be obtained quite simply by calculation was this. If one could manage effectively to introduce into the jet of an engine, such as that in a *Hunter*, enough water to cool it down to 100°C, the reduction of volume of the gas was to 50% of the volume of the gas as it left the jet. That meant that the volume of gas which had to be dealt with in the acoustic section of the muffler was only 50% of the jet volume with which it started. If one went on to the re-heat condition and had to deal with gas at that extremely high temperature more water would be required, but it would still be possible to get the volume of that jet gas, plus, of course, the steam that was put into it, down to 70%.

92. With this reduction of the volume of gas to be dealt with to 50%, and the temperature of the gas which had to be dealt with to 100°C, the problem of the jet muffler became entirely different. It would then be possible to use more or less conventional methods of noise reduction, which, of course, had been very highly developed for ordinary temperature conditions. He thought that it ought to be possible to achieve a very high degree of noise reduction in apparatus of reasonable size, employing no special metals or acoustic materials to absorb it. Everything depended on success in cooling the gas down to these low temperatures by water. They had made full-scale tests which showed that it could be done, but they were very anxious to repeat them under critical observation.

Mr N. J. Payne (Partner, F. S. Snow and Partners) said that it was rare, for the airport designer to be given such an aid as this Paper, in which the problems were dealt with so fully and with such excellent references.

94. In his view they were really concerned only with jet noise and not with the noise from piston engines, because the era of the piston engine was passing. That led him to make a point about which he wished to avoid misunderstanding. Fig. 21 showed a finger at Gatwick Airport, a structure with which he had been intimately concerned. That finger had not been designed to resist the kind of noise now expected from jet aircraft of any type manoeuvring alongside. At the time of design, the steel framework had been arranged to provide resistance to jet blast, but the light-weight glazing and cladding would not be sufficient to meet modern requirements. The Author had mentioned that it was possible that Gatwick would be a Continental airport. It was already known that short-haul and medium-haul aircraft coming to Gatwick would require to manoeuvre alongside, and this would entail alterations to the cladding of the structure rather than to the structure itself.

95. In § 28 reference was made to noise from aircraft on the ground. A good deal had already been said about jet mufflers and the attenuation which could be obtained from them, but a project with which Mr Payne's firm had been concerned recently was such that their clients did not consider that mufflers alone would be sufficient to satisfy the needs of the airport authority. At London the airport authority required that the noise at any time should not exceed the ambient, and that meant that his firm's clients were put to considerable expense in dealing with the problem of the ground running of

aircraft engines even at low power run-ups. His firm had recently completed a relatively large civil engineering project for them in that connexion.

96. He was not an expert on mufflers, but it might be of assistance to those who had been discussing the matter to comment on the particular type of muffler installations installed on this project. It was important to remember that to overcome the noise problem and to meet the levels now laid down by the authorities an airline had to embark on a very large expenditure. Fig. 20 showing Gatwick airport was of great interest to him, because he had had a tremendous amount to do with this airport. Following up Dr Bell's remarks, the area shown as residential to the south of the runway had been developed as an industrial area. It had been, for reasons other than noise problems, completely impossible to develop what Dr Bell had referred to as the industrial area in any way whatever, and it was virtually sterile apart from certain terminal building developments. The residential area to the north could be developed if there was only one runway, but it was likely that at Gatwick two runways would be provided, and then that area would be pushed even further north and probably merged with Horley; moreover the scheme took account only of take-offs in certain directions.

97. In § 16 reference was made to the absorption of noise travelling over a grass surface. In earlier discussions concerning noise at airports, civil engineers had heard a great deal of value attributed to the absorption contributed by large areas of trees. It seemed to him that if measurable absorption was found on account of grass there might be something to be said for trees and that it might be true that there was some value in a large belt of trees round an airport.

Mr J. L. Rodger (Senior Engineer, F. S. Snow and Partners) suggested that while there were adequate scientific methods of measuring noise or sound, there was no equally scientific method of recording the reactions of people to it. It was not possible to draw up a code of practice to define generally acceptable limits. One of the variants on which more information was needed was the effect of meteorological conditions on, for instance, the sound contours which the Author had shown and on which he had based certain recommendations. It was probable that in the planning of new airports the sound nuisance round the airport would be of less consequence than that caused by sound generated on the airport itself. He said that, because obviously in choosing the site for a new airport the knowledge now available of jet noise could be taken into account for positioning the runway and associated installations, and development after the construction of the airport could be controlled. He believed this was being done at Paris (Orly) where construction was not allowed within the 100-db contour. In Britain a similar restriction was already in existence, not governed by noise, to designate the public safety zone which limited the development within the approach funnels to a runway.

99. Mr Rodger wished to take further the points mentioned by Mr Payne with regard to the Author's recommendations for the development of Gatwick airport (Fig. 20). The centres of population were to the south in Crawley and Three Bridges and to the north in Horley, and there were isolated communities in other places. Even taking account of the limitations mentioned by the Author in making his recommendations, Mr Rodger still said it was wrong to base the recommendations for residential and industrial development on these noise contours, partly because they showed only one condition, namely take-off and landing to the west. They did not take into account one of the major sources of complaint at Gatwick (fortunately there were not many complaints there) which was the maintenance-area noise. The position of this area was shown on the map. This generated a good deal of noise through running up of aircraft and would rule out the possibility of a residential area in the vicinity. Meteorological conditions would also affect the position of the noise contours.

100. On the landing approach side the decibal contours in Fig. 20 were not given a value, but the Author recommended industrial development in the area shown. Apart from the fact that Crawley and Horley would never allow their two areas to be joined,

why put industry into a high noise area at all? Associated with industry there were always offices and other sedentary activities. The place for industry was not in a high-noise area.

101. That led him to another point on which he would like the Author to comment. Very little was known about the relationship between noise and vibration. Mr Rodger mentioned this because he believed that Dr Bell was aware of a problem which had already arisen at the end of the runway at Gatwick, where there was a small factory producing sensitive components. The complaint there was associated not directly with the noise of aircraft but more with the vibration caused by the aircraft during take-off. It would be interesting to have more information about vibration in relation to noise.

102. Other recommendations by the Author were ruled out by the need for a second runway north of and parallel to the existing one, and possibly a maintenance area to the north of that.

103. The Paper appeared to concentrate particularly on jet noise. Mr Rodger agreed that this was the most likely cause of future complaint, but it was not the only cause of complaint. The *Viscount*, at Gatwick at any rate, still caused a few complaints from the local residents living near the maintenance area.

104. It was probable that in the future helicopters would be used both for inter-airport and city-airport transport. As was known from recent experiments, the noise level associated with helicopter take-off and landing could reach the grading of "intolerable" at as much as 1,000 to 2,000 ft from the take-off point. That was something to be borne in mind in planning a future terminal area.

105. With regard to the terminal area itself, the noise source generally was associated with the aircraft achieving break-away from a stationary position on a self-maneuvring stand. To do that it could use as much as 8% of the all-up weight as a breakaway thrust. There were two solutions in the terminal area, first, to stop the noise occurring, secondly, the expensive solution of sound-proofing the terminal building, reducing the amount of glazing, increasing the air conditioning and so on. The former solution could be achieved by the use of nose-in parking of the aircraft which would reduce both the noise nuisance and the associated blast problem.

Mr R. H. Laver (Facilities Officer, Engineering and Maintenance; British Overseas Airways Corporation) said that his colleague Mr Jackson had referred to some of the problems of B.O.A.C. in operating jet aircraft from London Airport. In particular his own contribution would be concerned with the ground operation of aircraft at London as distinct from the take-off and flight problems of which Mr Jackson had spoken.

107. In § 33 the Author commented on the towing of aircraft and said that the procedure might be acceptable to the long-haul operator. In fact B.O.A.C. had been faced with a situation where they had had to do this at London Airport, but they did not like it. It prolonged the departure time and passengers hated to be delayed on departure; the Corporation also disliked it. It might be necessary, but it was not normally acceptable.

108. On the use of ear protectors, B.O.A.C. had used British manufactured, Canadian-designed liquid-seal ear protectors, and these had proved exceptionally efficient for fitters working around the aircraft. He had used them himself within about 6 ft of some of the largest jet engines in use today when running at full power, and, though he had felt a little shaking in his stomach, particularly from the low-frequency noise, so far as his ears were concerned, the protectors had been effective.

109. On the question of maintenance-area noises generally, it was not practicable for B.O.A.C. to limit their engine ground running to daytime only. It would be very nice if they could, but passengers preferred to travel during normal working hours, which meant that a good deal of maintenance had to be done at night. He imagined that with the coming of supersonic aircraft it would be necessary to contemplate doing even more maintenance at night, so that the aircraft could be flown and earn revenue in the daytime, when travelling was more acceptable to the public.

110. Reduction of ground noise by correct alignment of aircraft was a possibility of which it was worth taking advantage. In the slide which Mr Payne had shown of an engine "run-up" area, account had been taken of this. Mr Payne had also referred to the subject of screens. It had been B.O.A.C.'s experience that earth banks did not give very good value for the money which had to be spent in constructing them. They had to be very high to be worth while and the optimum height around an airport at reasonable cost was about 30 ft. At that height the sound shadow was not very great; at a distance of 1,500 ft it would give something like 5 db, or 8 db overall reduction, and he did not think this was worth the cost.

111. In § 49 the Author commented on "hush houses". He probably knew of those used in the U.S.A., primarily by aircraft manufacturers, and also the only one Mr Laver knew of used by an aircraft operator, the Scandinavian Airlines System, which had one at Bromma Airport, Stockholm for their *Caravelle* aircraft. In designing such a structure care must be taken not to set up sympathetic vibration of the aircraft structure, which could happen very easily, and thereby cause early fatigue failure of some part of that structure.

112. On the subject of jet exhaust noises, Mr Payne had shown a slide of the muffler installation in the B.O.A.C. maintenance area. They had altogether 12 mufflers for *Boeing 707* and *Comet* aircraft and they had made provision for the *V.C. 10* by including a sub-structure under the concrete.

113. It depended on weather conditions—wind, temperature and humidity—what noise reduction was obtained from the mufflers but between 18 and 23 db overall at take-off power for the *Boeing 707* was the best that had been achieved with these devices as they were known today. From 28 to 30 db overall reduction had been achieved with the *Comet* when using mufflers.

114. A point which Mr Laver wished to emphasize—no doubt the Author had given much thought to it—was air-intake noise. This was now their biggest problem; noise from the air intake had given them a great deal of trouble. They were currently investigating it with one company and only trials would tell the effect of intake suppressors on both noise reduction and engine performance.

115. In § 51 the technique for using mufflers was referred to. All B.O.A.C.'s 12 mufflers were of the fixed type, trials with mobile mufflers had not been successful since it had been necessary to move two mufflers to the *Comet* and four to the *Boeing 707* every time the engines were to be run. It was much easier to move the aircraft to the mufflers, also the mufflers must be tied down or they would blow away, and that had happened with one weighing 26 tons.

116. The Author mentioned light-weight mufflers. B.O.A.C. were very anxious to use these if a successful one could be produced. Experience had been that light-weight units tended to be buffeted by the bigger engines having 18,000 to 20,000 lb static thrust, and they had not proved suitable for such large engines.

117. With regard to maintenance and the relatively short life of light-weight structures, B.O.A.C. liked to buy devices which would last for the whole life of the aircraft, say 10 years. They did not want, after 8 years, to have to buy a new set of mufflers, and it was likely that light-weight mufflers would be completely useless by then. Furthermore, from observation they had come to the conclusion that light-weight units did not attenuate so efficiently as the heavier and more permanent mufflers.

118. Wing Commander Cave-Browne-Cave had mentioned the use of water-cooling. Mr Laver appreciated its advantages, but it had many disadvantages. Air was free, but very often water was not.

119. Finally, to re-emphasize something that Mr Jackson had said, B.O.A.C. took very seriously their responsibility to the community in the matter of the reduction of noise, and they had spent something like £1,500,000 on ground installations and associated constructional work to deal with this problem. If noise had not been a problem, B.O.A.C. could have saved a great deal of money. He agreed with the Author that noise

reduction was a question of cost and suggested that the law of diminishing returns applied very strongly above about 30 db reduction.

Mr C. H. Jackson, thanking the Chairman for allowing him to make a brief additional comment, emphasized that they could not afford to be parochial in dealing with this problem. The problem at London Airport, or at any particular airport, was simpler only in that it could be defined for dealing with noise on the airport itself and in its buildings. The problem which defeated them, and was not under their control, was that of the fringe beyond the airport; elsewhere he thought that they might have experienced the worst of this problem, given continued acceptance of the criteria to which the Author referred of about 110 PDnb during the day and about 100 at night. However, as the economies of the newly emerging nations developed, there could be a tendency for such restrictions to be introduced more widely, and they could only ask civil engineers who were concerned with airport projects in the developing countries to be aware of the importance of the zoning of communities beyond and adjacent to the airport.

121. He had been concerned that both the Author and Dr Bell had referred, almost as an aside, to the possibility of requirements in the future being even more severe than they were at the moment. No miracles were to be expected in the development of aircraft, and compliance with very much stricter requirements would be either not possible for technical reasons or very demanding economically and possibly such as to cause added difficulty of operational procedures. The need must be recognized to zone areas industrially and residentially and the obligations of the civil engineer therefore could extend beyond airport construction.

Mr R. T. Davies (Principal Assistant Engineer, Luton Borough Council) observed that there was general awareness of the incompatibility of two desires in the planning of new airports. In the first place, that the airport should be near to the centres of population for obvious reasons of access and so on, and secondly, that the noise problem should be overcome. In that connexion he would like to ask the Author to elaborate on the significance of the figures of 110 PNdb in the daytime and 100 at night. Would those limits prevent complaints from the public, or could complaints be expected in any case?

The following contributions were received in writing:

Mr W. J. O. Scott (Principal Scientific Officer, D.S.I.R. Road Research Laboratory) wrote as a member of the Institution who happened to live on the fringe of London Airport in the area of intense noise indicated by the Author in Fig 17. His comment was therefore first-hand experience.

124. He found it difficult to select appropriate descriptive terms but he could assure all concerned that the noise conditions were absolutely appalling. The noise level customarily described by physicists as the "threshold of pain" was very frequently exceeded every day. Such intensities were known to be positively harmful; quite populous neighbouring areas were thus affected. It was therefore deplorable that major public authorities should have so gravely neglected their responsibilities as to permit such conditions to arise.

125. Professor Richards quoted an estimate that 40,000 people in the vicinity of London Airport were subjected to excessive noise. But the accepted noise tolerance level was about 75 to 80 db so it was hardly surprising, as was common knowledge, that complaints of excessive noise arose in large volume in areas several miles from London Airport such as Slough (population 77,000) and Windsor (27,000) in the west, Richmond (42,000) and Barnes (39,000) on the east side—without mentioning intervening areas, so that the lives of something like half a million people were affected by objectionable noise due to aircraft. This, it must be remembered, was for only one airport out of many where jet-engined aircraft operated, or desired to operate in the future.

126. The inescapable question therefore arose "Is it rational to subject continuously a considerable proportion of the country's population to serious interference due to noise throughout their lives, and to some degree of physical and/or mental harm in many cases, so that an extremely small proportion of their fellow citizens can very occasionally travel a little more quickly by air than they did previously?" There could surely only be one answer in a nation or world which called itself civilized. Yet both the question and the rational answer seemed to have been carefully, or carelessly, avoided by the responsible authorities. The only sign of wisdom had emanated from Norway where the people of Oslo had insisted that they would not have noisy aircraft overhead—at night, at any rate.

127. The internal-combustion-engined road vehicle was required to be silenced from the early days of its inception. There was no logical reason why civil aircraft should not be subject to similar reasonable requirements. The aircraft-developing countries, necessarily the world's leading nations, were all equally guilty of pursuing an irresponsible policy, in defiance of the only rational conclusion, viz., that the unsilenced jet-engined aircraft was an unacceptable device in a civilized world. International consultation and recognition of this fundamental truth were called for before the situation got out of hand. Grave signs of an intolerable situation were already evidenced by the attention being given to the development of aircraft intended to operate at supersonic speeds. Their operation was envisaged, apparently regardless of the fact that the entire population on the surface of the globe would be subjected to an incessant succession of supersonic "bangs", with their attendant consequences. This ought to be unthinkable, yet the expenditure of fantastic sums of money was calmly contemplated—with the very questionable objective of almost insignificant reductions in travelling time for an extremely minute number of persons. It was pertinent to recollect the terms of the Institution's Charter and that it existed to promote "the art of directing the Great Sources of Power in Nature for the use and convenience of man"; in this light, the proposed vast expenditures by leading nations on the development of supersonic aircraft for quite disproportionately small benefits to mankind could only be regarded as a wasteful misdirection of scientific effort, especially when it was considered that two-thirds of the world's population was undernourished.

Mr J. N. McFeeters (Engineering Department, BP Trading Limited) offered a marginal note to the latter part of Professor Richards's Paper derived from the design of establishments for engine testing where the firms concerned, such as Rolls-Royce, Bristol Aeroplane Co., de Havilland, Metropolitan Vickers, had to test their engines at their main centres of production, usually in built-up areas, some at the margins of airfields.

129. For propeller engines, there were two principal sorts of testing, propeller swinging and dynamometer testing. Propeller swinging was largely for the endurance or acceptance tests of new or reconditioned engines. Dynamometer testing tended to be confined to development engines because of the valuable equipment employed.

130. The principal requirement for propeller swinging was to provide for the large volumes of air displaced by the propeller, demanding large open areas at the intake and slip-stream ends of the hangar. Dynamometer testing had no such requirement and, for oil-cooled engines, all that was necessary was for the exhaust gases to be carried outside a closed building where they could be dealt with by a giant silencer similar in principle to the type used on motor cars. The silencing of hangars for propeller swinging was done by "splitters". This term meant a labyrinth, perhaps 25 ft long, constructed of acoustical panelling. The noise inside such a hangar might be 125 decibels—outside the splitters, 80 or 90 decibels.

131. Two types of hangar for propeller swinging were sketched (Figs. 24a and 24b) and it was interesting to compare their acoustical features. The first of these, an American type, which was erected at several factories in the early days of the war (e.g. at D. Napier & Co., Park Royal). It consisted of a substantial building with two

vertical towers equipped with splitters. The ordinary hangar had the same basic design but splitters were disposed horizontally. In the former case the object was to project the sound upwards, and this had some merit, but the theories on which the design was based, viz. that the noise was very directional and would naturally travel upwards were considerably exaggerated. It was true that the higher frequencies were directional but it was the higher frequencies that could be most easily eliminated by the acoustical treatment. The low frequencies were largely non-directional and the result of transmitting them at 60 or 80 ft above ground was to transfer the noise source to a position which would be very appropriate for a loud hailer. Then again the normal atmospheric conditions during the day were such that the noise did tend to rise into the upper

FIG. 24a.—TEST HOUSE FOR PROPELLER SWINGING—VERTICAL INTAKE AND EXIT SPLITTER-TUNNELS

atmosphere owing to the progressive cooling of the temperature gradient until hot layers were met, sometimes at heights of 20 miles or more and the sound was diverted downwards again. However, this condition tended to reverse at nightfall and the sound to be turned downwards by the temperature gradient when the demand for peace and quiet was greatest, both because industrial noise had ceased and because this was the normal time for relaxation. The horizontal hangars at first sight appeared to be projecting the sound directly at nearby buildings but there was considerable attenuation

FIG. 24b.—HANGAR FOR PROPELLER SWINGING. HORIZONTAL INTAKE AND EXIT SPLITTER TUNNELS

due to the passage of the noise over the ground helped by the velocity path which increased the tendency for the noise to pass downwards. Thus if the hangars were satisfactorily aligned, noting, as Professor Richards had remarked, that the maximum noise was at 45° to the axis, there was every reason to suppose that the normal hangar was a better way of keeping down noise at some little distance than more ambitious schemes for projecting the noise upwards.

132. When jet engines came into use the problems were to provide intake air while silencing the exit jet. The entry for intake air was once more silenced by splitters. The popular way of silencing the jet was by means of the de-tuning tube, a tube of metal 2 ft, 2 ft 6 in. or 3 ft in diameter, some 20 ft long packed with acoustic material 3 in. to 6 in. thick. Air was entrained at the intake of the tube by the impingement of the

DIAGRAMMATIC SECTION
 Arrows show direction of air flow
 * Shows main noise areas

FIG. 24c.—TYPICAL TEST HOUSE FOR JET ENGINES

SECTIONAL PLAN
 * Shows main noise areas
 Splitters are shown diagrammatically

FIG. 24d.—EXIT TUNNEL FOR JET ENGINE TEST BED

jet, thus cooling the gases in the tube (Fig. 24c). For a time this seemed to be the correct answer and it was thought that with increased thrusts it would be sufficient to lengthen the tube for enough attenuation to result. Unfortunately, for this theory, at a certain limiting length the exit noise caused by the expansion of the gases from the de-tuning tube became the loudest noise, and therefore "critical".

133. Various efforts were made to improve overall silencing by flaring the exit, e.g. by putting on "pepper pots", etc., and by the popular means of enclosing the testing area in compound walls or embankments. None of these succeeded in eliminating the low-frequency noise, below the bass clef. These 8-ft or longer waves still remained the real problem requiring a very large thickness of acoustic material to deal with them. As there appeared to be a practical limit to de-tuning tube sizes, one step tried was to augment the de-tuning tube with a tunnel of reinforced brickwork or of cast iron plate, lined with considerable thickness, 12 in. to 18 in., of acoustic material and provided with splitters on the end. Two such tunnels were put up at the Rolls-Royce testing establishment in North Yorkshire and one had an interesting history (Fig. 24d). Complaints were first received from an occupier who lived at approximately 45° from the axis and at this stage the directional aspect was made use of as an additional length of tunnel was put on at 45°. There were, however, still complaints from some distance downwind as to noise and also as to the smell of paraffin which travelled at least 2 miles. It was thought that both these could be met by arranging to cool the jet by a large discharge of water.

134. Accordingly perforated pipes were built in the tunnel, the day arrived, the Avon was started up, the noise began, and at a given signal the water was turned on. The observers at once became invisible to each other for the whole valley was filled with steam. They groped their way to the control and got the water shut off, but it was some time before the heavy mists dispersed and they saw each other once more. The experiment cracked the tunnel, though not irredeemably. Clearly the water could not have been let in as "intelligently" as Professor Cave-Browne-Cave demanded. A considerable diminution of noise was achieved but the overall nuisance had been increased and the experiment was not repeated.

The Author, in reply, congratulated the Institution on the very fine discussion which had taken place on the Paper. It was clearly impossible for him to do justice to it in the short time available and he would reply more fully in writing.

136. He and Mr Jackson were old friends and Mr Jackson appreciated that each was doing his job by preaching his own gospel. While the Author appreciated that it would be difficult to get aeroplanes down to lower noise levels, he sincerely and firmly believed that the time would come in the not too distant future when noise levels should be reduced by 6 db or so. There were many complaints per week regarding the noise at the airport and it could not be said that the situation was completely satisfactory. There was also evidence that the noise nuisance was directly related to the numbers of noise intrusions per day. Proposals for the increase of jet operations at London Airport during the next ten years, and the fact that by then *Viscounts* and other aeroplanes of that type would have given place to jets, would imply a more uniformly higher noise level which would occur more often, particularly in the landing of such aircraft. Those who had flown in the big turbo-prop aeroplanes and compared them with jets would be convinced that jets would move in in a very big way and oust the propeller aeroplanes from quite medium routes in the very near future. The problem at London Airport, therefore, would be that of about a continuous roar of large noises, which would tend to make people say that it must be brought down. It would be wrong for people such as himself to try to go along with Mr Jackson, because once this clamour became apparent it would be too late to do anything about it. That was the real difficulty.

137. When it came to the question of doing something about it, he would point out that in the very early stages of jet noise research, what had been very apparent from the

start, had been that lower jet velocities were needed. But a full six years had elapsed with people like himself and many others preaching that the basic thing to do was to reduce jet velocity and have bigger mass flow before the engine designers had seen the real need for this. Now fan engines and others had come in and had reduced the noise at London Airport, and certainly the noise at airports in America, to a much more acceptable level. It was true to say that the fan engines on the *B.707* had brought down the complaints level to a very considerable degree.

138. Again looking to the future, it was the job of people such as himself to point out the dangers, and he would do so with regard to supersonic transport. Mr Jackson had pointed out that it would have a high rate of climb and, therefore, would tend to be quieter than the present craft. But it would use a lot more power and thus generate a lot more noise, and half of this noise would come down on the ground. Although the noise level might not be any higher it would therefore last longer, so that the problem some distance away from the airport, over the whole of London, as opposed to the environment of the airport, might be the problem of the future. When Mr Jackson spoke of looking after the communities beyond the airport, this problem of supersonic transport must be kept in mind.

139. Mr Edwards had done a magnificent job with his B.E.A. office block. The Author thought it was true that there was no point in setting false limits of sound and noise. One of the fields in which most work was going on in regard to noise was the subjective field. To indicate the type of problem to be dealt with—and there were plenty—there was a very different level of acceptance of noise from a motor car and from an aeroplane. There was a very different level of acceptance if one was making the noise or not and a different judgement occurred depending whether one was inside the house or outside; similarly one established a very different level depending on whether or not one was carrying out a task. If people were asked, they would give answers differing by about 10 db, so that it was almost impossible to set limits. Having a real office block of which the details were available, designed with a view to getting the noise level down, and being able to ask questions about it in a year or two's time, would be a most valuable contribution. He suggested that Mr Edwards should publish a Paper in a year or two on the comments made on this building.

140. The question of low-frequency noise and vibration was a most interesting one. It was one which he had met with on a large scale only a few weeks ago in the U.S.A., where so much din was made by rocket motors that houses eight or nine miles away were being vibrated, though the people there did not hear the noise. High-frequency noise did not seem to get through; it was frequencies of 20 cycles/sec. or even less which were getting through and gave people the feeling that a tornado was coming. Once one had this enormous amount of power coming out of the new aeroplanes there were likely to be at quite considerable distances, *viz.* nine miles, problems of vibration on the houses below in certain circumstances of wind. Incidentally, wind had a very big effect, but it was a very curious effect. What decided whether the noise came up and down again was the gradient of the wind, the gradient upwards. Depending on the exact gradient at various heights there could be a focusing effect at certain points, so that the problem of siting a maintenance area, or a housing area near a maintenance area, was sensitive also to the gradients of the wind in the area. It was impossible in a short Paper to do justice to all these effects.

141. He had been disappointed that Dr Bell's comments on Gatwick gave the impression that the authorities had done nothing to see that noise requirements were met; it had just happened. The Author knew that that was not true and that Dr Bell and his colleagues had had a great deal to do with planning for noise control. In the Paper, Gatwick had been used as an example although the Author realized it was not necessarily suitable for extensive large jet operations. In this country once automatic landing had come about—and it was due in the near future—civil flying from London to Manchester, London to Glasgow, London to Belfast, Cardiff to Edinburgh and so on would grow to such a degree that there would be plenty of scope for planning, so

long as the planning authorities thought in terms of the future and not of the present. He suggested that there had not been properly ordered planning in the past, in the sense that the planners had not thought far enough ahead. Five or ten years was not enough, and that fact should be emphasized.

142. Dr Bell mentioned annoyance and noisiness. In tests done recently by the National Physical Laboratory it had turned out that when people said they were annoyed and people said it was very noisy, the "very annoyed" and "very noisy", given by two sets of people coincided, which suggested that there was a relationship between the two.

143. Mr Fleming, in his comment on ground mufflers, seemed to have mixed up two different things referred to in the Paper. The reason for the rectangular outlet with the Hall ground muffler was the need to push the jet of gas vertically to reduce blast. The velocity out of the outlet was small, being only about 100 ft/sec. In the full-scale muffler it might be 200–300 ft/sec. The jet noise generated by the efflux gas was almost non-existent, so that the question of whether or not the frequency was raised or lowered when that velocity was occurring did not arise. The mistake might have arisen because of the idea put forward a long time ago that with jet aircraft it would be possible, by making a long, thin slot jet, to get high velocity and less noise. That was a different matter.

144. Both Wing-Commander Cave-Browne-Cave and Mr Fleming asked about full-scale experiments. A full-scale experiment had been carried out recently at Larkhill on a copy of the muffler referred to in the Paper and the results of model and full-scale tests were in good agreement. The type of reduction was about the same. A report was about to be issued and the Author would send both those gentlemen a copy. He agreed with Wing-Commander Cave-Browne-Cave that it was the high frequency which mattered in the intake, but not so much as the Wing-Commander made out. The noise from a compressor had frequencies in it which were up in the 2,000 cycles/sec. range, but there was a lot of white noise coming in as well, and this even on the low-frequency side might only be 5–6 db lower than the discrete frequency noise on the 2,000-cycles/sec. side. At Southampton they had quite a programme on this, as had Rolls-Royce and others also, to try to reduce the high-frequency noise. But he agreed with what Wing-Commander Cave-Browne-Cave had said, and that in stating his case he had been stating the general philosophy that light-weight silencers were worth putting in if only a certain noise-level reduction was wanted, but to get a big noise reduction it was necessary to add weight to stop the whole thing vibrating and acting as a second noise generator.

145. The whole question of using water deserved comment. His design had been on the basis of re-heat, in the sense that to put water into a jet it must be assumed that it was not going to penetrate very deeply. If one worked out on a pure momentum basis how far a stream of water would penetrate a very hot moving gas it would be found that it would penetrate only for a fraction of an inch. Therefore the whole idea of his ground muffler had been to spread the gas out into a sheet and, while it was doing that, squirt water at it in such a way that the efficiency of adding the water to the gas would be acceptable. Basically the principle involved was that of a reduction of velocity. If one added the same mass of water as existed in the gas, one halved the velocity. But, as Wing-Commander Cave-Browne-Cave said, there was an enormous heat sink available in the latent heat of water; otherwise one might just as well use sand instead of water.

146. The Author wished to thank Mr Payne for his kind remarks and to emphasize that it was almost impossible in a short time to cover the whole field of noise in all its aspects; it was possible to give only a preliminary indication rather than a complete coverage. On the question of the absorption due to grass, the Building Research Station team had found that under certain conditions there was attenuation along the surface. If there was a sound 5 ft above the ground and the attenuation was measured, they found that in the 200–400 cycles/sec. range the attenuation was far greater than could be accounted for on the basis of distance, so that there would seem to be

possibilities of noise reduction there. He would emphasize, however, that this was a far different effect from anything that would happen due to trees. Trees did have an effect which was known, but it was an entirely different one, and anything said about grass and absorption in the surface of the earth did not apply to trees in the same way.

147. He had already answered Mr Rodger's question about noise and vibration. At these very high powers, and particularly with a very high velocity jet, in which the sound waves were so intense that they built up into shock waves, a sharp pulse developed. Such conditions were conducive of vibration and could set houses vibrating.

148. Probably the only reason why helicopters were not noisier than they were was that they were usually not very powerful. He agreed that the only purpose of using a helicopter in civil aviation was as a link with city centres, and, therefore, the whole question of design in relation to a whole area was probably more important with the helicopter than with an ordinary aeroplane.

149. He had been asked to elaborate on the reasons for the limits of 110 db by day and 100 at night. This was a very controversial topic. Basically the figures had been obtained because in New York, at the Idlewild Airfield, it had been found that the complaint rate went up at about the time that people went to bed. There had been very little evidence at that time with regard to the noise that would be tolerated at 2 a.m. because so few aircraft operated at that hour. But, between 10 p.m. and midnight, the indications were that the complaint rate rose at a rate equivalent to raising the noise level by 8-10 db; it was, therefore, deduced that at night the noise level should be brought down by 10 or 8 db, or something of that order, so as to give the same amount of annoyance as during the day. That had been the basis of the figures, and it showed the state of the art.

150. To those who felt that the jet was the only problem he would emphasize that there were no regulations about propellered aircraft at London Airport, but a large number of the complaints about jets could be traced to old propellered aircraft going off at night on some journey or another. The jet was very much maligned. The jet operators at London Airport, or some of them, and certainly B.O.A.C., were extremely good at keeping below the levels set for them to observe.