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Aircraft Noise Measurement, Evaluation and Control.

by

G. Arnesen, cand. real.

Institute of Physics

University of Oslo, Norway

ABSTRACT

The problems of aircraft noise in the vicinity of airports are briefly outlined and international co-operative work towards the control and limiting of the noise are described. The measurement units used and some approximate relationships which seem to exist between them are discussed. An outline is furthermore given of methods commonly used to "map" the noise around an airfield, and an example of the noise reduction obtained by special aircraft take-off procedures is shown.

Finally an aircraft noise monitoring system installed at Oslo Airport is described and various technical details of the installation are discussed. It is shown that apart from normal "warning" arrangements in cases where a preset noise limit has been exceeded, also the storing of exceedance data on magnetic tape, and statistical noise distribution analysis are very useful tools in the control of airport noise.

SOMMAIRE

Le problème du bruit des avions au voisinage des aéroports est l'objet d'une brève esquisse et l'on décrit l'oeuvre de coopération internationale réalisée en vue du contrôle et de la limitation du bruit. On discute ensuite des unité de measure utilisés et de quelques relations approchées qui semblent exister entre eux. Une vue est en outre donnée des méthodes communément utilisées pour dresser la carte du bruit à l'entour d'un champ d'aviation ainsi qu'un exemple de la réduction du bruit obtenu par des procédés spéciaux de décollage.

Pour finir on décrit let dispositif moniteur de bruit d'avions installé à l'aéroport d'Oslo et l'on discute divers détails techniques de l'installation. On montre que, outre les dispositifs normaux d'avertissement en cas de dépassement d'un niveau limite prédéterminé de bruit, l'emmagasinage des données de dépassement sur ruban magnétique et l'analyse de la répartition statistique du bruit constituent également des outils très utiles pour le contrôle du bruit d'aéroport.

ZUSAMMENFASSUNG

Das Problem des Fluglärms in der Nachbarschaft von Flughäfen wird kurz skizziert, und die internationale Zusammenarbeit zum Zweck der Kontrolle und Begrenzung des Lärms wird beschrieben. Die benutzten Einheiten und ihre Beziehungen werden diskutiert. Weiterhin wird ein Überblick über die gemeinhin benutzten Methoden zum »Kartografieren« des Lärms und einen Flugplatz gegeben, und ein Beispiel für die Lärmverminderung durch besondere Startmaßnahmen wird angegeben.

Schließlich wird eine am Flughafen Oslo installierte Fluglärm-Warnanlage beschrieben, und verschiedene technische Einzelheiten dieser Anlage werden diskutiert. Es wird gezeigt, daß neben den normalen Warneinrichtungen für die Fälle, wo eine vorgegebene Lärmgrenze überschritten worden ist, auch das Aufspeichern der Überschreitungen auf Magnetband und eine statistische Auswertung der Pegelhäufigkeit sehr wertvolle Hilfsmittel bei der Kontrolle des Fluglärms darstellen.

Introduction.

Due to the increased air traffic intensity and the use of greater and more powerful aircraft the noise problem in the vicinity of airports has increased rapidly all over the world during the last decades.

As this bears a number of serious economical consequences, an international

"attack" was launched some years ago, the purpose of which has been to limit the problem as far as possible.
O.E.C.D. (Organization for Economic Cooperation and Development), I.S.O. (International Standardization Organization), I.E.C. (International Electrotechnical Commission) and a number of semi-official institutions have been working on recommendations and regulations for the measurement, evaluation and restriction of aircraft noise.
Because of the complexity of the problem, general and simple solutions cannot be produced overnight and it might be of interest in this connection to cite the "aim" of the work as formulated during the formation of the Co-operative Research Group in the O.E.C.D. Central Service for International Cooperation in Science Research, Aircraft Noise Abatement Group:
"The growth in air traffic since the war has posed serious noise problems in many countries. Both the number of flights and the size of aircraft have continued to increase, and the introduction of jet-powered aircraft further raised noise levels. The greatest problem arises at take-off and landing while the aircraft is at a low altitude, and quite large areas around airports are subject to varying degrees of disturbance. At present only very limited reductions in noise can be expected from engine design changes or the use of silencers, the only practicable control is by siting airports and regulating take-off procedures so as to bring aircraft to an adequate height before passing over densely populated areas. To effect this may involve reductions in the permitted take-off weight.
Air transport is international; noise regulations at one airport may affect the aircraft of a score of countries. Co-operation is therefore important on both regulatory and scientific levels. Moreover, the complexity of the problem and the lack of easy solutions render desirable the maximum exchange of ideas and information through co-operative groups. The O.E.C.D. groups, while concerned solely with the scientific aspects of aircraft noise measurement, and effects, have maintained contact with other international bodies concerned with the question".
All of the above mentioned international institutions (O.E.C.D., I.S.O., I.E.C.) have issued, and are working on, important documents regarding the measurements to be made, and the measuring equipment and evaluation methods to be used for the control of aircraft noise.

The Measurement of Aircraft Noise and Measurement "Units".

The concept of "noise" as used in daily life is an ambiguous one. This might be most clearly visualized by considering the rather great discussion which is taking place regarding the units to be used in noise measurements. On the one hand it is possible without too great trouble to obtain the measurement data which describe the noise physically. On the other hand, however, these data can not easily be used to directly determine for instance the loudness or the annoyance that the noise causes.

Aircraft Noise Abatement Group I (O.E.C.D.) recommends for the measurement of aircraft noise, the use of the unit "PN dB" (1) or the unit "Phon" calculated according to the method derived by E. Zwicker (2). This is discussed in O.E.C.D. document E.P.A./AR/4098, Annex 1 (3) and the methods of calculation are described in the Brüel & Kjær Technical Review No. 2, 1962 (4).
As no presently available commercial instrument is capable of measuring noise directly in PN dB or Phon (Zwicker) units the Group recommends the use of dB (A) for monitoring purposes. The dB (A) units are derived from measurements with a Sound Level Meter as standardized by the I.E.C. and used with the frequency weighting curve termed (A) inserted (4). A further reason for this recommendation is that a crude connection excists between the noise level obtained in dB (A) units and that determined in PN dB when the noise source is an aircraft. When the requirement to accuracy is not too strict it is thus possible to express the aircraft noise in dB (A) and, by means of a correction factor, estimate the corresponding PN dB-values, see also Table 1 and Appendix A.

Perceived Noise Level minus Sound Level A.

Aircraft Class	Mean Value	Standard Deviation	Number within ± 1 dB of mean	Number within ± 2 dB of mean	Extreme differences from mean
	dB	dB	per cent	per cent	dB
Jet	11.9	1.1	70	94	— 3.1 to + 3.7
Propeller	14.2	1.2	59	84	— 3.0 to + 2.5

Table 1.

It should be noted that the comparison made in Table 1 was made at a fixed distance from the aircraft of some 500—1000 meters and that the difference between the dB (A) and PN dB data will have other values at other distances. Table 2 shows the relationship as determined more specifically for a number of aircrafts. Both Table 1 and Table 2 contain values measured during takeoff. It is, however, also possible to estimate the relationship between dB (A) and PN dB during landing from similar measurements. The result of such estimates is given in Table 3.
Depending upon the ultimate use of the measurement data, and thus the accuracy required, aircraft noise may therefore be expressed in terms of PN dB, Phon (Zwicker) or dB (A). A necessary requirement for the collection of measurement data is, of course, that the measuring equipment has a high degree of accuracy. Formulation of the requirements to the instrumentation is, as stated earlier, being laid down by I.E.C.

Aircraft Class	Group	Group mean	Standard deviation
Jet	Comet	12.3	1.5
	Boeing 320	11.7	1.0
	Boeing 120	12.1	1.0
	Boeing 420	12.0	1.1
	DC8-30	11.8	1.0
	DC-40	12.0	1.2
	Caravelle I	12.2	0.8
	Caravelle III	11.0	0.6
	TU-104	11.9	0.7
Propeller	Super-Const.	14.2	0.9
	Constellation	14.0	1.1
	DC7	13.7	1.1
	DC6	14.6	1.3
	Viscount	14.2	1.4
	Britannia	14.8	1.2

Table 2.

Perceived Noise Level minus Sound Level A.
Aircraft approaching to land.

Aircraft Class	Mean Value	Standard Deviation	Number within ± 1 dB of mean	Number within ± 2 dB of mean	Extreme differences from mean
	dB	dB	per cent	per cent	dB
Jet	15.3	2.2	55	68	— 4.9 to + 4.2
Propeller	14.7	1.2	64	91	— 1.6 to + 2.6

Table 3.

Apart from the PN dB concept, which does not only describe the loudness, but to a certain extent also the "annoyance" effect of aircraft noise, other methods of taking the "annoyance" into consideration have been proposed in the course of time. Some of the problems involved have been described in a proposal of the Technical Committee 43 Acoustics (I.S.O.) in a document termed: "Noise Rating with Respect to the Conservation of Hearing, Speech Communication and Annoyance".
A second method, specifically aimed at the aircraft noise problem, has been termed the "Noise and Number Index Method" (N.N.I.-Method) and is based on sociological investigations made around London Airport (5). These in-

vestigations have made it possible to establish a connection between measurement data (noise level), number of aircraft movements on one side and the human reaction to the noise on the other side. As the relationship so obtained is closely connected with the air traffic density and its distribution in time (number of movements and noise levels of day and night traffic) at London Airport, it is not yet known, whether the N.N.I.-method is applicable also to other airports and traffic-patterns.

Mapping of the Noise in the Vicinity of Airports.

To obtain an exact picture of noise "climate" in the vicinity of an airport, a great number of noise measurements and evaluation of measurement data are necessary. This is a very time-consuming and expensive task. However, under certain circumstances it is possible, on the basis of some "fundamental" data, to estimate the noise level in different areas theoretically. In the following a method of estimation is described whereby the noise level can be calculated. The result of such calculations may then afterwards be checked and thoroughly evaluated at certain preselected measurement stations (6).

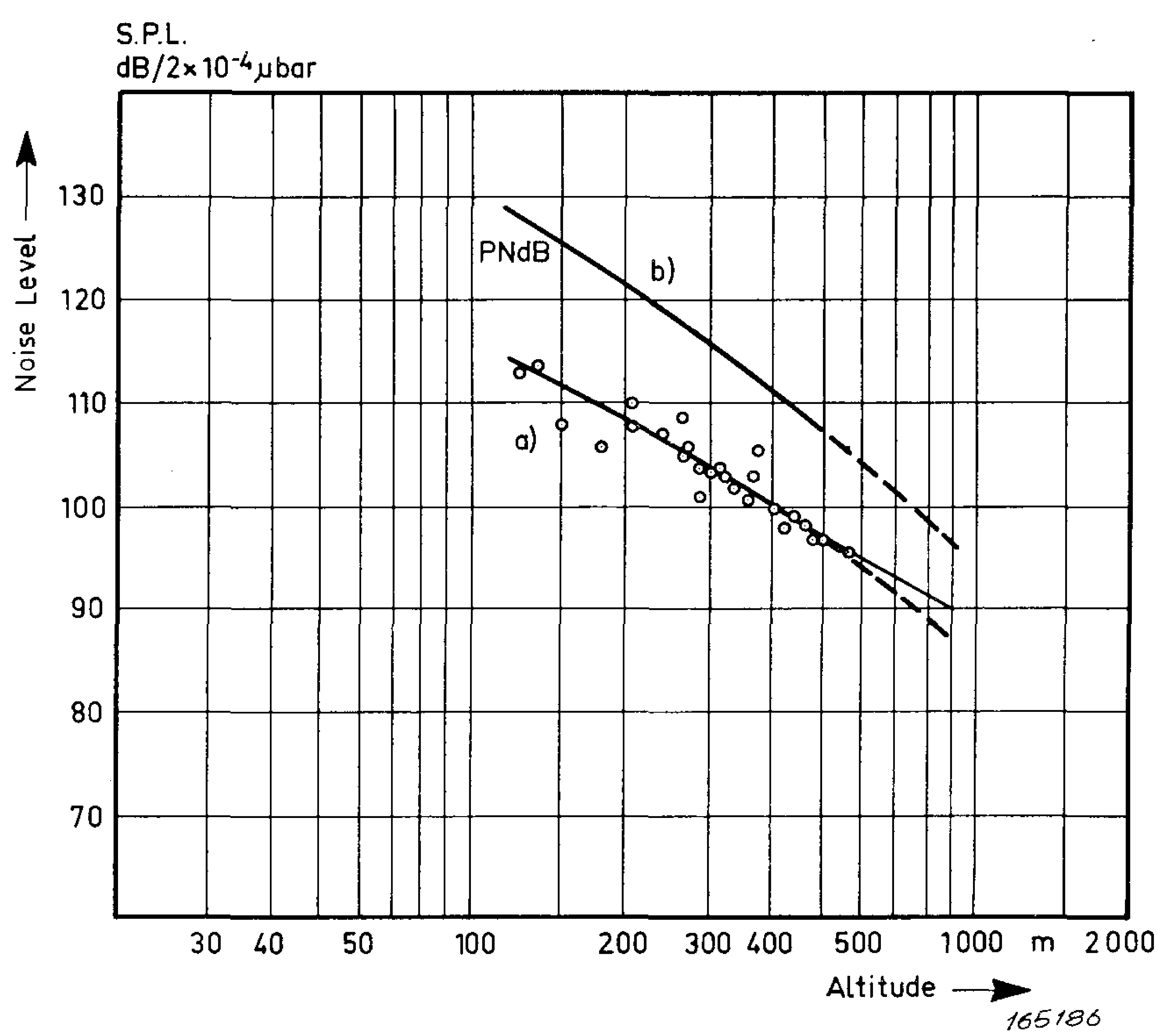

Fig. 1. Acoustic noise produced by Caravelle Stage III during take off. (Engine setting: 7350 r.p.m. Climb Power). The noise is measured as a function of the shortest distance from the measuring point to the aircraft.
a) The overall maximum sound pressure level during fly-over.
b) PN dB-values obtained under the same conditions as a). (6).

At a certain distance from the aircraft the noise level during take-off depends on the take-off procedure of the aircraft, i.e. the power setting of the engines, as well as the take-off path. In Fig. 1 is shown an example of the sound pressure level (and the noise level in PN dB) as a function of distance, produced by the Caravelle St. III during start according to the take-off procedure normally called "climb power". Other engine powers and speeds of rotation will, of course, produce different curves.

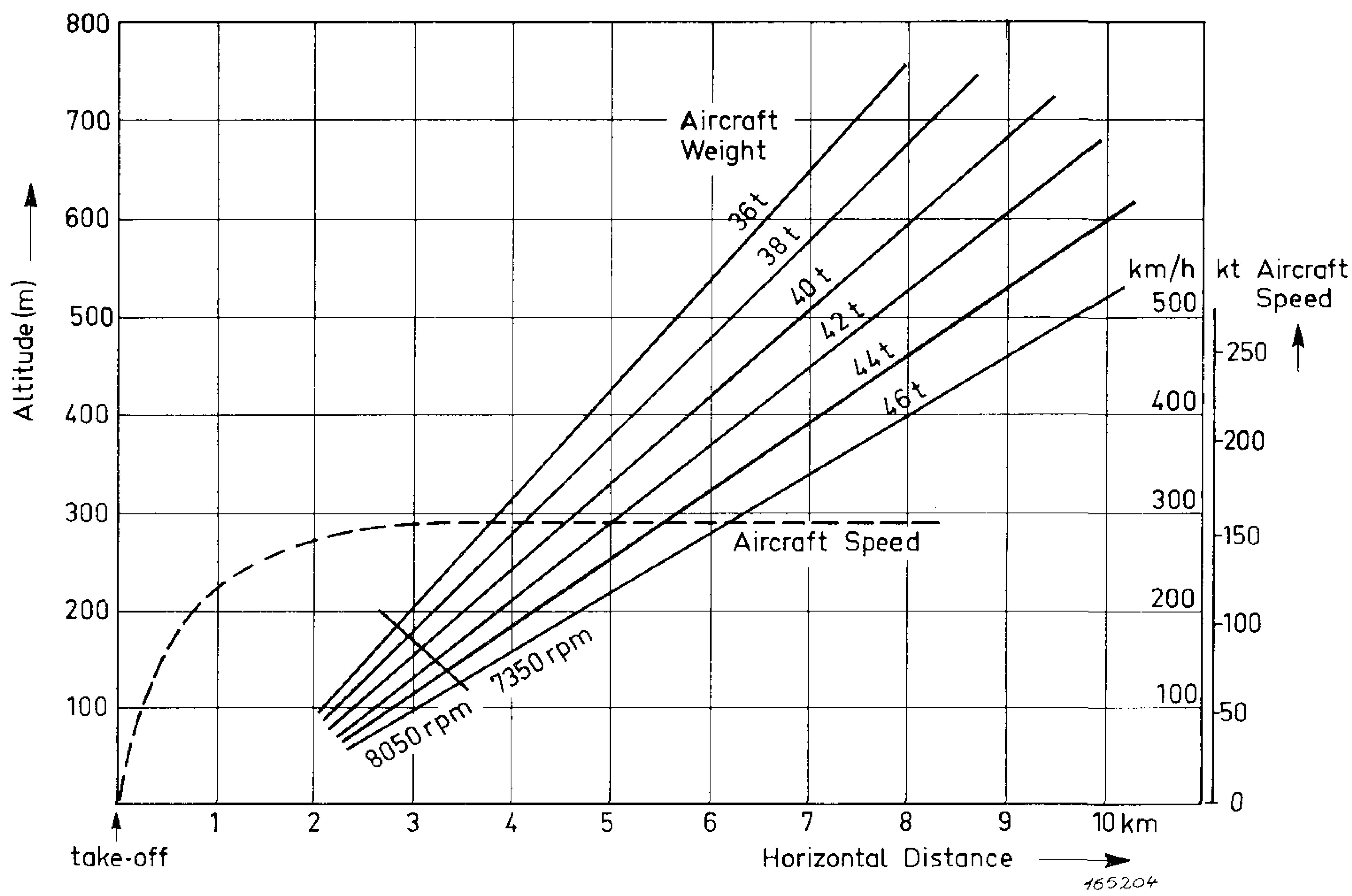

Fig. 2. Take-off profiles for Caravelle St. III with different loads. The profiles are given at standard temperature of 15°C and 0 kt. wind velocity. Dashed line indicates aircraft speed (6).

Regarding the actual distance from the measuring point to the aircraft this depends on the aircraft rate of climb, which again depends on:

a) Weight. The rate of climb increases with decreasing weight, see Fig. 2.
b) Atmospheric temperature. The rate of climb increases with decreasing temperature, Fig. 3.
c) Relative wind velocity. The rate of climb increases with increasing relative velocity, Fig. 4.

Thus, if the atmospheric conditions, the weight and the take-off procedure of the aircraft are known, the sound pressure levels in different areas around the airport can be estimated from curves of the type shown in Figs. 1 through 4.

The sound pressure level estimated according to this procedure is the maximum sound pressure level which occurs during fly-over. An example of the time dependence of the sound pressure level during fly-over is shown in

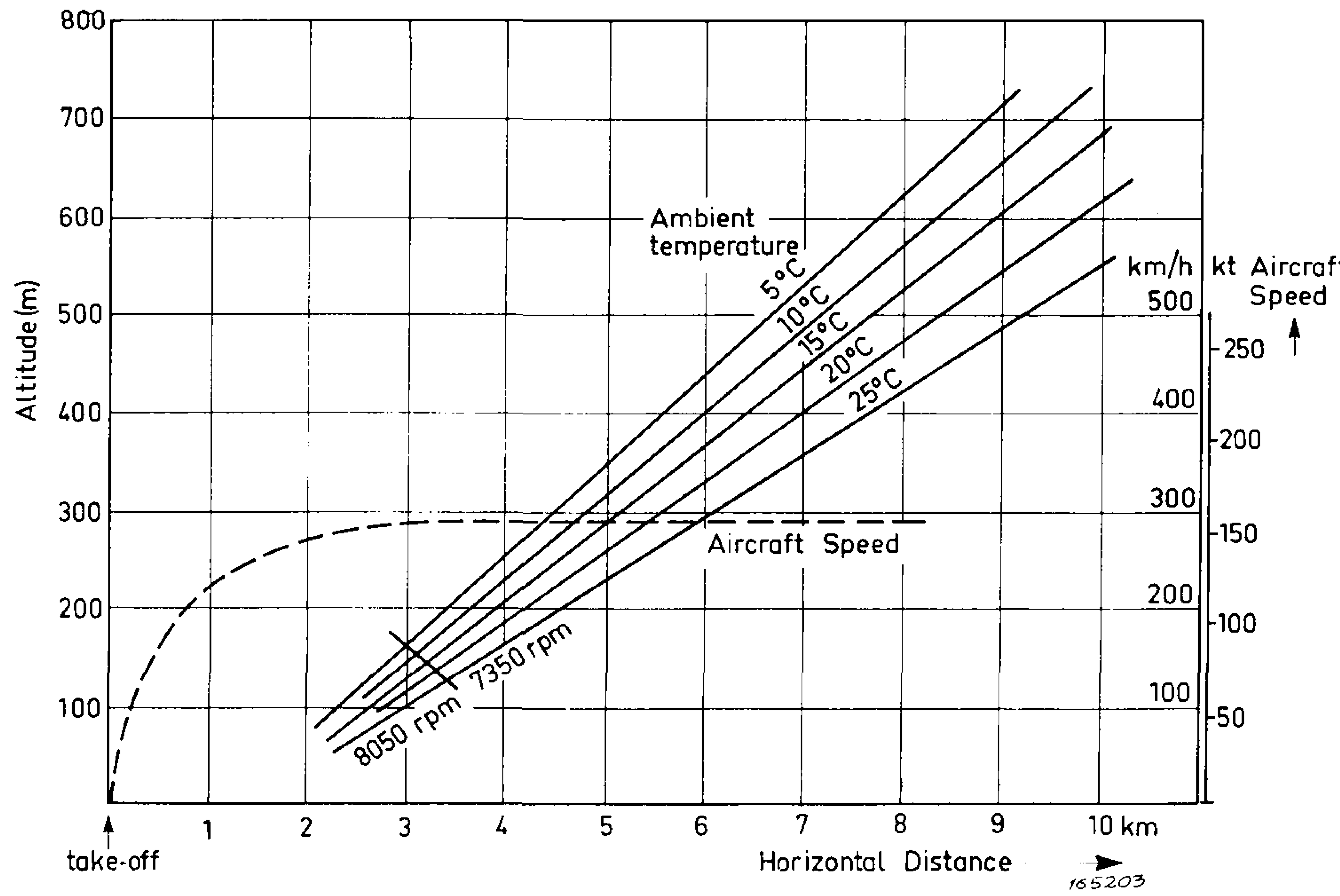

Fig. 3. Take off profiles for Caravelle St. III at different ambient temperatures. Take off weight: 42 t. Wind: 0 kt (6).

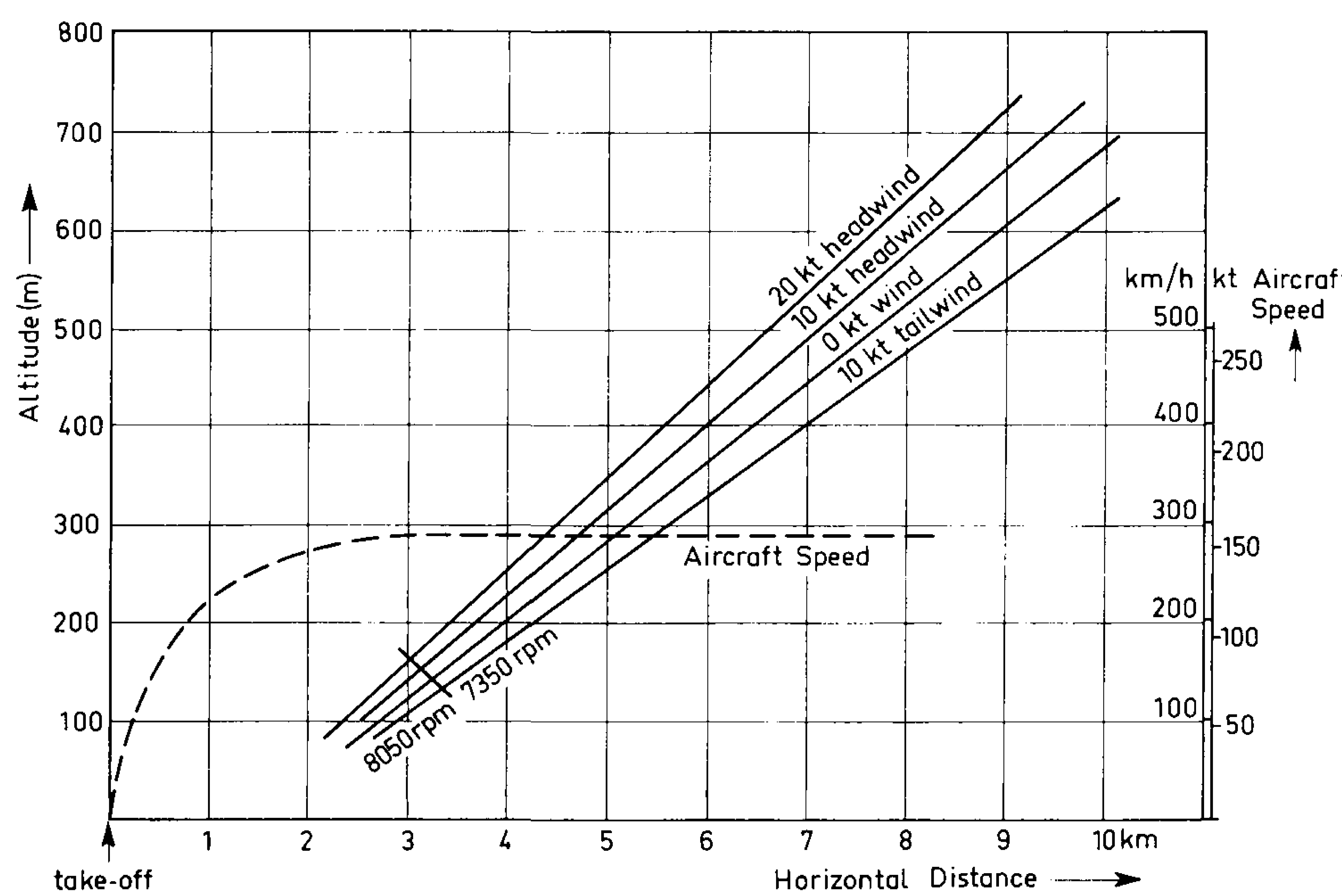

Fig. 4. Take off profiles for Caravelle St. III under different ambient wind conditions. Take off weight: 42 t. Temperature: 15°C (6).

Fig. 5. The three different curves shown are measured with a precision sound level meter switched to weighting curve A, B and C, respectively. Finally, Fig. 6 shows the octave band sound pressure level produced by a Caravelle St. III at a distance of 300 meters and the engines set for "climb power".

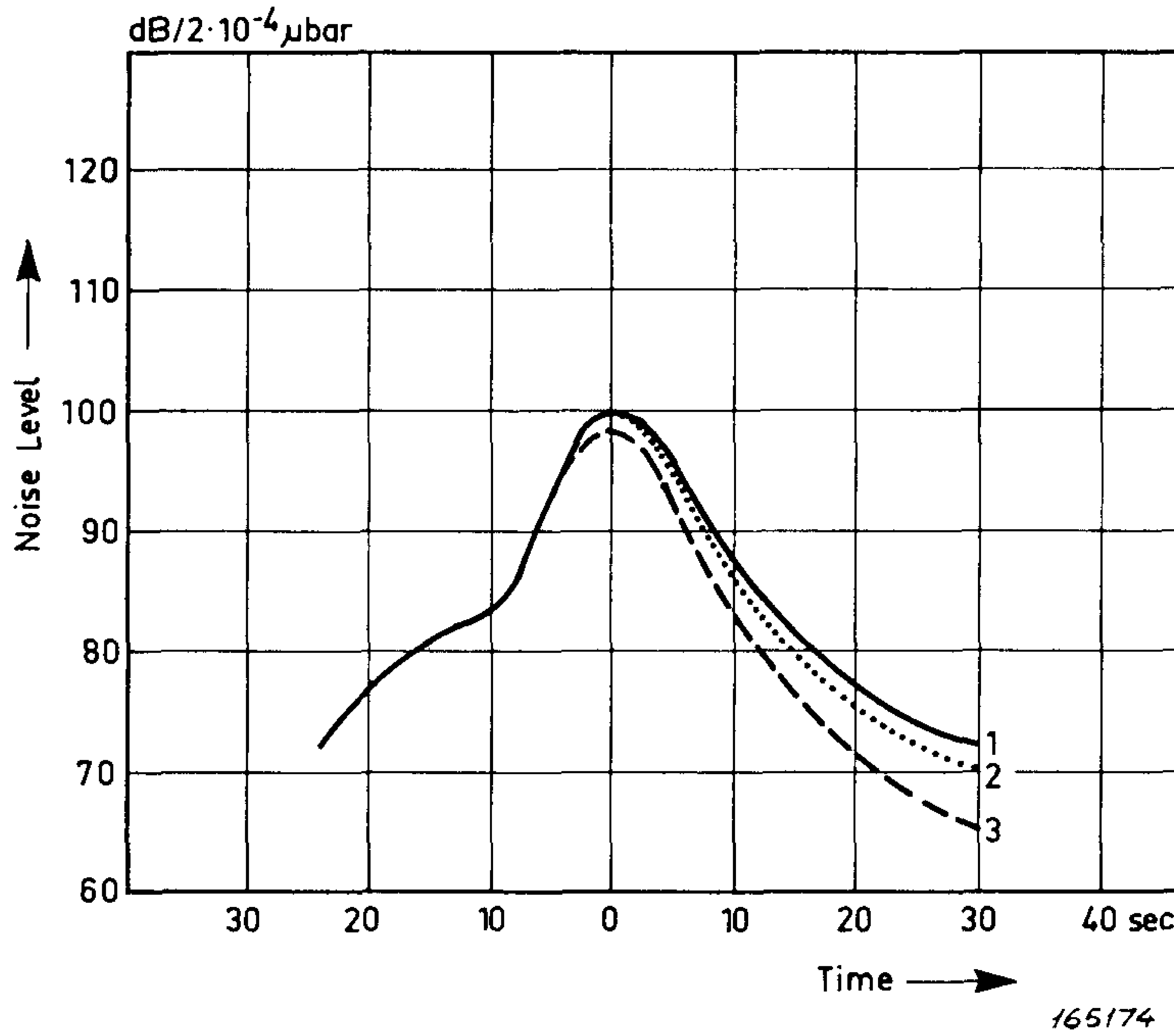

Fig. 5. Example of the variation in noise level with time during fly-over (Caravelle) (6).
Curve 1): Measurements obtained with the weighting network (C) inserted in the Sound Level Meter.
Curve 2): Same as 1) but with weighting network (B) inserted.
Curve 3): Same as 1 but with weighting network (A) inserted.

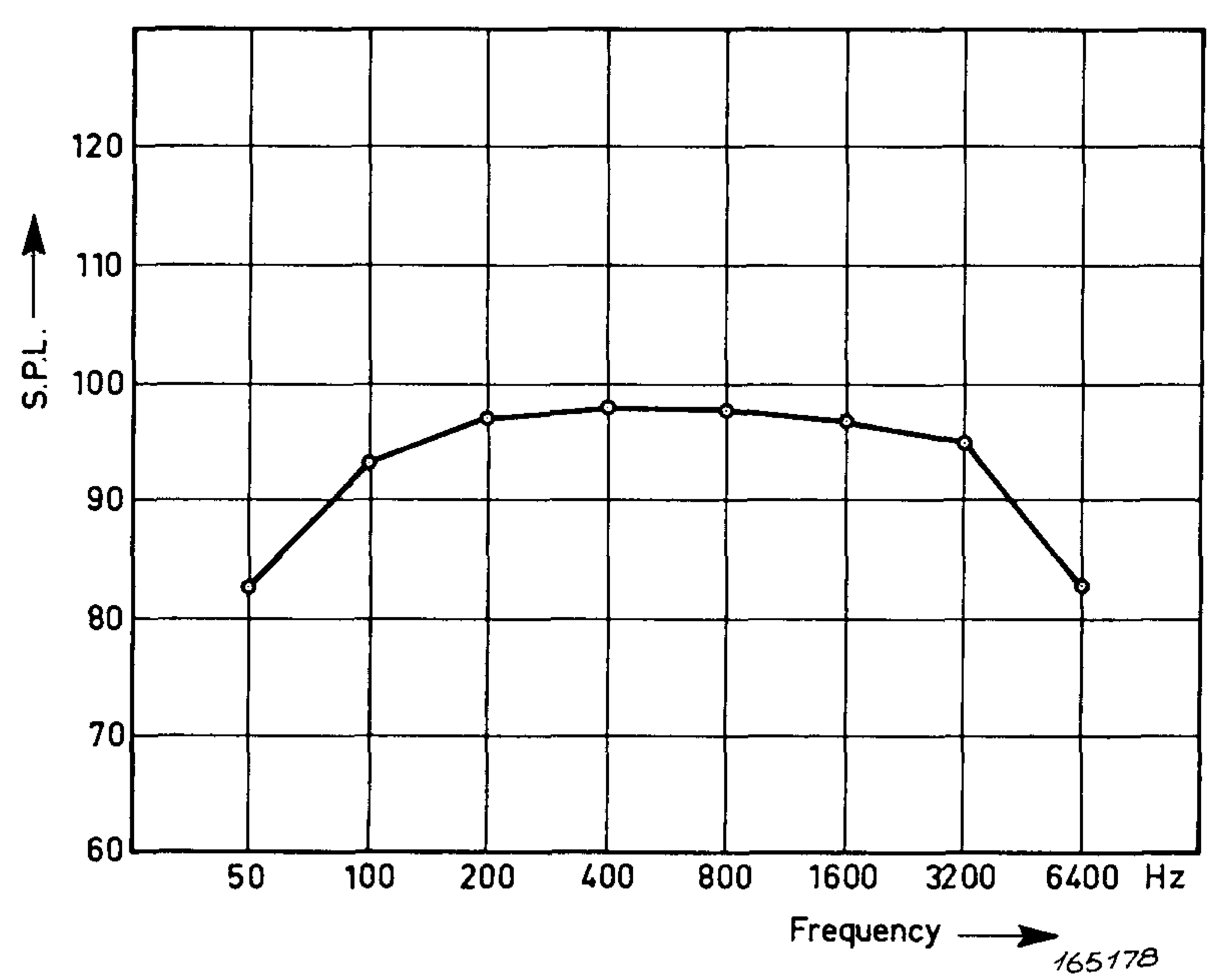

Fig. 6. Octave band analysis of the maximum sound pressure level at an altitude of 300 m during take off (Caravelle St. III). Engine setting climb power 7350 r.p.m. (6).

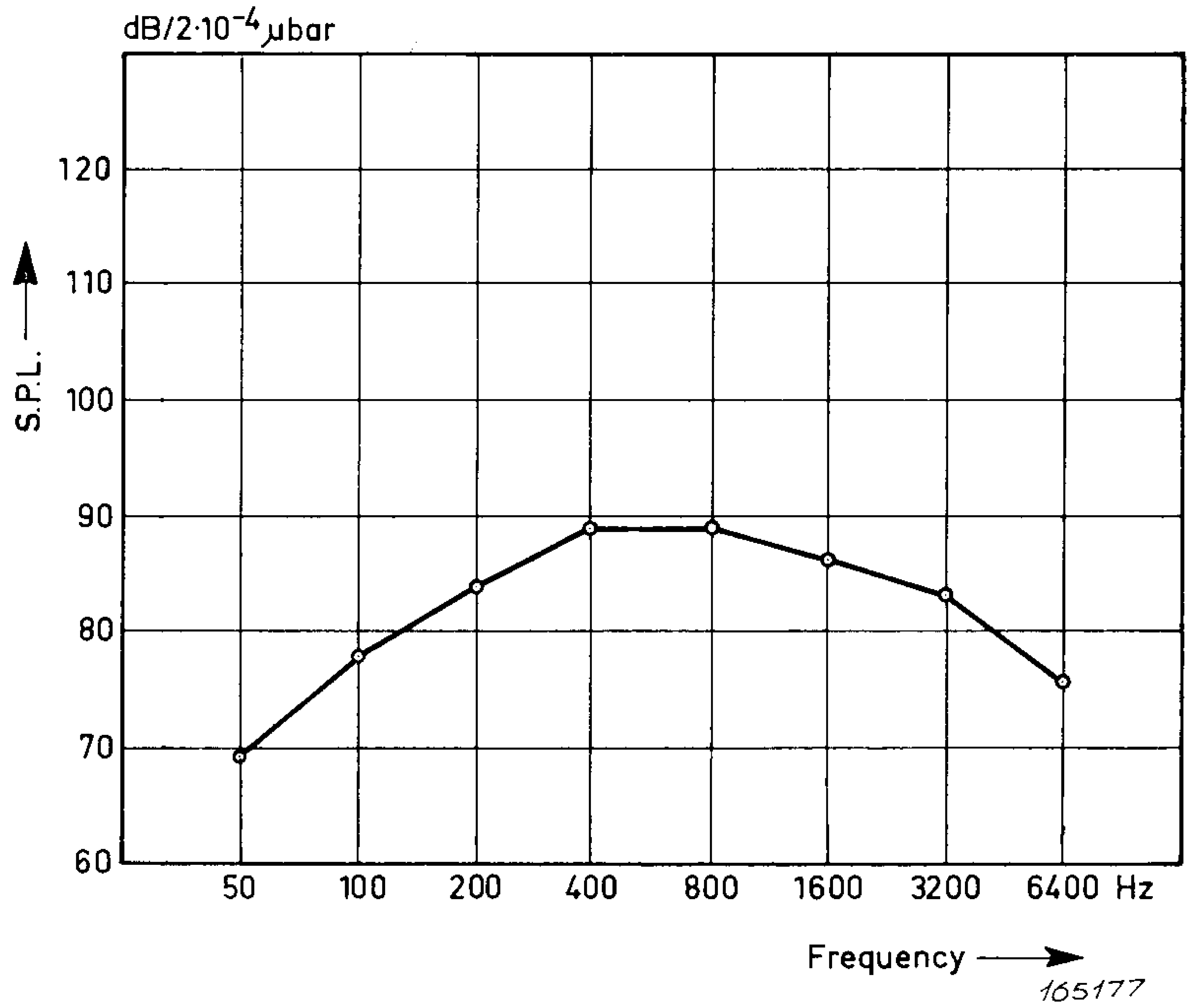

Fig. 7. Octave band analysis of the maximum sound pressure level at an altitude of 200 m during landing (Caravelle St. III) (6).

Estimates of landing noise may be carried out in a similar way. The noise spectrum produced by the Caravelle St. III during landing is shown in Fig. 7, and Fig. 8 shows the sound pressure level as a function of height for this case. It should be noted, however, that the noise produced during landing depends greatly upon the landing procedure used (Choice of engine power setting).

If it is desired to map the noise level over greater distances it is necessary to take into account the influence of both the surrounding topography and the meteorological conditions.

The necessary corrections are at present being considered by the I.S.O. for standardization purposes and a proposed recommendation for the measurement and estimation of aircraft noise is in process.

To obtain reliable results from the calculations the angle of observation of the aircraft at the "measurement" point must exceed a certain minimum value, for example 20—30°, depending upon the accuracy desired.

Ultimate Use of Measurement Data.

The ultimate use of noise data, whether measured or estimated as described above, is normally in the reduction of the noise.

It might be of interest in this connection to briefly discuss some of the viewpoints which have been taken by the working group of the "Scandinavian Committee for Building Regulations". In a comment from the group regarding the possibilities for more quiet aircraft in the future it is stated, for instance:

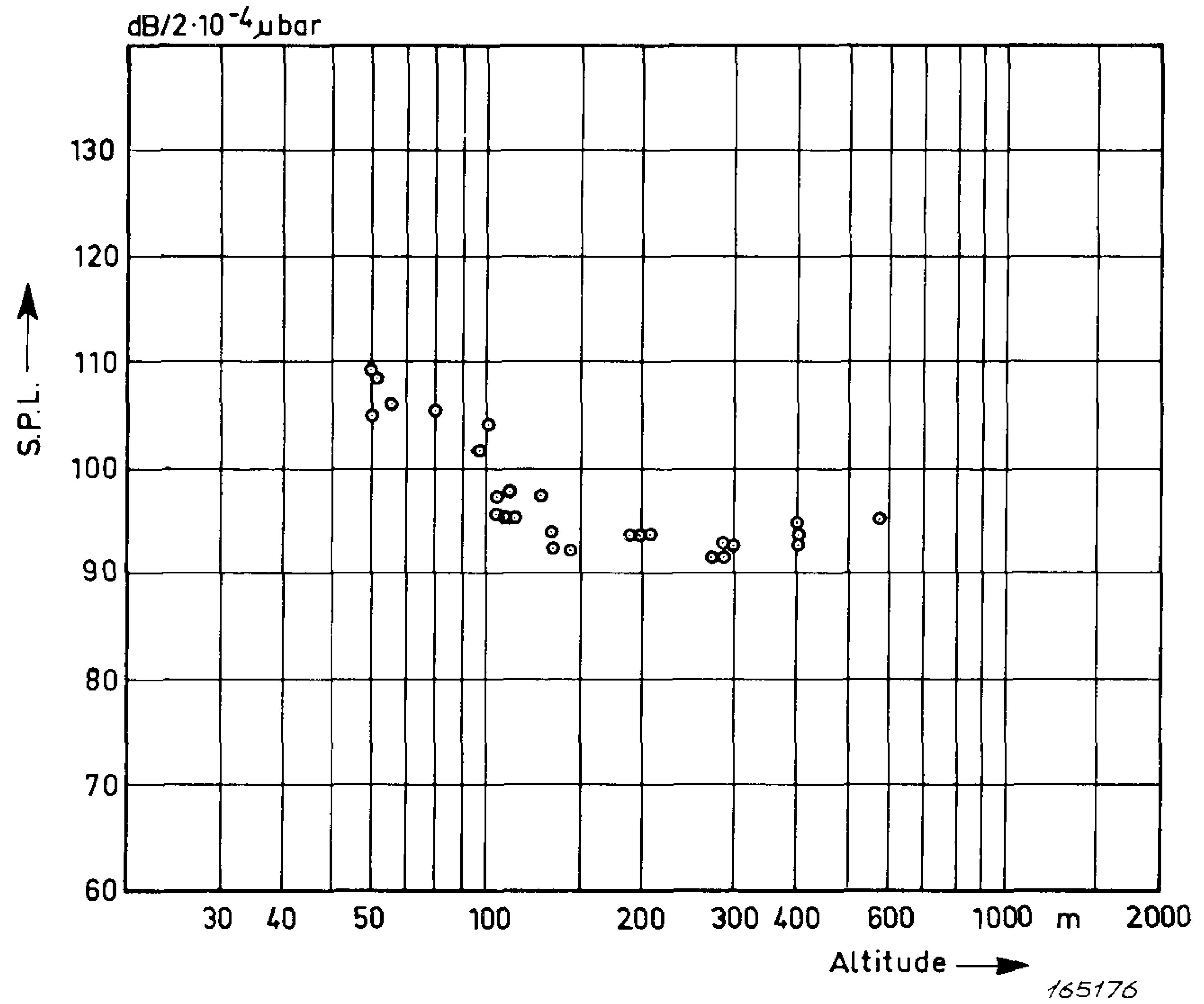

Fig. 8. Maximum overall sound pressure level versus altitude during landing (Caravelle St. III) (6).

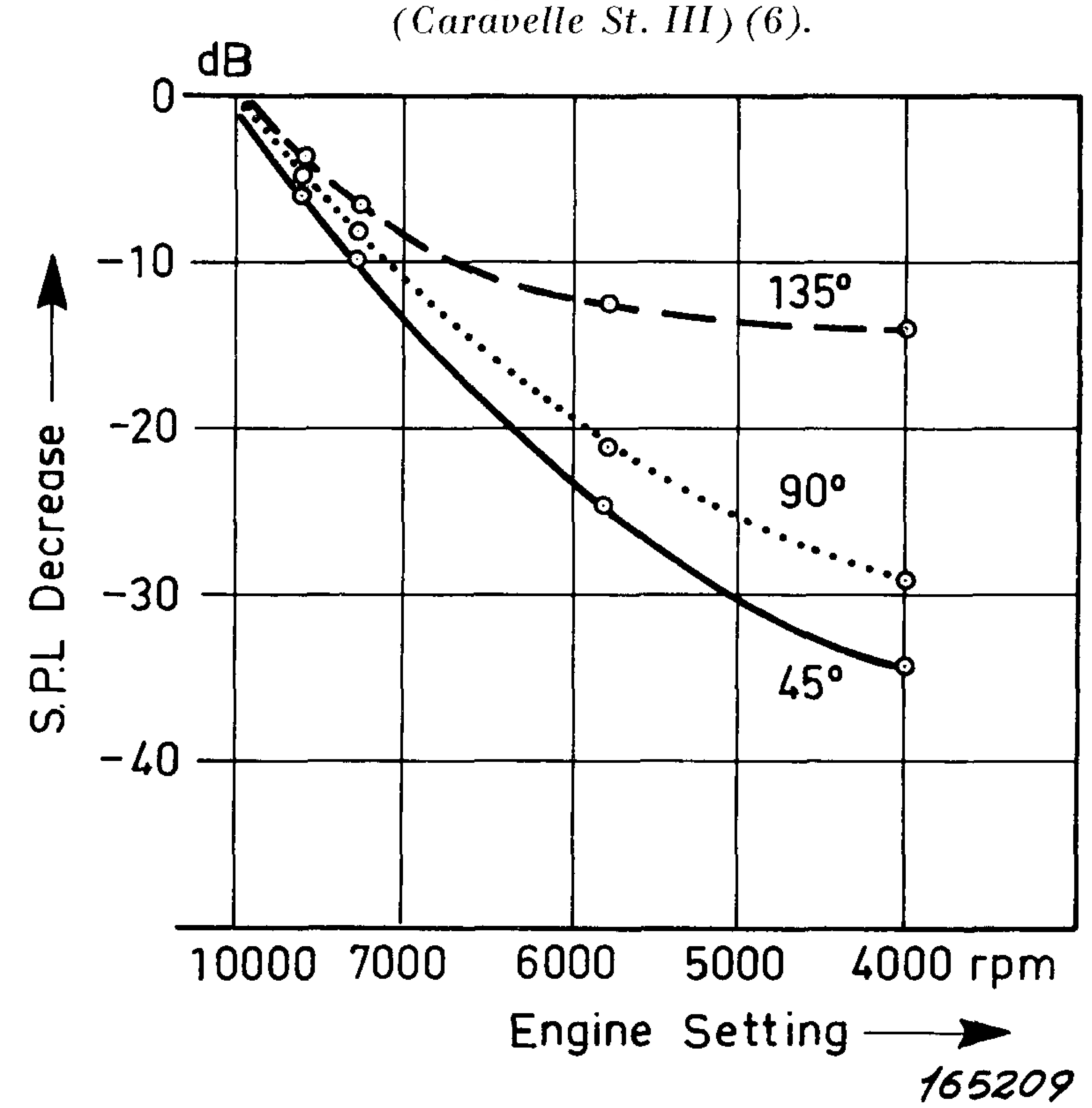

Fig. 9. Overall sound pressure level as a function of engine power setting measured at a distance of 100 m from the aircraft (Caravelle St. III). The three different curves describe the reduction in S.P.L. in three different directions away from the aircraft. Note that the decrease in S.P.L. is smallest in front of the aircraft.

"The reduction of aircraft noise at the source is in reality possible only by a limitation of the noise from the engines . . .". "With regard to aircraft noise the group would like to remark, even if this falls outside its actual working area that the development of supersonic aircraft will produce new and very serious noise problems due to the pressure wave which is produced at these high speeds, and which follows the aircraft like a wake during flight".

Due to the fact that noise limits have at present been established around a number of greater airports it is to be expected that the design of future aircraft will take this into account. However, even if the noise limits are not to be exceeded, the development of more silent engines will most probably only result in higher power ratings and the existing noise levels will thus not be reduced, but merely kept. One of the few methods which seem useful for the reduction of aircraft noise is a change in the aircraft take-off procedure. This, of course, with due regard to passenger safety. As an example of the connection between the speed of rotation of the engine and the reduction in sound pressure level, Fig. 9 shows a set of curves obtained from measurements on a Caravelle St. III. In Fig. 10 is shown the sound pressure level during fly-over measured for two different take-off procedures.

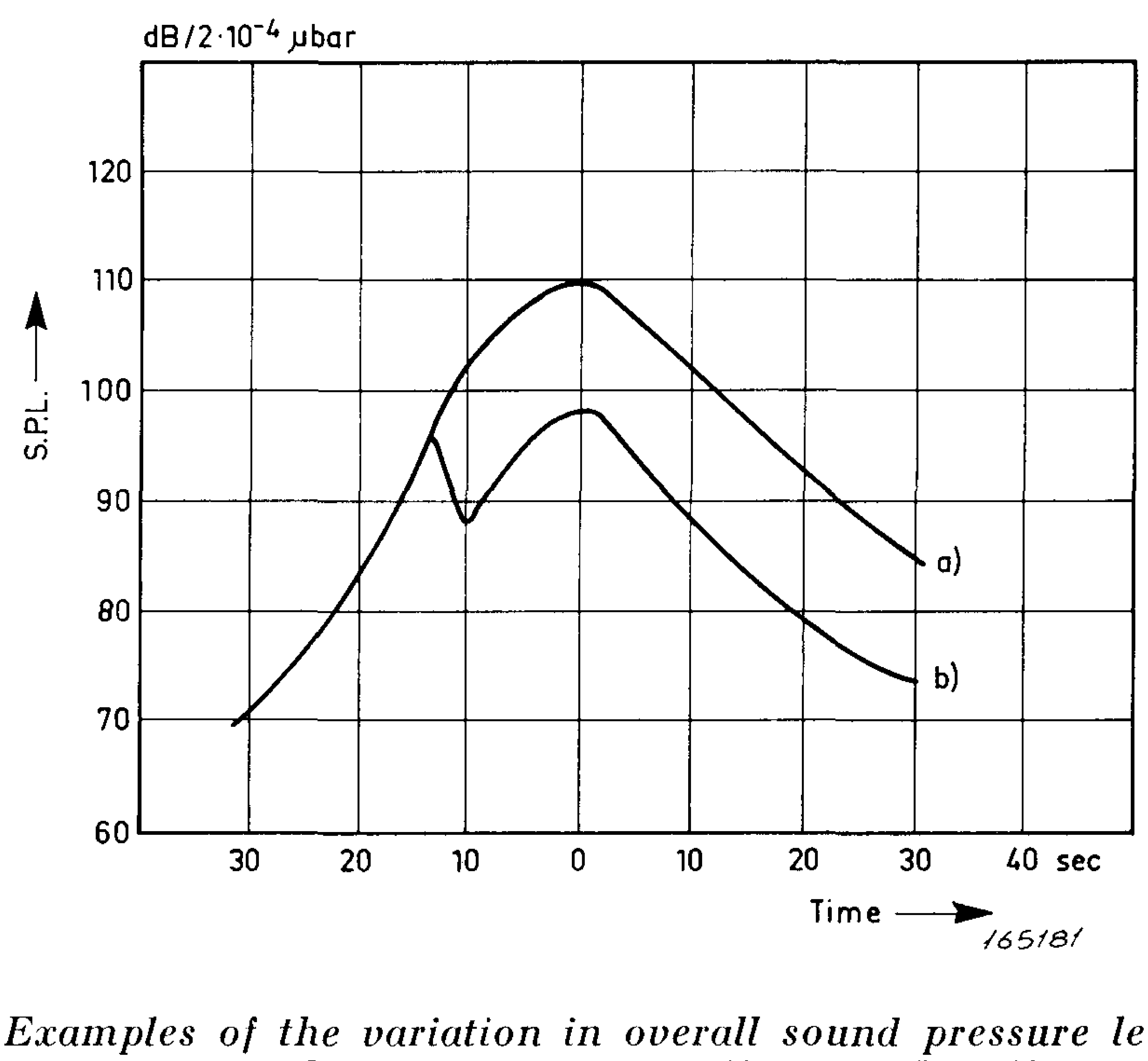

Fig. 10. Examples of the variation in overall sound pressure level with time during fly-over obtained with two different take off procedures.

Curve a) describes the sound pressure level when no reduction in engine r.p.m. is made, while curve b) has been measured under the same ambient conditions but with the aircraft taking off according to the procedure given in Table 4.

Caravelle Stage III. a) During gear and flap retraction increase speed to 150 kt. Maintain take off rpm. b) After 60 sec. from start of take off roll begin to reduce from take off rpm. to 7000 rpm with de-icing off, or 7100 rpm with de-icing on. c) After 2 min. 20 sec. from start of take off roll increase to 7350 rpm and continue climb at 150 kt. d) After 3 min. from start of take off roll increase to 7650 rpm and accelerate to normal climb speed.

Table 4.

As in most cases take-off can take place according to more than one procedure, the possibility exists at the different airports to enforce those procedures which take due account of the noise produced in the built-up area around the airfield. An example of two possible climb profiles are shown in Fig. 11.

Further possibilities for effective aircraft noise control in areas situated some distance away from the airport itself consist in requiring certain preferred flight paths to be used during approach and departure.

When the air traffic authorities require the use of special take-off procedures

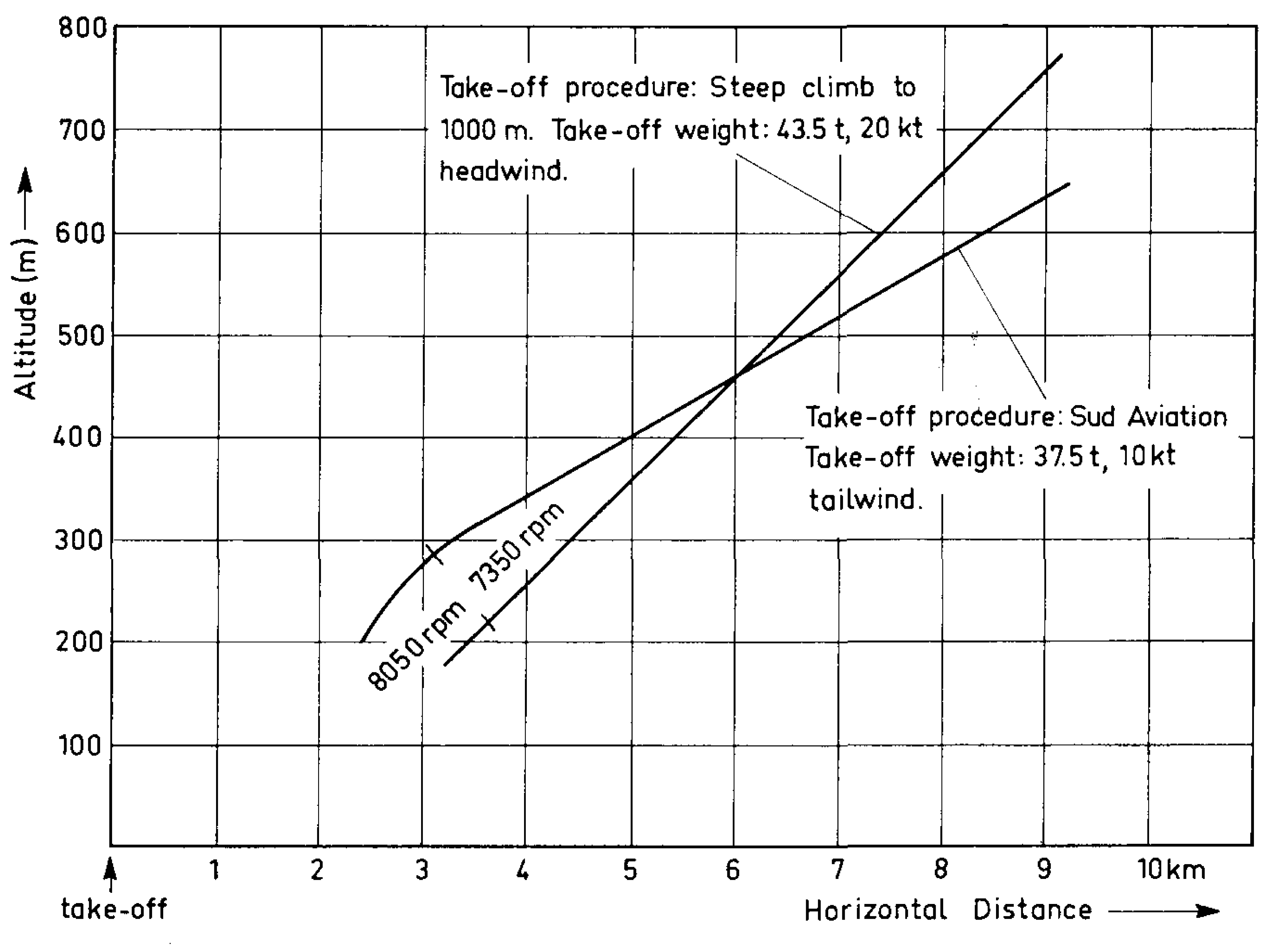

Fig. 11. Take off profiles for two different take off procedures at standard temperature (Caravelle Se 210).

and/or flight paths to reduce noise in the neighbourhood of airports it is absolutely necessary, however, to have some sort of noise monitoring instrumentation installed to check that regulations are complied with.

Description of the Aircraft Noise Measuring and Monitoring System Used at Oslo Airport (Fornebu).

By resolution of the Norwegian Government, dated March the 6th, 1964, a commission was set up to evaluate the aircraft noise problem at Norwegian airports and to advise on possible action that might be taken to reduce the noise.

The commission was asked to set up and maintain a noise monitoring service around Norwegian airports. Its first task was to propose an arrangement suitable for noise measuring and monitoring at Oslo Airport, and the complete system was set into operation on the 13th of July 1965.

The main purpose of the system is to check that the noise limit of 112 PN dB, given by the Norwegian authorities as the maximum permissible noise in built-up areas around airfields, is not exceeded during take-off on the east-west runway. A second, and also very important purpose of the system, is to check to which extent other areas around the airport is exposed to excessive noise as well as to investigate the variation with time of the noise exposure.

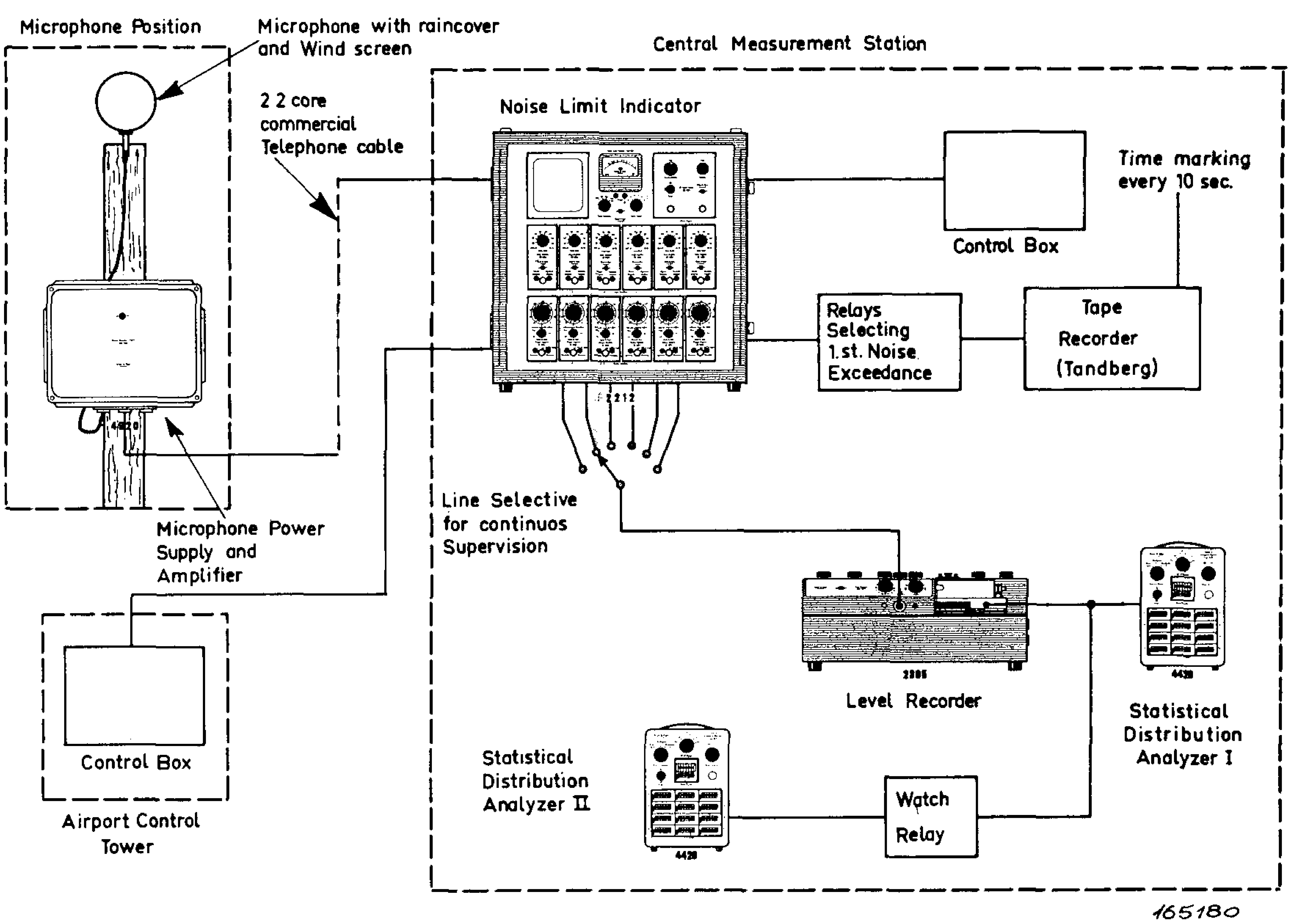

Fig. 12. Block diagram of the noise measuring and monitoring system used at Oslo Airport.

Fig. 12 shows a block diagram of the system. It consists of a number of measurement microphones, duly protected against the influence of varying weather conditions, and a main control unit to which various recording and data reduction arrangements have been attached. A total number of seven microphones is used, and the signals from the microphones are transmitted to a central measurement station of the airport via *ordinary telephone lines.* The location of the microphones as well as the actual positions of the telephone lines are shown in Fig. 13.

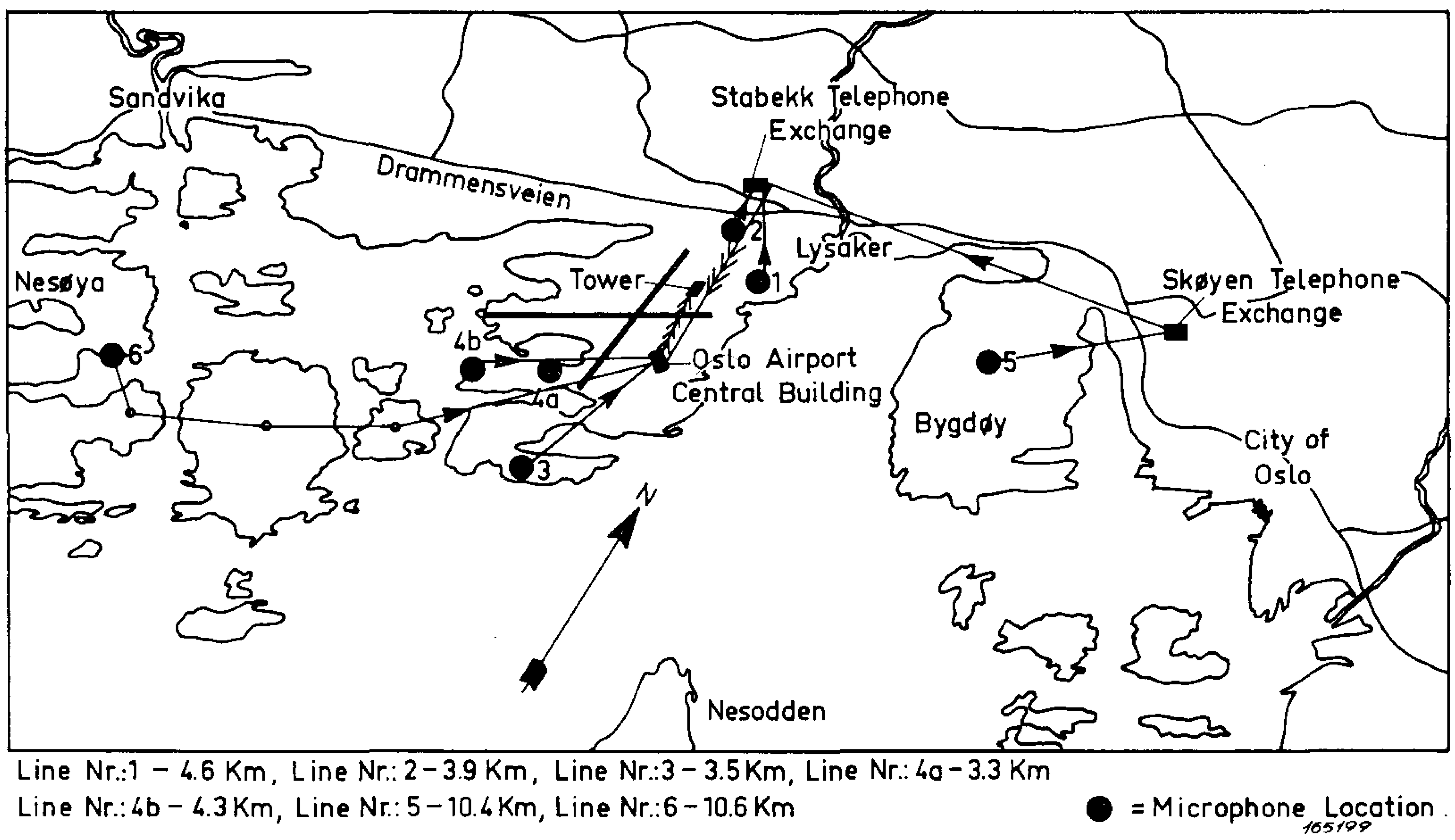

Fig. 13. Map of Oslo Airport and the surrounding country showing microphone and cable locations.

When the signal from one of the microphones exceeds a preset limit in dB (C) or dB (A), a number of relays are activated at the control measurement station starting a magnetic tape recorder and indicating visually that certain noise limits have ben exceeded by lighting a number of red lights. The lights are located on special control panels both at the measurement station and in the airport control tower. To allow the time of exceedance to be determined the exact time is recorded on a second track of the magnetic tape.

A separate recording system which utilizes a graphic level recorder and two statistical distribution analyzers is used for continuous recording of the noise level at a preselected microphone position. The statistical distribution analyzers also allow statistical analysis of the time duration of various noise levels to be made.

The location of the microphones have been chosen in accordance with the following considerations:

Microphones 1 and 4b) are located in such a way that the measurement data

obtained can be used to check whether the pilots follow the prescribed take-off procedure for the east-west runway or not, one of the very important points in the procedure being a reduction in engine r.p.m. as mentioned earlier in the article. The reduction normally takes place at the end of the runway (when the aircraft has gained a certain specified height).
Microphone 3 should be able to check whether the maximum permitted noise level has been exceeded by traffic on the north-south runway.
Microphones 2 and 4a) are located so that checks can be made on whether or not the maximum noise levels are exceeded in the near-by resident areas during take-off at full engine power (maximum engine r.p.m.).
Finally, the microphones 5 and 6 are located so that a check can be made on whether the aircraft has gained sufficient height or chosen a flight path that avoids unnecessary high noise exposure in the surrounding built-up areas.
The microphones used are of the precision condenser microphone type and are supplied from Brüel & Kjær as complete outdoor microphone systems. Such a system consists actually of two basic units:

1) A cathode follower and condenser microphone cartridge fitted with an electrostatic actuator and rain cover, all in one unit covered by a wind screen, and
2) A water-proof cabinet, which encloses an amplifier, a power supply and a calibration oscillator.

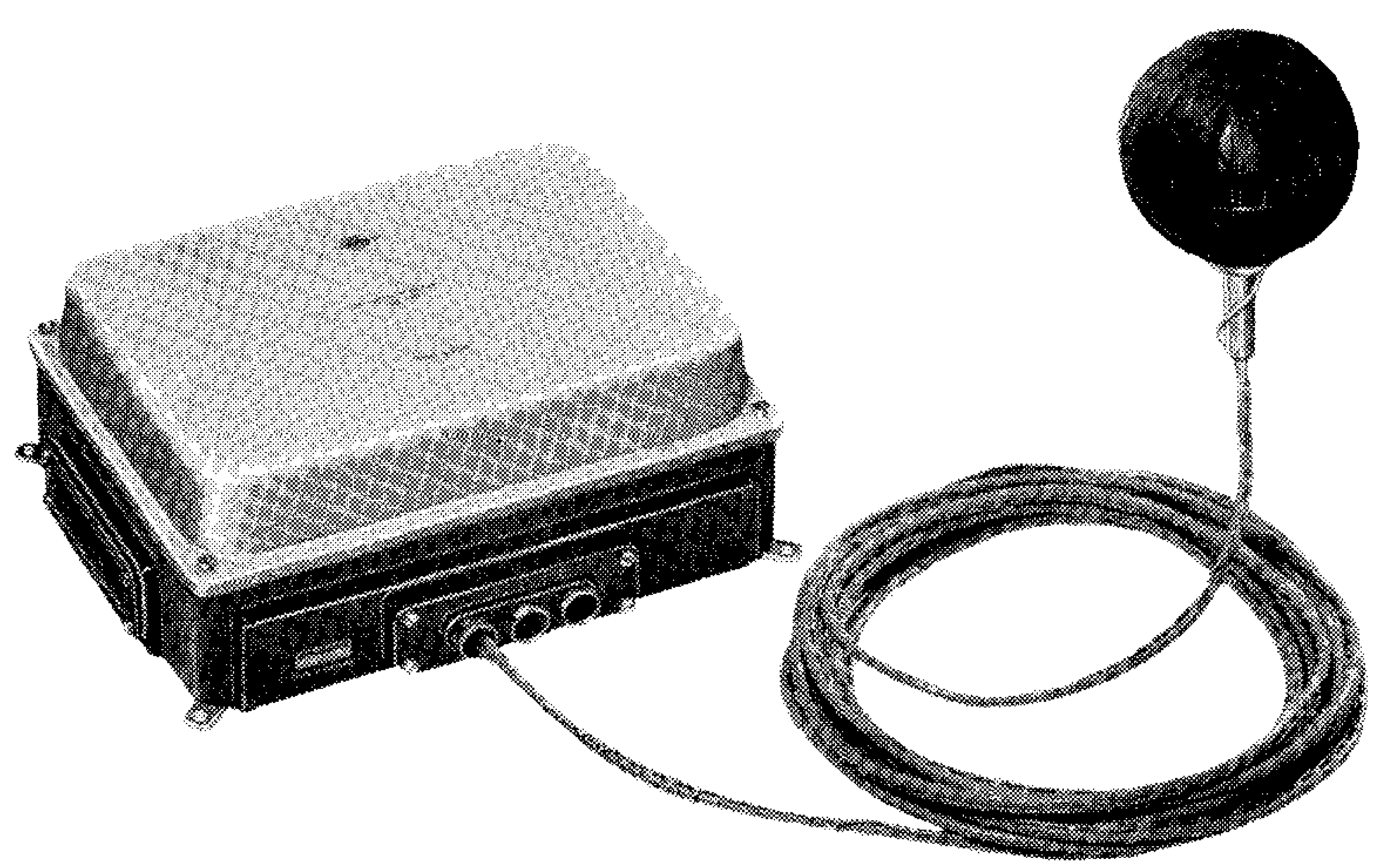

Fig. 14. The Outdoor Microphone System Type 4920 (Brüel & Kjær).

This set-up will convert sound pressures into electrical signals which, due to the low output impedance of the amplifier, can be transmitted over long distances by means of cables. An easy system check-out and calibration can be made when the built-in electrostatic actuator is switched into operation. Provisions are also made in the amplifier for a certain adjustable compensation of the high-frequency loss in long cables.
Fig. 14 shows a photo of the complete outdoor microphone system, and its

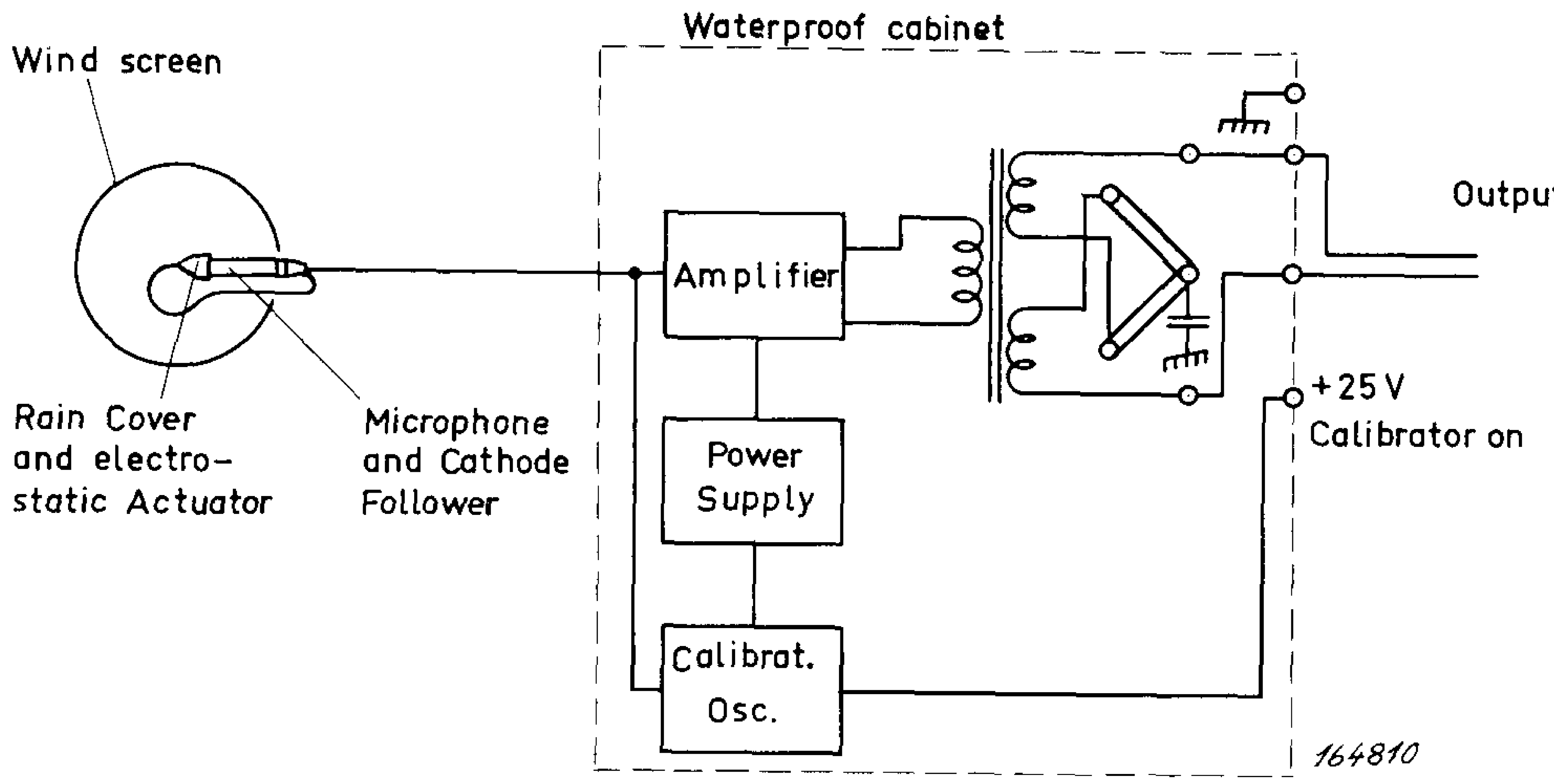

Fig. 15. Block diagram showing the principle of operation of the Outdoor Microphone System.

principle of operation is given in Fig. 15. A typical example of the practical mounting of the system is shown in Fig. 16 (microphone location 2).

The cables connecting the microphones with the central measurement station are *ordinary telephone lines* of lengths varying from 10.6 km to 3.3 km. As a typical example of the frequency response of one of the transmission systems the characteristic of the longest line, including microphone amplifier is given in Fig. 17. The line is in this case compensated by means of a capacitor in the amplifier of 1.22 μF.

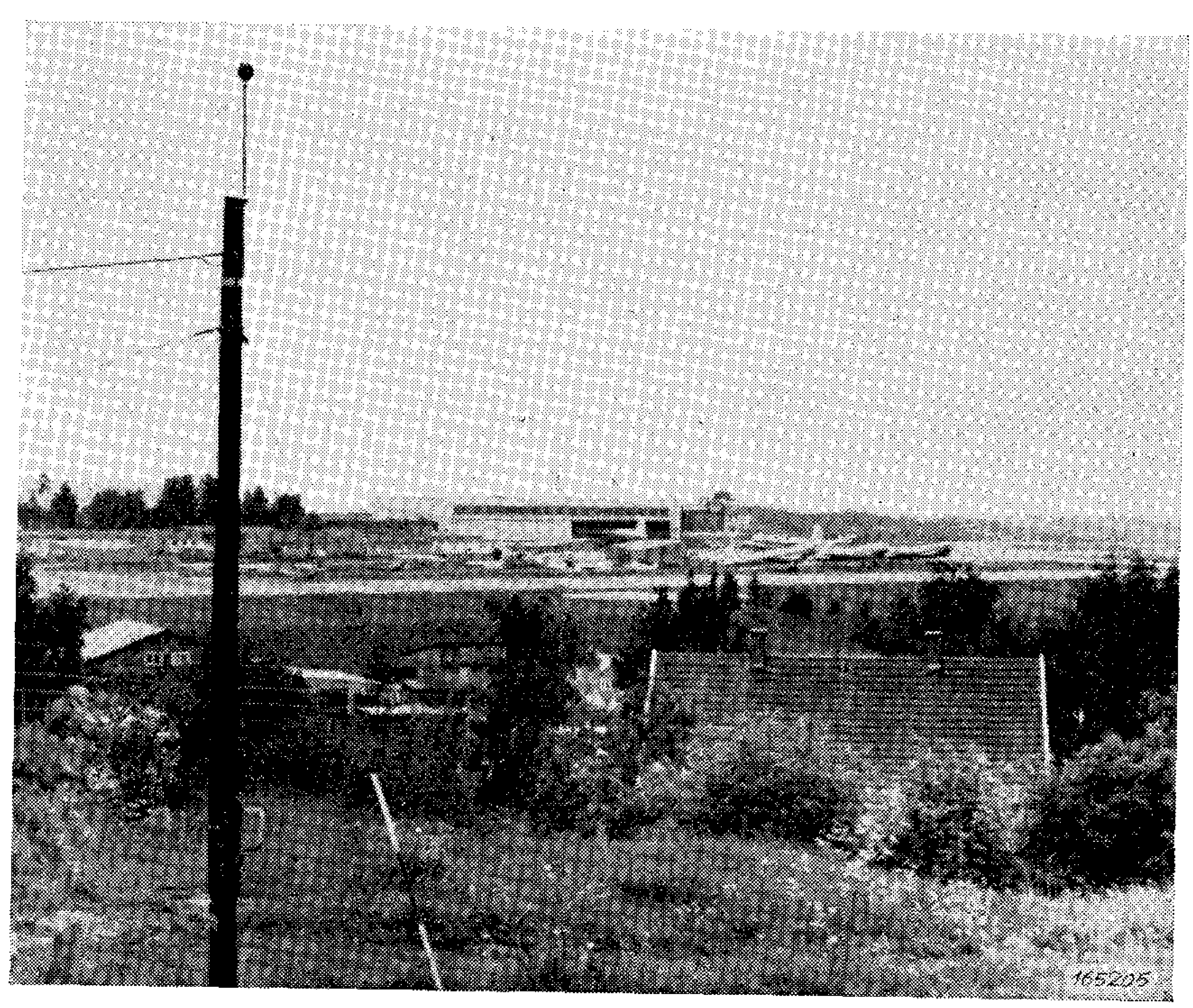

Fig. 16. Example of mounting of the Outdoor Microphone System (Microphone location 2 see also Fig. 13).

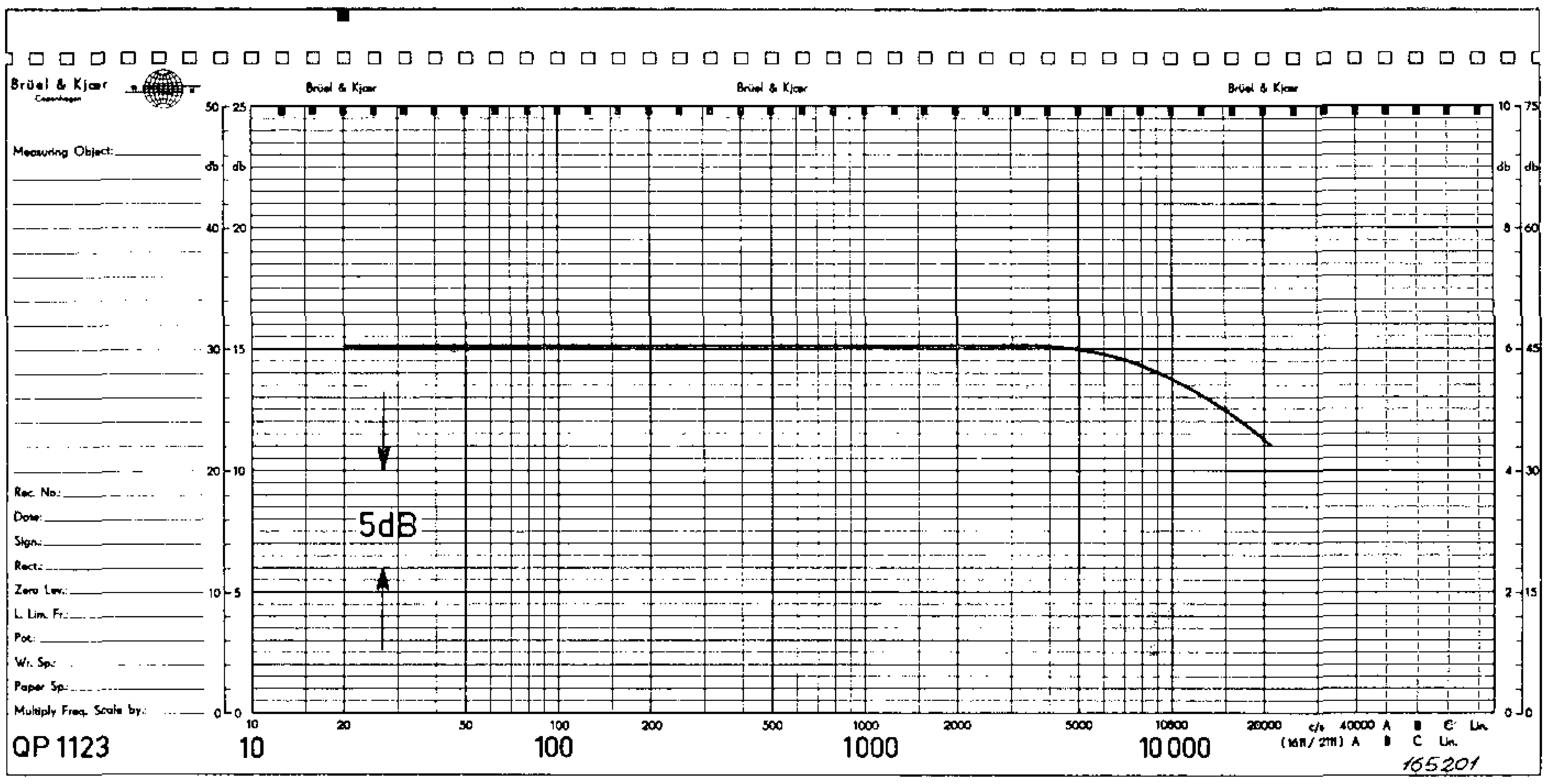

Fig. 17. Frequency response of the compensated transmission system from microphone location 6 (see also Fig. 13).

In the control measurement station the main indicating and data recording devices are located. One of the basic instrumentation units is here a noise limit indicator produced by Brüel & Kjær. It consists of six identical, separate input amplifiers and six output amplifiers. The input circuit of the amplifiers contains a transformer which allows connection to a symmetrical transmission system. The input transformer has been included, however, not only to allow connection to a symmetrical transmission system but also to facilitate remote control of the calibration oscillator in a connected outdoor microphone

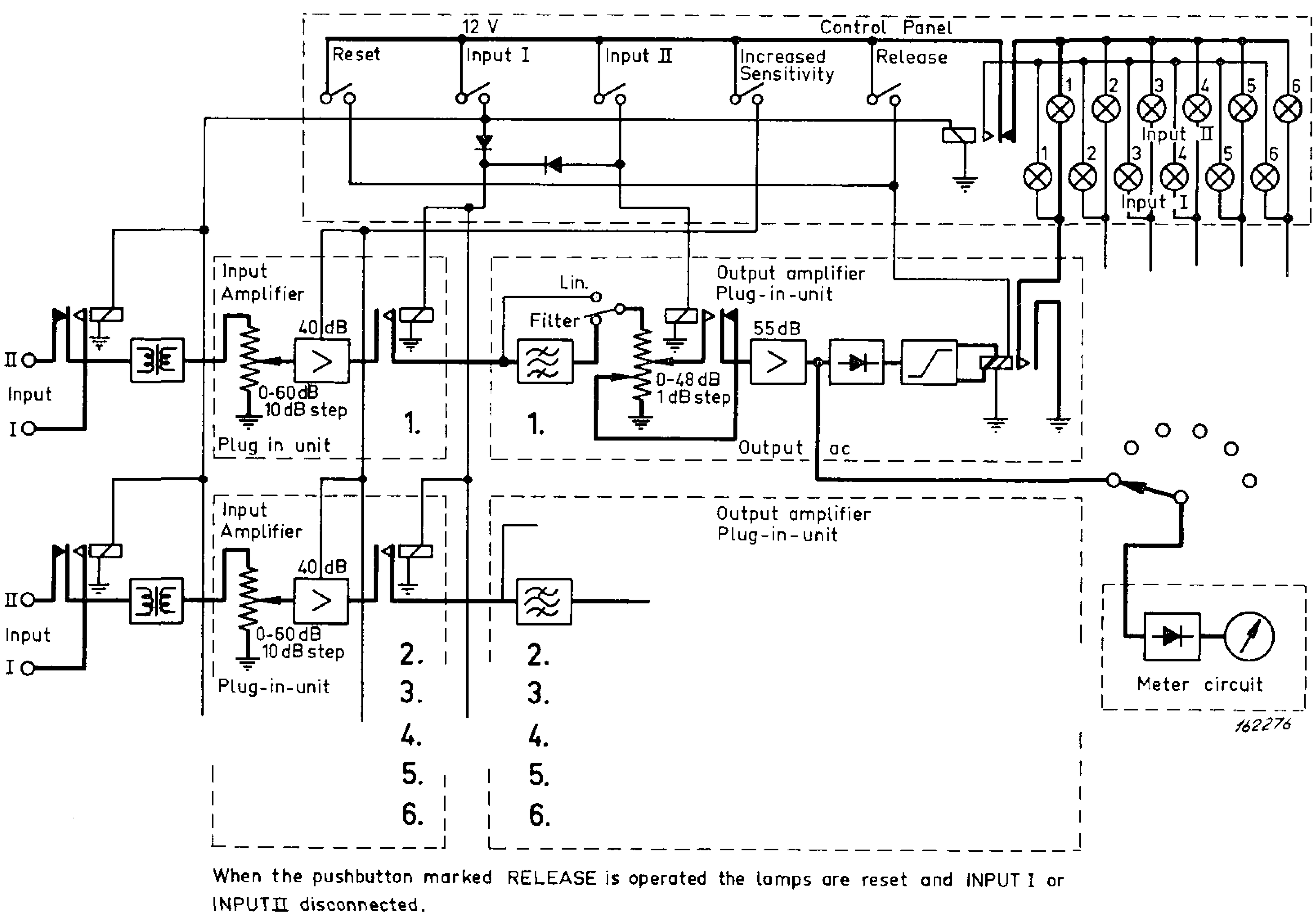

Fig. 18. Block diagram of the Noise Limit Indicator Type 2212 (Brüel & Kjær).

system. In the output amplifiers provision is made for the insertion of filters. A block diagram of the noise limit indicator is shown in Fig. 18, and Fig. 19 shows a photo of the complete installation in the central measurement station. At Oslo Airport it has, so far, been decided to use the unit dB (C) to activate the noise limit indicator when the prescribed sound pressure level is exceeded. This decision is partly based on the fact that the same microphone signal that activates the noise limit indicator is also recorded on tape. A complete analysis of the noise can then be made later from the tape, the signal not being restricted by a more heavy pre-weighting (dB (A)).

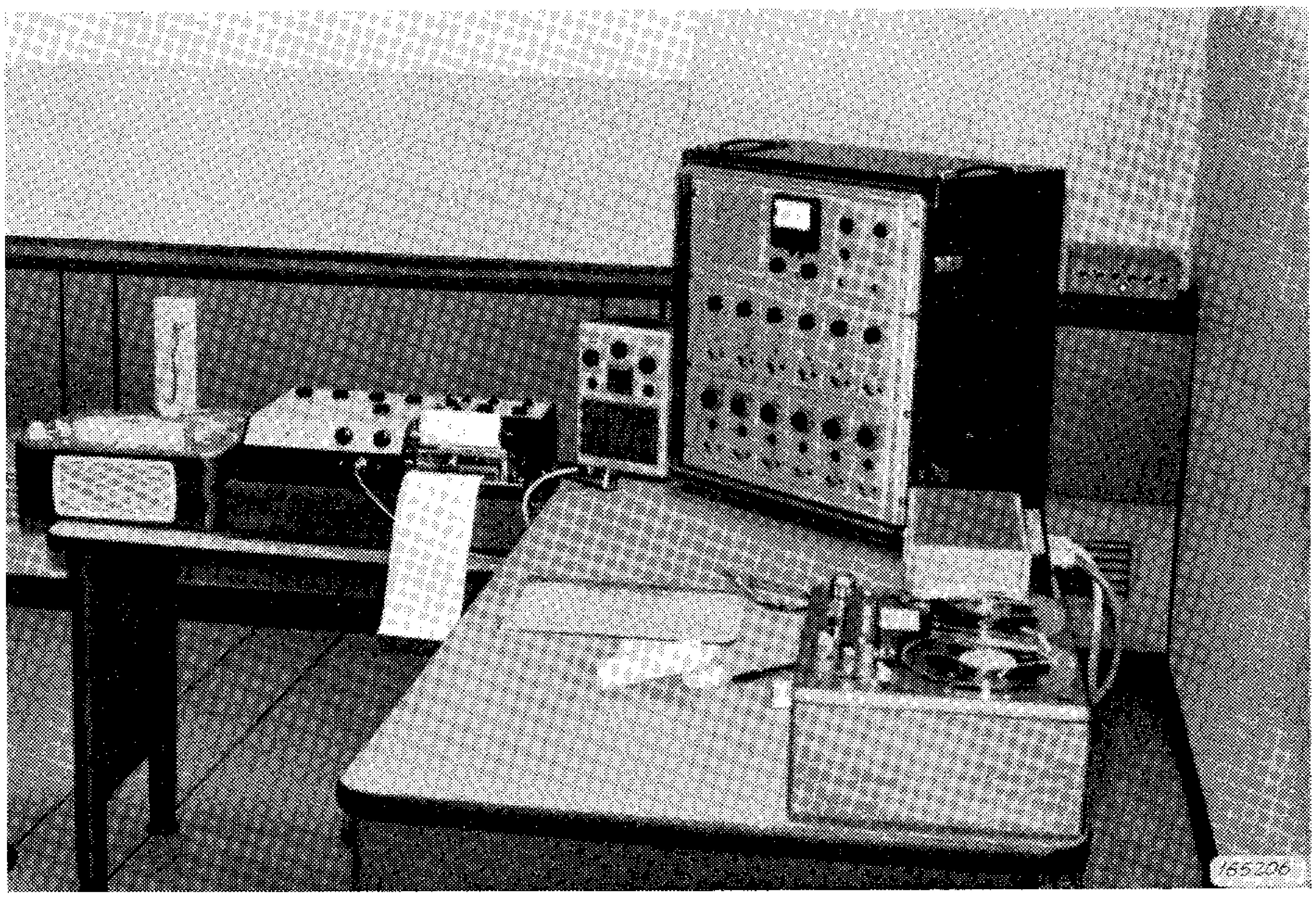

Fig. 19. Photo of the noise monitoring central measurement station interior.

As mentioned previously an exceedance of the prescribed noise level does not only start a magnetic tape recorder, but is also indicated both at the central measurement station and in the airport control tower by means of red lights. This facilitates inclusion of possible noise level exceedances in the flight control log. An example of such a log with the noise exceedance data included is shown in Fig. 20 (last column).

To evaluate the seriousness of the exceedances noted in the flight control log the magnetic tape recording can be carefully analyzed. It should be mentioned in this connection that a specially designed relay device ensures that the tape recorder records the signal from that microphone where the preset level was *first* exceeded.

A prime goal in the development of the complete monitoring system was that it should operate automatically, i.e. without constant manual supervision. Actually, only the flight control officer can be said to "operate" the equipment, apart from the necessary replacement and analysis of the magnetic tape and

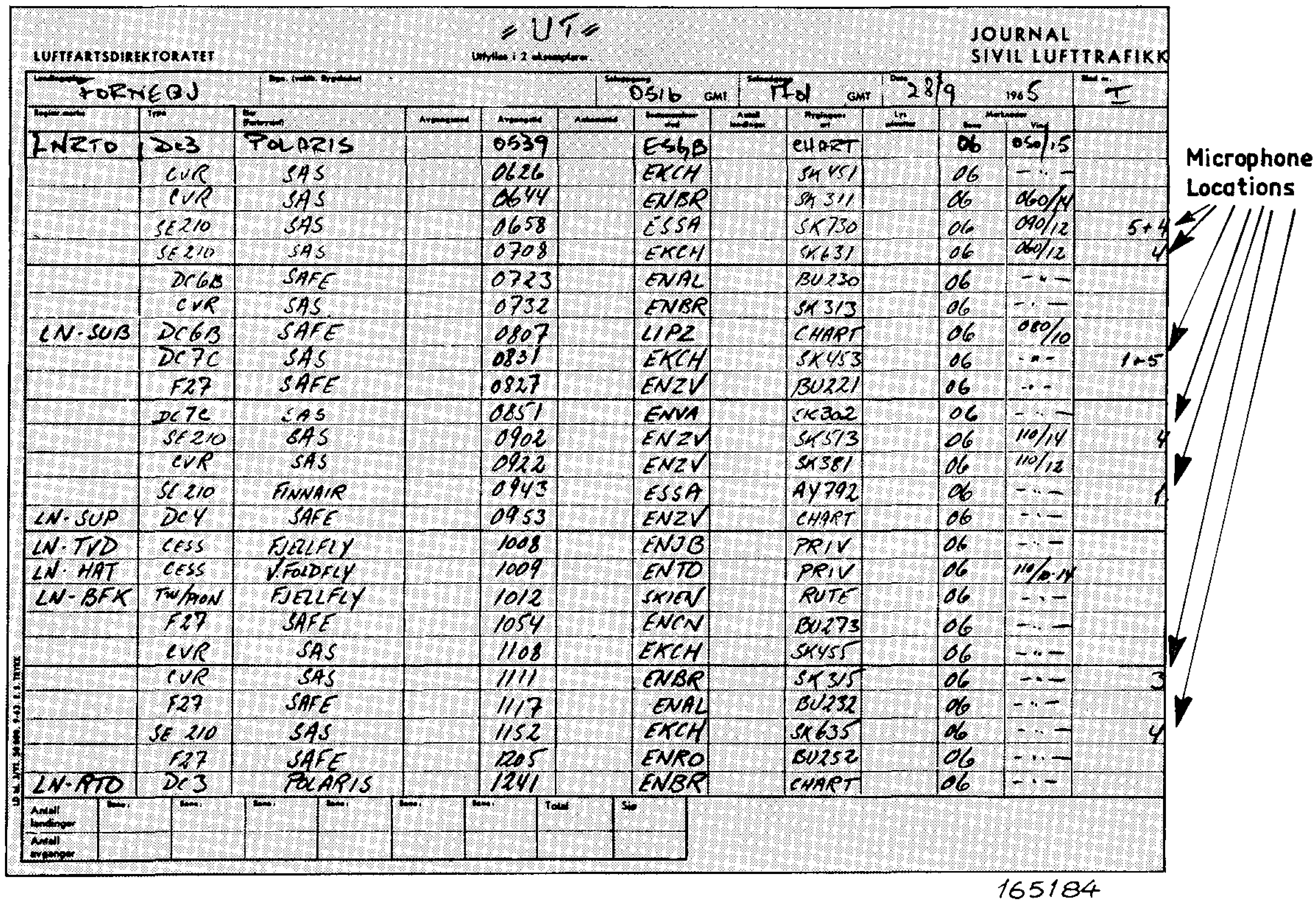

Fig. 20. Example of a flight control log with indications of microphones where the preset noise limit was exceeded (last column).

the collection of statistical data from the statistical distribution analyzers mentioned previously in the article. These analyzers are operated from a Brüel & Kjær Level Recorder Type 2305 which, at the same time, delivers a continuous graphic recording of the noise levels as a function of time.

The statistical distribution analyzers resolve the recorded information into twelve class intervals and present a numerical display of the data. To be able to distinguish between day and night noise one of the analyzers is set to operate continuously day and night, while the other only operates at night. The continuous operation can go on for about 11 days and nights before the main counter has reached its maximum number of counts (1.000.000 counts — 1 count/sec.). It is thus only necessary to reset the counters and check the arrangement every 11 days. If desired this period can be prolonged by the use of a different count rate. Count rates as slow as 1 count per 10 seconds are available on the analyzers, and the actual count rate used should be set according to the expected rate of change in the noise level. A photo of the Analyzer is shown in Fig. 21.

By switching the statistical distribution analysis arrangement to operate on the various microphones, a means is obtained for investigating how the noise exposure varies with time in various places, and also to check to what extent various noise reduction regulations function over certain periods of time.

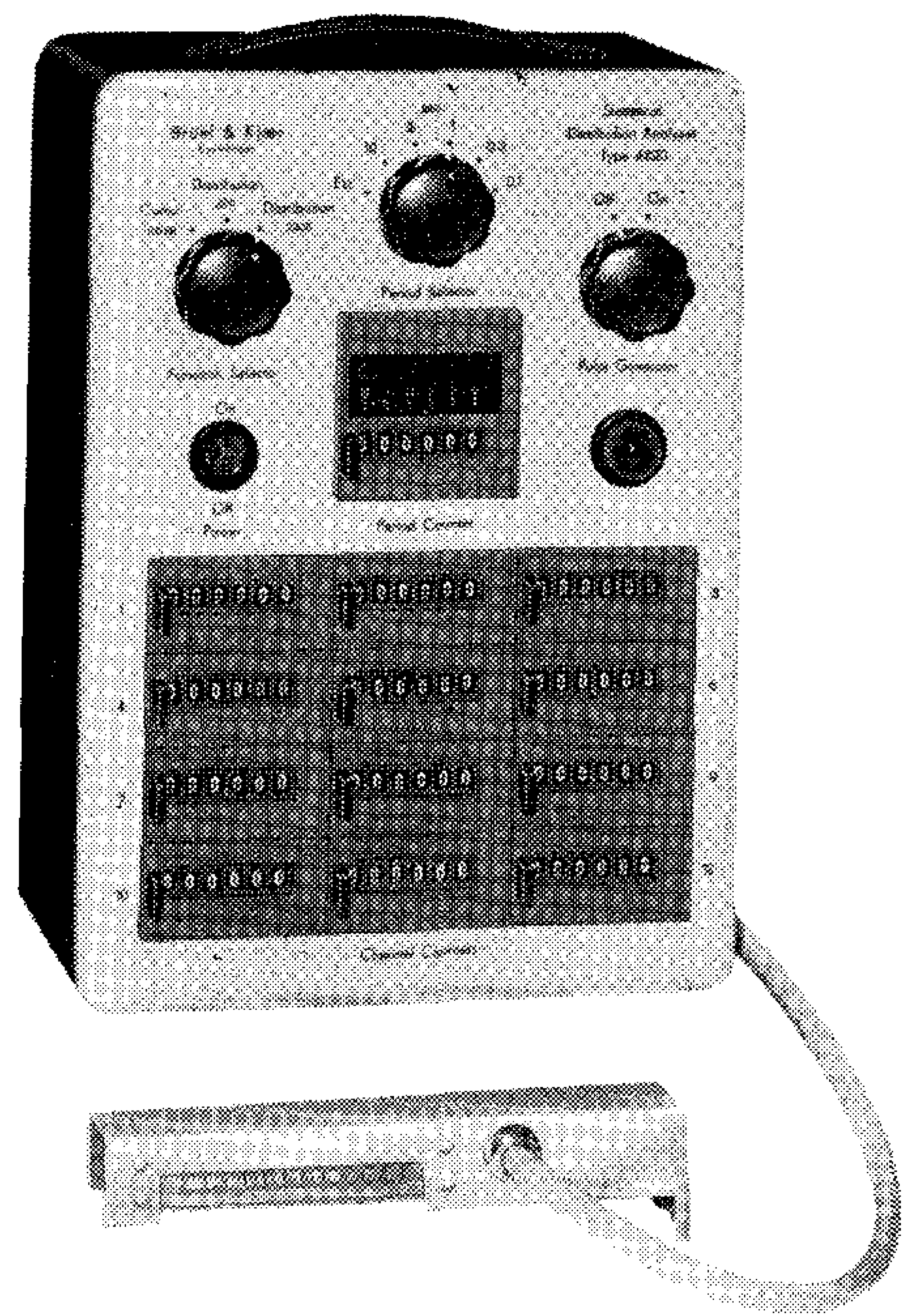

Fig. 21. The Statistical Distribution Analyzer (Brüel & Kjær Type 4420).

As an example of the use of the statistical distribution analysis arrangement Fig. 22 shows the result of such analysis for two different periods of time, one period lasting from July 16th to July 20th and the other from August 1st to August 5th 1965. From the diagram it is seen that there is a considerable

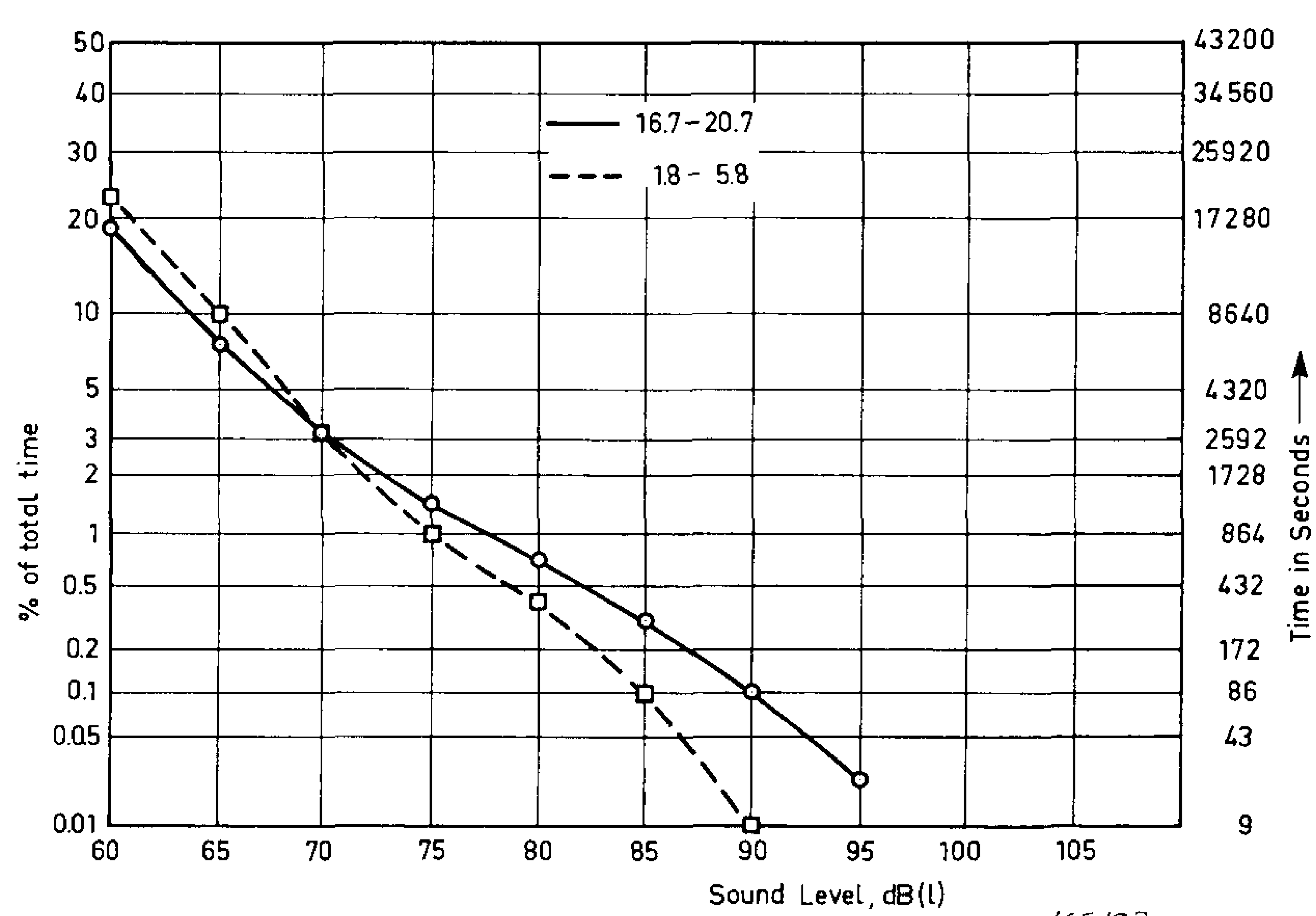

Fig. 22. Examples of the result of statistical analysis. The horizontal scale indicates the sound level in dB (C) and the left hand side vertical scale gives the percentage of the total time that certain sound levels were exceeded. The right hand side horizontal scale indicates the exceedance time in seconds.

difference in the noise level distribution with time between the two periods, which in this case was due to certain changes in the air traffic caused by meteorological conditions.
The Norwegian Aircraft Noise Commission considers this part of the noise monitoring system a very valuable tool for the evaluation of proposed noise reduction regulations.

Noise from Supersonic Aircraft (Sonic Bangs).

Before finishing this article on aircraft noise measurements and evaluation it seems in place to add a few words on one of the most important future aircraft noise problems,—the sonic bang from supersonic aircraft. It has frequently been pointed out by the O.E.C.D. expert group and a number of

Effects of sonic bang.

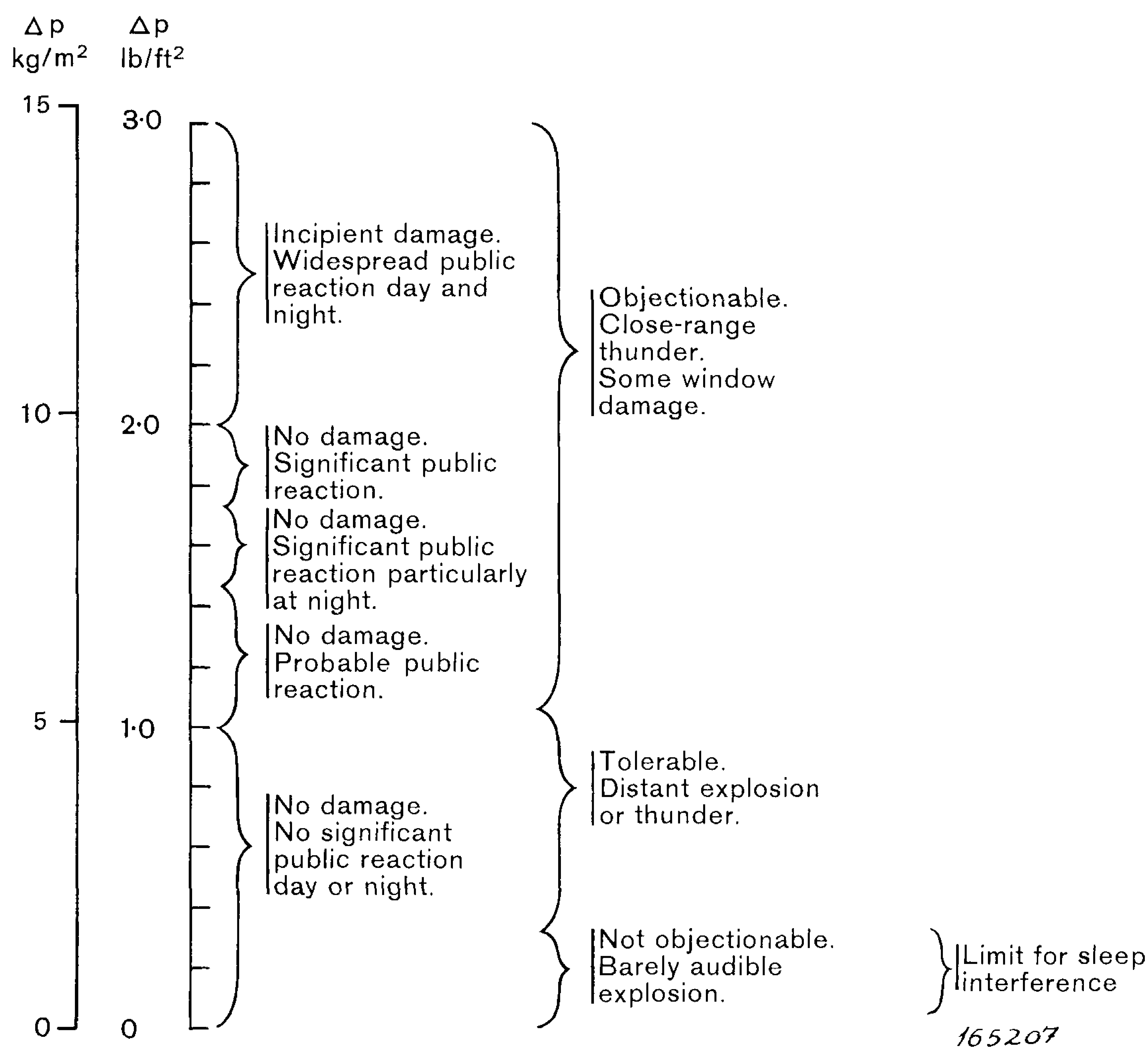

Table 5.

other institutions that the development of supersonic aircraft will cause new and very complicated noise problems. In Table 5 a "scale" of the expected effects of sonic bangs is given as a function of sound pressure (7). The sound pressure is here measured in Newton/m^2 (lb./ft.^{2}) rather than in decibels re 2×10^{-5}N/m^2 (2×10^{-4} μbar). Fig. 23 indicates the sound pressure to be expected for standard atmospheric conditions with the aircraft moving with different speeds and at different altitudes (7).

The solution of the noise problems created by supersonic aircraft must primarily be found in careful planning of the flight schedules. As the existing weather conditions strongly influence the flight schedules this must very seriously be taken into account in the planning, see for instance Fig. 24. The

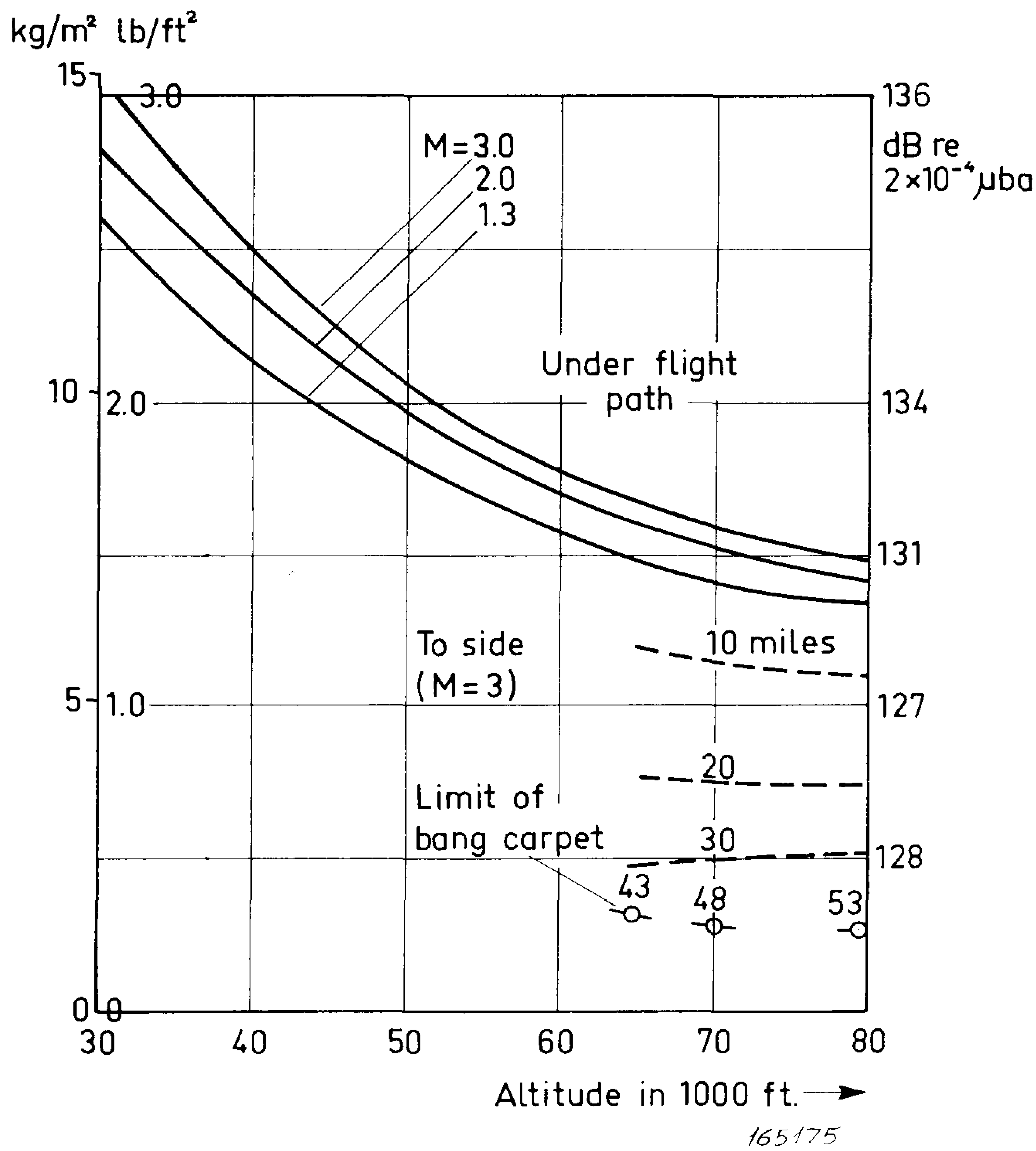

Fig. 23. Pressure rise on ground (sonic bang effect) for an aircraft of 180.000 kg (400.000 lb). The figures on the dashed lines indicate horizontal ground distance to the aircraft when this is flying at a speed of Mach 3 and in an altitude given by the horizontal scale (7).

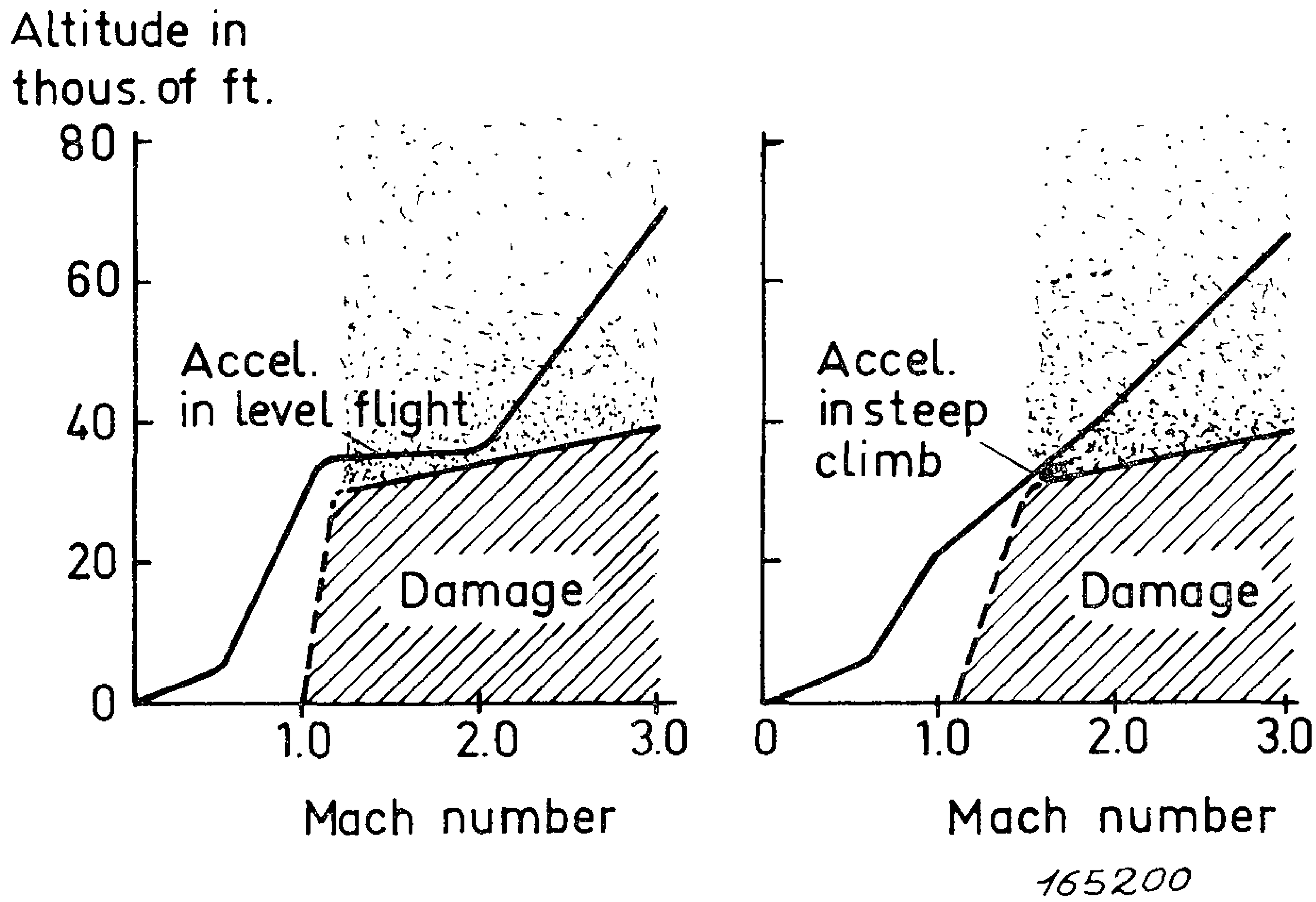

Fig. 24. Climb schedules to avoid damage.

figure shows two different climb schedules planned to avoid damage. A further factor in the planning, which has not been taken into account in Fig. 24 is that also the "damage area" changes with changing meteorological situations.

The result of such careful planning may very well be reduced to an economical question, and it is hoped that airport authorities and aircraft companies in cooperation can solve the problems to an extent that will be satisfactory for all the people to whom aircraft noise is a concern.

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2) ZWICKER, E.: "Ein Verfahren zur Berechnung der Lautstärke". Acustica, 10, 1960.

3) O.E.C.D. Document E.R.A./AR/4098.

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7) O.E.C.D.: Document DAS/RS/62.68.

Appendix A.*)

Recommendation for the Method to Be Used for Assessing the Subjective Effect of Aircraft Noise on Residents in the Vicinity of Airports.

The Group is of the opinion that experience concerning various methods used or proposed for assessing the subjective effect of noises from their objective characteristics is too limited for one exclusive method to be recommended for international use in assessing the annoyance of aircraft noise to residents in the vicinity of airports, but considers that Perceived Noise Level (1) and Loudness Level (computed by Zwicker's method for a free field) (2) are among the most promising. It recommends therefore that, for the time being, the subjective effect of aircraft noise should always be expressed in terms of Perceived Noise Level, and in the interest of furthering investigations in this field, also, whenever possible, in terms of Loudness Level (calculated according to the Method of Zwicker).

NOTE: For monitoring, or other purposes for which the highest precision may not always be demanded, there is a need for a suitable direct reading instrument. The Sound Level Meter with the A weighting, which is at present often used, goes some way to meeting this need. This practice is based on the experience that, for take-off noise, the difference between Perceived Noise Level and Sound Level A is roughly the same for aircraft of the same class at about the same distance from the start of the take-off roll. For example, an examination of the octave band spectra for the noise at about 4 miles from take-off of about 100 jet passenger aircraft, of 9 types currently in use, showed Sound Level A to be, on the average, about 12 dB lower than Perceived Noise Level, about 90 per cent of the differences lying within ± 2 dB of this average. A similar examination for propeller aircraft, including 12 different types, showed an average difference of 14 dB, about 80 per cent lying within ± 2 dB of this average. It should be recognised, however, that on occasion wider variations can occur, values up to about ± 4 dB having been encountered in the above examination. For other conditions, e.g. at smaller distances from take-off, or for landing, the average difference between Perceived Noise Level and Sound Level A will be different.

For the measurement of Sound Level A, the use is recommended of a high quality Sound Level Meter having the A weighting as close as possible to the values specified in the IEC Recommendation for Sound Level Meters, and using the slow response time of the meter.

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*) This Appendix is a reprint of Annex 1 of the O.E.C.D. document E.P.A./AR/4098.

(1) Karl D. Kryter — "Scaling Human Reactions to the Sound from Aircraft" — J.A.S.A. 31, 1415, 1959
or Noise Control 6, 5, September 1960.

(2) E. Zwicker — "Ein graphisches Verfahren zur Bestimmung der Lautstärke und der Lautheit aus dem Terzpegel-diagramm" Frequenz, 13, 234, 1959
or "Ein Verfahren zur Berechnung der Lautstärke" Acustica, 10, 304, 1960 (Figs .1 to 5).

Appendix B.

Some Noise Figures from Common Jet Aircraft.

In the following some results obtained from measurements reported by Bolt, Beranek & Newman Inc. (U.S.A.) are given.

Table B.1.

Noise figures for Caravelle III with silencer and RA 527 engines.

Engine Setting	8050 rpm (start)		7650 rpm		7500 rpm		7350 rpm	
Distance to the Aircraft (ft)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)
400	120	130	114	126	113	125	111	122
500	117	129	111	125	110	123	109	120
600	115	127	109	123	108	121	107	118
700	114	126	108	121	107	119	106	117
800	113	124	107	119	106	118	105	115
900	112	122	106	118	105	116	103	114
1000	111	120	105	116	104	114	102	112
1200	109	118	103	113	102	112	100	110
1400	107	116	102	111	100	110	99	108
1600	106	115	100	109	98	108	97	106
1800	105	113	99	108	97	106	96	104
2000	104	112	98	106	96	105	94	103
2200	103	111	96	105	95	104	93	101
2400	102	110	94	103	94	102	92	100
2600	100	108	93	102	93	100	91	98
2800	99	107	92	100	91	99	90	97
3000	98	106	91	99	90	98	88	96
3200	97	105	90	98	98	97	87	95

Table B.2.

Noise figures for DC-8 with silencer and JT 4A-9 engines.

Engine Power (start)				10.000 lb			8000 lb			6000 lb		
Distance to the Aircraft (ft)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)
400	121	133	115	113	126	108	107	121	102	102	116	98
500	119	131	113	111	124	106	105	118	100	100	114	95
600	117	129	111	109	122	104	103	116	98	98	112	93
700	115	126	109	107	120	102	101	114	97	97	110	91
800	114	125	108	106	118	101	100	113	95	96	108	90
900	113	123	106	104	117	99	99	111	94	94	107	88
1000	112	122	105	103	115	98	98	110	92	93	105	87
1200	110	119	102	101	113	96	96	107	90	91	103	84
1400	108	116	100	100	110	93	95	105	88	90	100	82
1600	107	114	98	98	108	91	93	103	86	88	98	80
1800	106	112	97	97	106	90	92	101	84	87	96	79
2000	104	110	95	96	105	88	91	100	83	86	94	77
2200	103	109	94	95	103	87	90	98	81	85	93	76
2400	102	108	93	94	102	85	89	97	80	84	91	74
2600	100	107	91	93	101	84	87	95	78	82	90	73
2800	99	105	90	92	99	83	86	94	77	81	89	72
3000	98	104	89	91	98	82	85	93	76	80	87	70
3200	97	103	88	90	97	81	84	92	75	79	86	69

Table B.3.
Noise figures for Comet 4 with silencer and RA-29 engines.

Engine Setting	8000 rpm (start)			7550 rpm			7350 rpm			6200-6300 rpm (landing)		
Distance to the Aircraft (ft)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)	Outdoor Sound Level (dBC)	Outdoor Noise Level (PNdB)	Indoor Noise Level (PNdB)
200	—	—	—	—	—	—	—	—	—	104	123	105
250	—	—	—	—	—	—	—	—	—	102	121	103
320	—	—	—	—	—	—	—	—	—	100	119	101
400	117	131	113	113	127	110	111	125	107	98	117	99
500	115	128	111	111	125	108	109	123	105	95	114	96
600	113	126	109	109	123	106	107	121	103	93	112	94
700	112	125	107	108	121	104	105	119	101	92	110	92
800	110	123	105	107	119	102	104	117	99	91	109	90
900	109	121	103	105	117	100	103	115	97	89	107	88
1000	108	120	102	104	116	98	102	114	96	88	105	86
1200	106	117	100	103	114	96	100	112	94	86	102	83
1400	104	115	98	101	112	94	98	110	92	84	99	80
1600	102	113	96	99	109	92	97	108	90	83	97	78
1800	101	112	94	98	107	90	96	107	88	—	—	—
2000	100	110	93	97	106	88	95	105	86	—	—	—
2200	99	108	92	95	104	87	93	103	85	—	—	—
2400	98	106	90	94	102	86	92	102	83	—	—	—
2600	97	105	89	93	101	85	91	100	82	—	—	—
2800	96	104	88	92	100	84	90	98	81	—	—	—
3000	95	103	87	91	99	83	88	96	80	—	—	—
3200	94	102	86	90	98	82	87	94	79	—	—	—

Appendix C.

Determination of Noise Levels in PN dB.

The PN dB-concept is basically a measure of the loudness of a noise, taking some of the "annoyance" effect caused by the noise into account. It is normally called a measure of "noisiness". To calculate the PN-dB-value of a noise the noise should be frequency analyzed by means of an octave band analyzer. From the sound pressure level measured in each octave band (re 2×10^{-4} μbar) the noisiness of the band sound pressure level is found by means of the chart Fig. C.1. The total noisiness (in Noys) is then found by adding the noisiness from the individual octave bands according to the formula:

$$N_{tot.} = N_{max} + 0.3\ (\Sigma N - N_{max})$$

Here $N_{tot.}$ is the total noisiness (in Noys), N_{max} is the noisiness of the "noisiest" octave band and ΣN is the sum of the noisiness of all the octave bands. When the value of $N_{tot.}$ is found in Noys this value can be converted into PN dB by means of the scale also shown in Fig. C.1.

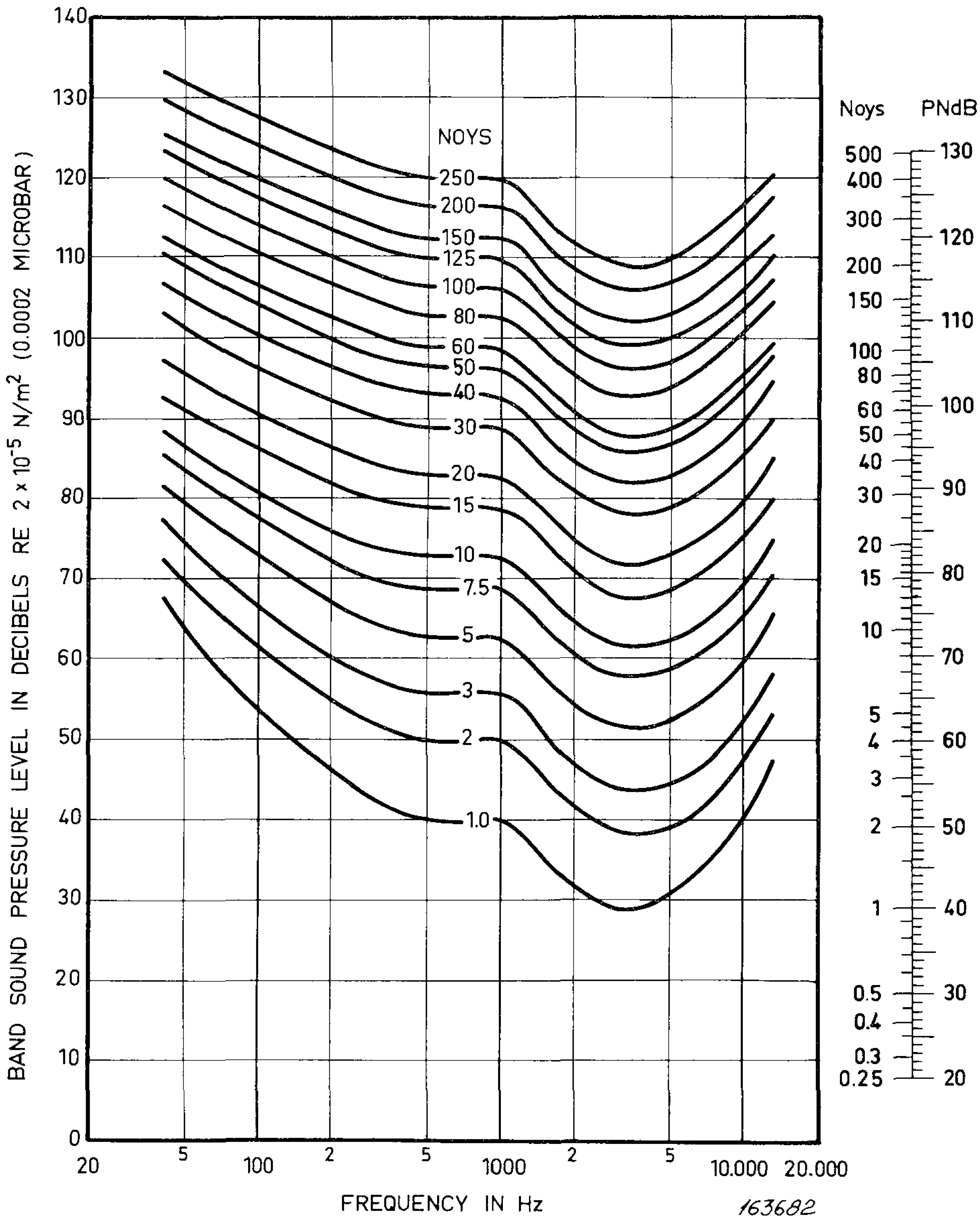

Fig. C.1. Equal "noisiness" contours.

Brüel & Kjær

ADR.: BRÜEL & KJÆR
NÆRUM - DENMARK

TELEPHONE: 800500
BRUKJA, Copenhagen

TELEX 5316

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