TECH. MEMO
FS 379

LEVEL II

TECH. MEMO
FS 379

ROYAL AIRCRAFT ESTABLISHMENT

A TEST FACILITY FOR THE OBJECTIVE MEASUREMENT OF CIRCUMAURAL HEARING PROTECTOR ATTENUATION

by

J. A. Chillery

February 1981

ROYAL AIRCRAFT ESTABLISHMENT

Technical Memorandum FS-379

Received for printing 5 February 1981

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

A TEST FACILITY FOR THE OBJECTIVE MEASUREMENT OF CIRCUMAURAL HEARING PROTECTOR ATTENUATION

by

J. A. Chillery

SUMMARY

The continuing development of the circumaural hearing protector requires control of the quality of this device. Current standard methods of protector attenuation measurement are expensive and time-consuming and wholly unsuitable for the quality control of quantity production. Performance of this task requires an objective test facility or 'artificial head'. This paper describes stages in the development of a facility suitable for quality control work and also useful as a research and development tool.

The paper was presented at the Second International Symposium on Personal Hearing Protection in Industry held at the University of Toronto, Toronto, Canada, 1980.

1 INTRODUCTION

Concurrent with the publication in 1974 of the British Standard method of measuring the attenuation of hearing protectors (BS 5108:1974) a need was expressed for a cheap, reliable and simple method of measuring this quantity which would be suitable for the quality control of quantity production and for monitoring the performance of protectors in use. It was acknowledged by the body responsible for BS 5108:1974 that the standard method was unsuitable for production testing and that further research was necessary before a suitable method, probably objective, would be recommended for this purpose.

As a consequence of these discussions Her Majesty's Factory Inspectorate stated a requirement for research into the development of an 'artificial head' to be used for production testing with the additional goal that this device might, in the long term, be developed for the type testing of protectors. It was stated that the method of production testing should generate data of a quality that would facilitate decisions concerning the maintenance or removal of official approval of a particular protector. These requirements initiated a research programme, funded by the Health and Safety Executive, carried out at the Institute of Sound and Vibration Research of the University of Southampton. This paper constitutes a summary of that programme.

The first step in the programme was a review of the current literature[1]. Two separate, but naturally linked, areas of research were examined. Firstly, the design of hearing protectors and those physical parameters of the human head which influence their performance were studied and secondly, the principles underlying past and present methods of hearing protector attenuation measurement were investigated, particular attention being paid to objective methods.

The first part of the review identified important factors in the attenuation and measurement processes and this facilitated discussion of past and present methods of attenuation measurement. The conclusions of the review provided a firm basis for the development of an 'artificial head' although some of the points raised required further investigation. Accordingly a prototype 'head' was built and a short programme of research aimed at clarifying these points was undertaken.

This work was performed concurrently with an assessment of the practical problems associated with objective attenuation measurement which was accomplished using three contemporary 'artificial heads' on loan to ISVR.

The information derived from all the sources described above was then used to design a final version of an objective test facility. The characteristics of this device were studied and some preliminary attenuation measurements were performed. Comparison of these latter data with standard attenuation values encouraged the possibility of prediction of attenuation.

2 LITERATURE REVIEW

2.1 Introduction

Initial considerations, illustrated in Fig 1, led to the identification of nine parameters of the circumaural protector and of the head of a wearer with a possible influence on the attenuation measurement process. Several of these were found to be unimportant given that an insertion loss* technique was used. Other parameters were found to be important although the exact nature of their influence on an objective measurement process could not be ascertained.

A summary of the findings concerning these nine parameters is given below.

2.2 Head geometry

The effect of the head, excluding the circumaural region, and upper torso were considered[2-5]. It was concluded that, given the use of an insertion loss type measurement, a rough approximation to a head in size, shape and mounting arrangements would be satisfactory.

The contours of the circumaural region of the head were also considered and found to have a significant effect on the fit of the protector to the head[6-8]. Fit, or lack of it, is a component of the phenomenon known as 'leakage'. In order that the attenuation data generated by an objective method resemble that generated by REAT methods it would be necessary to model leakage in the objective method. One way to achieve this would be to model the circumaural contours.

2.3 Head surface covering

2.3.1 Hair

Although opinions differ in the literature as to the precise nature of the effect, it is generally agreed that hair has a deleterious effect on hearing protector attenuation[6-14] in that it diminishes the integrity of the seal between the protector and the side of the head. It can thus be regarded as a component of leakage and the same argument that has just been presented for circumaural contours may be applied. That is, in order to simulate REAT data it may be necessary to represent the effect of hair.

To do this in a reproducible manner presents obvious difficulties. However, it may be possible to model leakage as a whole rather than model the individual components.

2.3.2 Skin and flesh layer

This parameter completes the description of the circumaural region. The action of the skin and flesh may be considered as being twofold. Firstly, it modifies the effect of the previous two parameters. For example, the leakage due to the notch formed at the junction of the jaw and neck may be modified as skin and flesh in that region is squeezed into the gap between the protector and the head.

Secondly, the compliance of the skin and flesh layer interacts with that of the protector cushion and by so doing limits the attenuation. The literature was found to disagree about the exact nature of this interaction[7,8,14] but it is generally believed to be an essentially low frequency phenomenon.

---

* Insertion loss is defined as the difference between two values of sound pressure level measured at the same point in the vicinity of the ear, one measured with and the other without the protector in position.

It is clear from the above that a skin and flesh simulation would be a desirable component of an objective method intended to generate attenuation data similar to that produced by REAT methods. Attempts to model skin and flesh have been made in the design of previous objective methods. The most recent of these is the design contained in ASA STD-1-1975[15] which uses a layer of cast vinyl. However, there is little experimental evidence to support this particular choice of material.

2.4 Pinna and concha

An objective measurement method in which the signal arriving at the observation point in the unoccluded state is important must have an ear replica capable of correctly modifying that signal. However, it was anticipated that the objective method developed here would utilise an insertion loss technique. This involved a subtraction process; that is, an occluded measurement would be subtracted from an unoccluded measurement.

In this case, as the literature indicated that the behaviour of the pinna and concha is not appreciably modified by occlusion[17,18], the effect of the pinna and concha would largely be eliminated during the subtraction[19].

2.5 Ear canal

The argument used in the previous sections may be applied equally well to the case of the ear canal. However, the literature is not clear about the behaviour of an ear canal in the occluded state and thus it was felt that experimental evidence was required in this case.

The most convenient method of acquiring such evidence was considered to be to investigate the effect of changing the ear canal geometry on the attenuation values generated by an otherwise unchanged system.

2.6 Bone conduction

The main conclusion from the literature dealing with bone or body conduction[10,20,25] is that the mechanisms of bone conduction are not yet fully understood, and that, even if they were, accurately modelling all the many conduction paths[26], would still present many problems.

A possible solution to this problem would be to utilise a correction curve. That is, to use one of the bone conduction threshold curves from the literature to set limits on the attenuation data produced by the objective method.

There are two drawbacks to this solution. Firstly, it is difficult to decide which of the bone or body conduction thresholds in the literature is the correct one in this case. Secondly, there exists the possibility that the circumaural protector influences the body conduction threshold[12] and that, therefore, different designs of protector produce different thresholds.

Given the above arguments it seemed wise to ignore, temporarily at least, bone conduction when designing an objective method.

2.7 Protector characteristics

Four components of the circumaural protector were found to be significant with respect to attenuation mechanisms. These, the cushion, the cup mass and volume and the headband were examined from two points of view. Firstly, their relevance to the design of an artificial head was assessed and, secondly, their importance to the intended applications of the objective measurement method was considered.

From the first point of view these four parameters were found to be of importance only in that they form part of the mass-spring system of which the remaining component is the skin/flesh layer. This therefore stressed the importance of a skin/flesh simulation to an objective measurement intended to produce similar attenuation values to REAT methods.

From the second point of view, cup mass and volume were discarded as being irrelevant. Interest in these cases lay in the usage of the objective method; either for production testing or for monitoring the degradation of protectors with use. Although cup mass and volume are important components of the attenuation mechanism the literature showed that attenuation values are relatively insensitive to minor changes in these parameters[7,27]. Therefore cup mass and volume were ignored when considering the calibration of the objective method.

This was clearly not the case with the protector cushion, which is the key component of a circumaural protector[8]. The literature was found to offer little information about the variation of attenuation with cushion characteristics. However, it can easily be appreciated that degradation of the cushion, for example a leak in a liquid-filled cushion, can cause appreciable loss of attenuation. In addition, it is not possible to estimate the variation in attenuation produced by fluctuations in production quality except to note that an objective method may be more sensitive to such variation especially in the absence of a skin/flesh simulation.

The last of these four parameters is protector headband force. The literature was found to contain information about the effect of this parameter on attenuation which indicated that, for a well designed and manufactured protector in a good state of repair, the attenuation would be insensitive to changes in headband force above a critical value[12]. However, in the absence of one or more of these conditions it may be that variations in attenuation with force could be quite large.

An objective measurement method would clearly show such variations but the cause would be unknown. In order to isolate the cause, an auxiliary method of measuring headband force would be required. As part of the experiments which followed the literature review a method to investigate the effect of headband force on attenuation was developed[28,29].

2.8 Existing artificial heads

The information gained from the examination of the literature described above was used in an evaluation of artificial heads described in the literature[9,10,30-35].

Eleven of these artificial heads all suffer from similar drawbacks and would not be suitable for standardisation. These drawbacks are:

(i) In many cases the choice of design features of the head is not explained.

(ii) The effect of changes in the design is not explored.

(iii) Several of the designs are highly individual and would be difficult to standardise.

However, one head[35] was observed to fulfil many of the requirements of an objective test method. It was clearly designed as a standard and operation would appear to be quick and simple, probably producing repeatable data. Drawbacks with this device would seem to be minimal, however the design is somewhat inflexible in that the device is only suitable for the specified purpose and could not easily be adapted.

2.8 Conclusions

The literature review allowed the relative importance of nine parameters of a protector and the head of a wearer to be established and the information gained was of assistance in a critical analysis of previous objective measurement methods. This provided a sound basis for the development of an objective measurement method suitable for standardisation as a production testing tool and for further development. Areas requiring further investigation were isolated. These were as follows:

(i) Investigation of the effect on attenuation values of different ear canal geometries.

(ii) Investigation of the possibility of simulating leakage in a simple, reproducible manner.

(iii) Investigation of the effect on attenuation values of different types of skin/flesh.

(iv) Investigation of the effect on attenuation values of using different forms of ambient acoustic field.

(v) Investigation of the effect on attenuation values of variations in headband force.

These five proposed areas of research were based on the assumptions that an insertion loss technique would be used and that the method might ultimately generate attenuation values similar to those produced by current REAT methods.

3 EXPERIMENTAL WORK

3.1 Introduction

Of the five areas pointed out by the literature review as requiring further investigation three, (i), (ii) and (iii) were considered to have an immediate bearing on the design of an objective test facility. The remaining two, (iv) and (v), which could influence the method of using the test facility, could be investigated later. Accordingly a series of experiments were performed in order to assess the relative importance of skin/flesh and leakage simulations and of the ear canal geometry. The majority of this work was performed using a prototype objective test facility of flexible design. However, certain experiments were also performed using three contemporary artificial heads. These were:

> the Knowles Electronic Manikin for Acoustic Research, REMAR[5];
> a 'head' known as KOJAK[10];
> a 'head' built to the design contained in ASA STD-1-1975[36].

The text below contains a brief account of this work. Unless otherwise specified experiments were performed in a near-diffuse field using the equipment shown in Fig 2[29].

3.2 <u>Ear canal goemetry</u>

The effect on attenuation spectra of ear canal geometry was investigated in two ways, firstly by measuring the attenuation spectrum of a protector several times using different ear-like couplers and secondly by studying the behaviour of the acoustic resonances inside an ear canal replica.

In the first case experiments were performed using the prototype 'head' shown in Fig 3, into which could be fitted a variety of ear-like couplers[29]. These were:

> three simple cylindrical couplers of internal dimensions (length × diameter) ½ inch × ¼ inch, 1 inch × ½ inch and 1 inch × ¼ inch;
>
> the Bruel and Kjaer Type 4153 Artificial Ear;
>
> the Zwislocki Artificial Ear.

Typical results from this work are shown in Figs 4 and 5.

Fig 4 shows spectra derived from the three simple couplers using the same earmuff. Although the high frequency differences are statistically significant in many cases it is clear that, in terms of practical attenuation measurement, the differences are unimportant.

The evidence from Fig 5 is less clear although similar trends may be observed. The marked differences at frequencies about 2000 Hz between the Zwislocki Artificial Ear and the remaining devices are ascribed to difficulties found when fitting protectors to the raised centre portion of this ear. The low frequency differences amongst the curves are judged to be a result of inadequate values of low frequency acoustic isolation of the Zwislocki and the Type 4153 which probably arose because the circumaural surface plates of both 'ears' are only one-quarter-inch thickness.

Studies of ear canal resonance behaviour were made using the Knowles Electronic Manikin for Acoustic Research[5] and probe-tube techniques developed at ISVR[37]. This well documented artificial head was developed primarily for studies of hearing aid response and contains a complete artificial ear including detachable pinna, ear canal and ear-like coupler. Using different lengths of small probe tube attached to a miniature microphone the sound pressure levels at different points along the ear canal axis were measured with and without occlusion of the ear by an earmuff of normal volume for single frequencies in the range 250-7000 Hz. This work was performed in a semi-anechoic room with low values of background noise.

Variations in the recorded values due to variations in fit of the earmuff on KEMAR were eliminated by referring all values to the output from a second microphone permanently positioned at a point equivalent to that of the tympanic membrane. A typical result is shown in Fig 6 from which it may be seen that the earmuff has had little effect on the behaviour of the ear canal resonances.

From these three pieces of experimental evidence it may be judged that an earmuff has little effect on the acoustic behaviour of the ear canal and that, within broad limits, practical insertion loss measurements are independent of the method of acoustically coupling the measurement microphone of a test facility to the volume contained by the earmuff under test.

3.3 Circumaural contours and skin/flesh simulation

A brief study was made of the effect on attenuation of an idealised circumaural contour and a skin/flesh simulation both separately and in conjunction. Experiments were performed using the prototype test facility shown in Fig 3. An idealisation of the leakage produced by the circumaural contours was produced by cutting a radial groove of triangular cross-section (approximately 2.5 cm wide and 2.0 cm deep) into the surface of the test facility. Skin/flesh simulation was provided by a novel material known as LCS or Sorbothane manufactured by Permali Gloucester Ltd.

This material has unusual characteristics which give it a particularly flesh-like quality. Although a soft solid it exhibits some of the properties of a liquid of very high viscosity. It has a density of 1.34 gm/cm^3 coupled with a low flexural rigidity and a Shore value of 40 (00 scale), at room temperature. Two thicknesses, 2 mm and 6 mm, were used in these experiments, each sample being in the form of a disc which completely covered the active surface of the test facility, except for the 'ear canal' entrance.

Two earmuffs were used. One with liquid-filled cushions (A) and the other with foam-filled cushions (B).

In the first set of measurements the effect on attenuation values of the two thicknesses of LCS was measured using the normal non-grooved surface of the test facility. Neither earmuff responded in an important way to the changes in the surface beneath the cushion. Secondly, the effect of the circumaural contour was measured by using the grooved surface. Here, although some minor high frequency decrease in attenuation was observed, earmuff B was again largely unaffected. Earmuff A however suffered considerable low and high frequency decreases in attenuation as shown in Fig 7.

Finally, the effect of the skin/flesh simulant LCS on attenuation values measured using the grooved surface was studied. As expected earmuff B was only slightly affected but the attenuation spectrum of earmuff A was raised at the low and high frequencies as shown in Fig 8.

The 2 mm layer restored the attenuation almost to the values observed for the non-grooved surface. The restoration was continued at the low and high frequencies when the 6 mm sample was used. However, a decrease, as yet unexplained, was observed over the

From these experiments it was concluded that there was no advantage to be gained at this time by the inclusion of either or both of circumaural contours and skin/flesh simulations in an objective test facility intended for production tests. Even if a suitable skin/flesh simulant could be manufactured reliably to a standard and did not 'age' significantly it is still clear that a much better understanding of the interaction between different surfaces and cushions is necessary.

Similarly the marked difference between the reaction of the two protectors to the different surfaces requires explanation before such contours could meaningfully be incorporated in the design of an objective-test facility.

3.4 Existing artificial heads

In order to assess the practical problems of objective attenuation measurement experiments were performed using three existing 'heads'.

One of these, the ASA STD-1-1975 'head'[15], was designed specifically for the quality control of quantity production and another, KOJAK[10], was designed for the measurement of protector attenuation by a purchaser of such devices whilst the third, REMAR[5], was not specifically intended for attenuation measurement. All three were found to be unsuitable, to a greater or lesser extent, for the quality control of protector attenuation.

Criticism of the ASA STD-1-1975 'head' arose from the failure of two separately constructed versions of this 'head'[29,38] to achieve the acoustic isolation spectrum (60 dB at all test frequencies) specified by the standard. It was considered unlikely that the quality of engineering at the two establishments where these 'heads' were constructed would be exceeded by other potential users and that the fault lies with the design of the ASA STD-1-1975[36] 'head' which possibly does not pay sufficient attention to the elimination of leaks.

A second, minor, criticism of the ASA STD-1-1975[36] 'head' was that the effects produced by the angle of the 'head' and the cast vinyl surface layer do not justify their inclusion in the design. The attenuation spectra produced by this 'head' differed little from equivalent spectra produced by the prototype ISVR 'head'. The effect of these two features has also been investigated by other workers[38] who also concluded that there was little to be gained, for a quality control tool, by the addition of these features.

Also, the artificial skin was found here to lengthen the experimental period as it was more difficult to clean and replacement required great care.

The main criticism of the head 'KOJAK'[10] was that although the data produced offers useful information about the behaviour of earmuffs on artificial heads the device is of too complex a construction to be suitable for quality control work. In addition, the acoustic isolation of the device is unknown and also, a lengthy test period is necessary.

It was found that severe practical problems arose when using a simulation such as KEMAR[5]. The presence of a flexible pinna which must remain undistorted and the lack of suitable reference points made it extremely difficult to reproducibly place the protector on the head. It was found that changes of position indiscernible to the eye produced changes in attenuation of up to 15 dB.

From the experiments with these three 'heads' it became clear that only the most simple device would be suitable for the measurement of earmuff attenuation for the purposes of quality control. None of the devices examined were found to offer any advantages over a simple mounting for a microphone with provision for attachment of the headband.

4 THE OBJECTIVE TEST FACILITY

4.1 Introduction

The conclusions from the literature review and the results of the experimental programme were combined in the design of a final version of the objective test facility or artificial head.

A sketch of the 'head' showing details of the design is shown in Fig 9. Fig 10 shows the 'head' when assembled and also the brass cup, used for acoustic isolation measurements.

The fundamental intention of the design was to produce a simple device for quality control work with very high acoustic isolation whilst at the same time incorporating a capacity for changing the geometry. This flexibility was envisaged as allowing changes in contact with the protector under test which would facilitate both the development of improved protectors and further development of the 'head' itself.

These considerations led to the concept of a central mainframe, containing the microphone and with high acoustic isolation, to which could be attached accessories to interface the device to the protector in the manner desired. That is, the accessories would not be essential to the acoustic seal which would only be disturbed to replace defective components and therefore comparisons amongst attenuation spectra measured using the same protector under different conditions could be quickly and easily performed.

The 'head' mainframe and accessories were constructed from Duralumin to the dimensions shown in Fig 9. These dimensions may be adjusted at will by choosing different accessories. The values chosen approximate those of the median human head[38,39].

The 'head' is supported by a pillar constructed from mild steel. Earlier success, in terms of acoustic isolation, of the prototype head had been attributed in part to the housing of the microphone emitter follower inside the body of the device. Here, the volume inside the mainframe was insufficient for this purpose and an alternative method was required. By choosing heavy gauge tubing for the support pillar it was found possible to mount the emitter follower inside the support pillar.

The internal diameter of the pillar was such that the emitter follower was a push-fit and it was clamped in position using a screwed collar arrangement. The emitter follower cable exit was via a shallow groove machined into the underside of the base plate brazed onto the support pillar. This base plate was of such dimensions that it mated with the support platform of the vibration isolated tripod.

When the base plate and the tripod were securely clamped together the emitter follower cable was compressed between the two in the groove and a good acoustic seal was achieved. Sealing between the main frame and the support pillar was easily achieved by screwing the pillar, with a taper thread, into the base of the mainframe. In this condition the acoustic isolation was shown to be in excess of 65 dB at all frequencies except 6300 Hz and 8000 Hz where it was 61 dB and 63 dB respectively.

4.2 Main frame

Details of the main frame are shown in Fig 9. The design shown represents a slight modification of the original concept in that a screw-in plug to seal what is shown as an open end was dispensed with as being unnecesary for these experiments but could be added to the system at a later date.

The main frame is a right cylinder with three features of interest, the first of these is a hole, let into the centre of the end face, which is machined such that a Bruel and Kjaer Type 4166 microphone cartridge with the protective grid removed can be screwed firmly into it. When the microphone is fully inserted the diaphragm plane lies just below the plane of the outer surface of the end face. This is necessary so that when an accessory is fixed on to the end face the fragile diaphragm of the microphone is not damaged.

Clearly, mounting the microphone in the main frame meant that it was displaced from the sound field inside the protector to be measured by a distance equal to the thickness of the accessory. This was regarded as an advantage for several reasons:

(i) It was essential to the concept of a main frame to which could be attached accessories without disturbing the acoustic seal.

(ii) It placed the delicate microphone cartridge at a point where it would not be easily damaged.

(iii) It obviated any problems with summation of the sound field[35] in that the microphone operates under the same conditions independently of whether the orifice is occluded or not.

Displacing the microphone from the contact surface in this way was justified by the work described in section 3.2 where it was shown that there were only slight variations amongst the data gathered from the ISVR prototype 'head' using a variety of couplers. That is, the attenuation spectra generated using an insertion loss method of measurement were largely independent of the microphone placement and the nature of the path between the microphone and the protector sound field.

The second feature of interest is the hole let into the curved surface of the main frame. This was tapped to accept the support pillar which, containing the Bruel and Kjaer Type 2619 emitter follower, is inserted into the main frame such that the end of the Type 2619 protrudes slightly above the interior surface of the main frame. This allows contact to be made between the Type 2619 and the Type 4166 using a Bruel and Kjaer Type UA0023 flexible adaptor. The practical minimum radius of curvature of the flexible adaptor formed a convenient lower limit on the internal dimensions of the main frame.

The third interesting feature of the main frame is the provision made for the attachment of a headband contact surface analogous to the top of the human head. The influence of this on the test data was unknown and therefore the headband contact surface was hinged so that it could be swung away after protector adjustment and measurements could then be made both with and without contact between the headband and the test facility.

4.3 Accessories

The two end plates used were identical except that one had a ¼ inch diameter coaxial hole. Both were machined to be a push-fit on to the main frame and were firmly attached using Allen screws.

As may be appreciated the end plates are easy to manufacture and a range of these with different thicknesses (to change head width), angles, contours and surface treatments could easily be produced.

The flexibility introduced into the system by these possible accessories is one of the main features of the design.

However, initial interest in the device lay in its usefulness as a quality control tool and therefore only simple end plates were manufactured.

5 ATTENUATION MEASUREMENT USING THE OBJECTIVE TEST FACILITY

5.1 The characteristics of the test facility were examined. The effects of different types of test sound field, test field sound pressure levels and degrees of contact between the headband of a protector and the top of the test facility on attenuation spectra were studied. The knowledge thus gained was combined with information derived from earlier experiments with the prototype and other artificial heads to produce the equipment specifications and test procedure described below.

Following this some preliminary measurements of the attenuation of protectors previously tested using the British Standard method[40] were made. The coefficients of the regression line of subjective on objective attenuation were calculated.

5.2 Equipment

The instrumentation and test environment were similar to those used in earlier experiments and shown in Fig 2. A 'pink' noise signal was used to power two loudspeakers placed asymmetrically in a normal hard-walled room. The sound field produced was diffuse almost to within the specifications of the British Standard for the subjective measurement of protector attenuation[40]. Signal analysis was performed using standard analogue instruments although the broad band nature of the test sound field clearly argues for the future use of digital analysis techniques which would decrease the experimental period considerably.

5.3 Procedure

The experimental procedure finally decided upon was as follows. The protector to be tested was removed from storage and fitted to the test facility with headband contact. This entailed ensuring that the headband was adjusted to the correct width and that the protector cups were symmetrically placed on the headband and on the test facility surface. If the headband was of more than one piece this was also adjusted to be symmetrical. The protector fitted tightly to the test facility.

The positions of the cups were then marked (with a dab of paint) and the protector carefully removed and returned to storage. Any additional protectors were then adjusted in the same way.

After measurement of the unoccluded spectrum at the test facility when placed in the test field and cleaning of the test facility surfaces the protector to be tested was then placed on the test facility in such a way that the previous adjustments were not disturbed, the headband was firmly in contact with the 'head' top and the protector cups were symmetrically placed on the appropriate surfaces. A light horizontal momentary force was then applied to both cups along the axis of the test facility. The occluded spectrum was then measured and the protector carefully removed and returned to storage. Other protectors to be tested were then treated in the same manner. This process was repeated five times and the unoccluded spectrum measured again.

The mean value, at each test frequency, of the five occluded values was then subtracted from the corresponding mean value of the two unoccluded values provided that the latter had not changed by more than 1 dB. Otherwise the sound generation system was checked for malfunction.

5.4 Protector attenuation measurement using the objective test facility

The attenuation spectra of four protectors were measured using the test facility and the method described in the previous section. The purpose of this work was firstly to check that the method was viable for protectors in general and secondly to produce comparisons between data derived from this objective technique and that produced by current standard subjective methods. Although the primary purpose of the test facility was a quality control tool it has been developed to also be a flexible base from which either a type test or a tool for the investigation of protector characteristics may be developed. Also, before this device can be used for quality control, measurements of many samples of many types of protectors must be performed in order to allow the setting of standards.

The following measurements represent a first step towards the accomplishment of these objectives. The protectors tested all had foam-filled cushions and plastic headbands. Subjective data were available.

Differences between the subjective and objective data at standard[40] subjective test frequencies were calculated and the results are shown in Fig 11. The coefficients of the regression line of subjective attenuation on objective attenuation are shown in Table 1.

It may be seen that the curves in Fig 11 all follow a similar pattern. The differences are at a low minimum at frequencies below 250 Hz and then rise steadily to a maximum value at 2000 Hz. A second minimum occurs at around 4000-6300 Hz and a second maximum at 8000 Hz. Similar trends may be observed in the results of other workers[7].

Although not ideal, the values of correlation coefficient are sufficient to encourage the collection of more data. Further work in which the attenuation spectra of many samples of many types of protector would be measured both subjectively and objectively is required. Suitable analysis of these data might allow the following:

Prediction of subjective values of attenuation from measured objective values with appropriate confidence intervals.

Calculation of objective and subjective inter-protector sample variances which would allow quality control limits to be set.

6 CONCLUSIONS

Stages in the design of an objective test facility primarily intended for the quality control of quantity production have been described. Important features of the design are high acoustic isolation (greater than 60 dB at all test frequencies between 63 Hz and 8000 Hz) and simplicity of use. Additional features have been incorporated, without affecting the primary design goals, which extend the possible use of the device.

The performance of the device using various test sound fields and procedures was examined. It was found that reliable data were generated using a simply obtained diffuse field and a simple test procedure.

Use of this device for quality control would require criteria to be established. Further work in which attenuation spectra of many samples of many types of protector would be measured both subjectively and objectively in order to provide a basis for such criteria has been suggested. It was also proposed that a different analysis of such data might lead to the production of a method of predicting subjective values from measured objective values.

Shortage of time precluded the performance of all but a pilot study of one sample of four protectors. These data cannot be used as a basis for quality control criteria but do encourage the possibility of prediction of attenuation values.

Table 1

LINEAR REGRESSION OF SUBJECTIVE ON OBJECTIVE ATTENUATION FOR OUR PROTECTORS

Frequency	r^2 Correlation coefficient	Slope	Intercept
63	0.82	0.63	4.7
125	0.05	0.13	7.6
250	0.97	0.61	6.1
500	0.23	0.34	12.1
1000	0.66	0.59	5.6
2000	0.35	0.32	15.9
3150	0.51	0.52	11.8
4000	0.80	0.43	14.6
6300	0.72	0.62	5.1
8000	0.94	0.34	16.0

REFERENCES

No.	Author	Title, etc
1	J.A. Chillery	Attenuation properties of circumaural hearing protectors: A review of the factors involved in their objective measurement. Institute of Sound and Vibration Research Memo No 576, The University of Southampton (1978)
2	L.A. Abbagnaro B.B. Bauer E.L. Torick	Measurements of diffraction and interaural delay of a progressive sound wave caused by the human head. J. Acoust. Soc. Am. 58, 693-700 (1976)
3	R. Kasten S.H. Lotterman	Azimuth effects with ear level hearing aids. Bull of Prosth Res. 10-7, 50-61 (1967)
4	E.A.G. Shaw	Transformation from the free field to the ear drum in the horizontal plane. J. Acoust. Soc. Am. 56, 1848-1860 (1974)
5	M.D. Burkhard R.M. Sachs	Anthropometric manikin for acoustic research. J. Acoust. Soc. Am. 58, 214-222 (1975)
6	J.C. Webster	Ear defenders: Measurement methods and comparative results. Noise Control 1, 34-42 (1955)
7	J.J. Zwislocki	Factors determining the sound attenuation produced by earphone sockets. J. Acoust. Soc. Am. 27, 146-155 (1955)
8	E.A.G. Shaw G.J. Thiessen	Improved cushion for ear defenders. J. Acoust. Scc. Am. 30, 24-36 (1958)
9	P.G. Joyce	Determination of the attenuation characteristics of circumaural hearing protectors for impulse noise. Development Branch Notes DN. 50 Reference YS/150/050, Quality Assurance Directorate (Weapons), Development Branch, Woolwich (1973)
10	M.F. Russell S.P. May	Objective tests for earmuffs. J. Sound Vib. 44, 545-562 (1976)
11	P J. Soilleux	The design of more effective acoustic ear protectors. SRDE (RSRE) Memo No T21/78 BR 724-24, Christchurch (1973)
12	A.G. Gorman	Factors affecting the design of circumaural hearing protectors. Paper presented at a Symposium at the National Physical Laboratory, Teddington, Middlesex, England (1976)

REFERENCES (continued)

No.	Author	Title, etc
13	E.M. Whitham A.M. Martin	An investigation of an artificial ear technique for the evaluation of hearing protectors. Institute of Sound and Vibration Research, Tech Memo 513, The University of Southampton (1976)
14	J.J. Zwislocki	Ear protectors. In Handbook of Noise Control by C.M. Harris, McGraw Hill Book Co. New York (1957)
15	American Standards Association	Method for the measurement of real-ear attenuation of ear protectors at threshold. ASA Z24-22 (1957)
16	K. Brinkmann K-H. Broksch	Sound attenuation provided by ear defenders Parts I and II. Uber die Schalldammung von Gehorschutzern, Z Hor-Ak/J Audiol Tech 9, (1970), 178-193 and 10, 10-28 (1971)
17	E.A.G. Shaw	Ear canal pressure generated by circumaural and supra-aural earphones. J. Acoust. Soc. Am. 39, 471-479 (1966a)
18	E.A.G. Shaw G.J. Thiessen	Acoustics of circumaural earphones. J. Acoust. Soc. Am. 34, 1233-1246 (1962)
19	G. Rood	Towards a semi-objective method for the measurement of the acoustic attenuation of flying helmets. Paper presented at a Symposium at the National Physical Laboratory, Teddington, Middlesex (1976)
20	E. Barany	A contribution to the physiology of bone-conduction. Acta-Otolaryngol Suppl. XXVI (1938)
21	G. v Bekesy	Vibration of the head in a sound field and its role in hearing by bone conduction. J. Acoust. Soc. Am. 20, 749-760 (1948)
22	J. Tonndorf	Bone-conduction. Chapter 5, in Tobias (1972) pp 195-235; Academic Press, New York and London (1972)
23	S.M. Khanna J. Tonndorf J.E. Queller	Mechanical parameters of hearing by bone conduction. J. Acoust. Soc. Am. 60, 139-148 (1976)
24	J.J. Zwislocki	In search of the bone conduction threshold in a free sound field. J. Acoust. Soc. Am. 29, 795-804 (1957)

FS 379

REFERENCES (continued)

No.	Author	Title, etc
25	C.W. Nixon H.E. v Gierke	Experiments on the bone conduction threshold in a free sound field. J. Acoust. Soc. Am. 31, 1121-1125 (1959)
26	J. Tonndorf	Bone-conduction. Chapter 5, in Tobias (1972) pp 195-235; Academic Press, New York and London (1972)
27	J.J. Zwislocki	An investigation of certain means of sound attenuation at the ear. AD 257039, Armed Services Technical Information Agency, Arlington Hall Station, Arlington, Virginia, USA (1961)
28	J.P. Cox	An apparatus for the measurement of hearing protector head-band force. BSc final year project, Department of Mechanical Engineering, The University of Southampton (1978)
29	J.A. Chillery	Objective measurement of the attenuation of circumaural hearing protectors. Institute of Sound and Vibration Research Memo No 602, The University of Southampton (1978)
30	J.R. Forstall	Manikin measurements of the noise attenuation provided by flight helmets. AD 676 885, Naval Aerospace Medical Institute, Pensecola, Florida (August 1968)
31	M.E. House A.M. Martin K. Howell	Cockpit noise - flight helmet attenuation. A contract progress report 1499 for the Ministry of Defence, Institute of Sound and Vibration Research, The University of Southampton (September 1972)
32	G.W. Unsworth	Acoustic attenuation of the Mk II flying helmet. BSc final year project, Faculty of Engineering and Applied Science, The University of Southampton (1972)
33	E. Schiller J.B. Rosenfeld	Development of objective technique for ear protector attenuation measurement. Reports 1,2 and 3, Project 920-46, US Naval Applied Science Lab., Brooklyn, New York (1967), (1968), (1969)
34	P.L. Michael D.F. Bolka	An objective method for evaluating ear protectors. Final report, Department of Health, Education and Welfare, Grant 1 RO1 OH 00341-01, Environmental Acoustics Laboratory, 3, Psychology Building, Pennsylvania State University, USA (1972)

REFERENCES (concluded)

No.	Author	Title, etc
35	A.G. Gorman	Objective measurement of hearing protector performance. Proposals presented to ISO/TC 43/SC 1/WG 17 meeting June 1977 by A.G. Gorman, Technical Director, Racal-Amplivox Ltd, Wembley, Middlesex, England.
36	Acoustical Society of America	Method for the measurement of real-ear protection of hearing protectors and physical attenuation of earmuffs. ASA STD-1 (1975)
37	M. Lower	Institute of Sound and Vibration Research, The University of Southampton, private communication (1976)
38	L.S. Whittle G.J. Sutton D.W. Robinson	The objective measurement of hearing protectors of the circumaural type. National Physical Laboratory Acoustics Report Ac. 87 (1978)
39	C.B. Bolton M. Kenward R.E. Simpson G.M. Turner	An anthropometric survey of 2000 Royal Air Force Aircrew 1970/71. RAE Technical Report 73083, Procurement Executive, Ministry of Defence, Farnborough, Hants (1973)
40	British Standards Institution	Method of measurement of attenuation of hearing protectors at threshold. BS 5108: (1974)

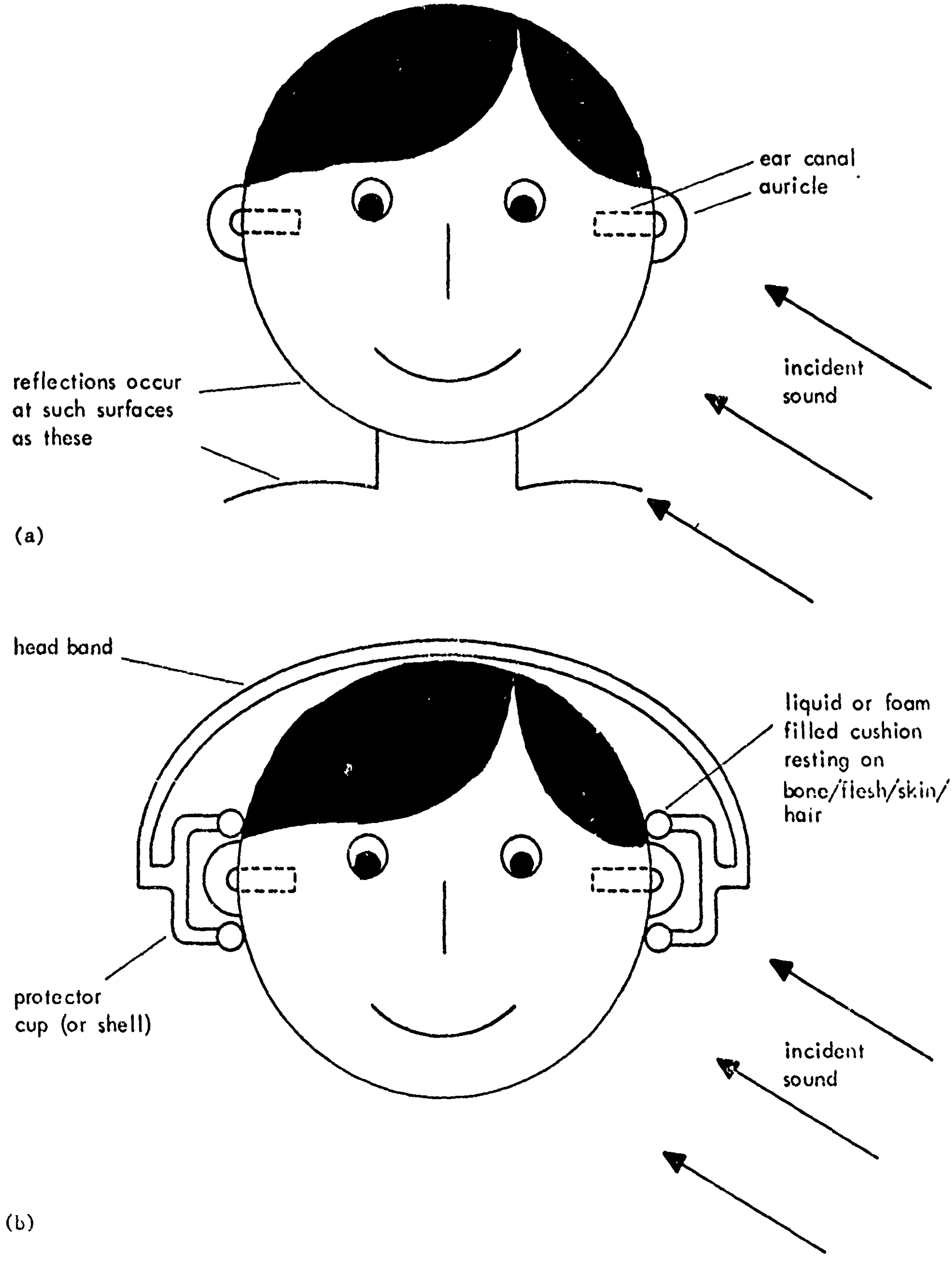


Fig 1 Illustrating important factors in the measurement of the attenuation of circumaural hearing protectors

Fig 2

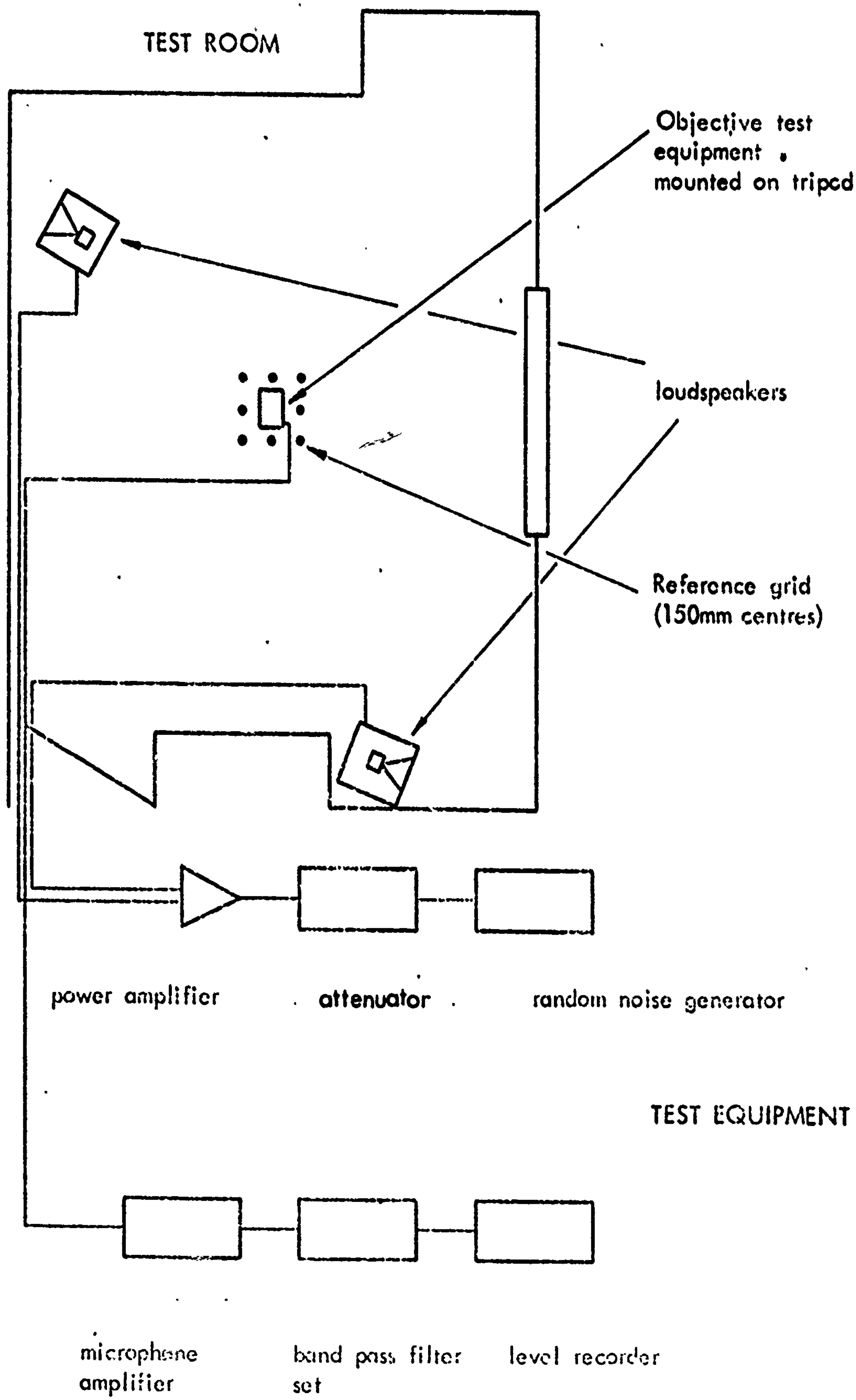
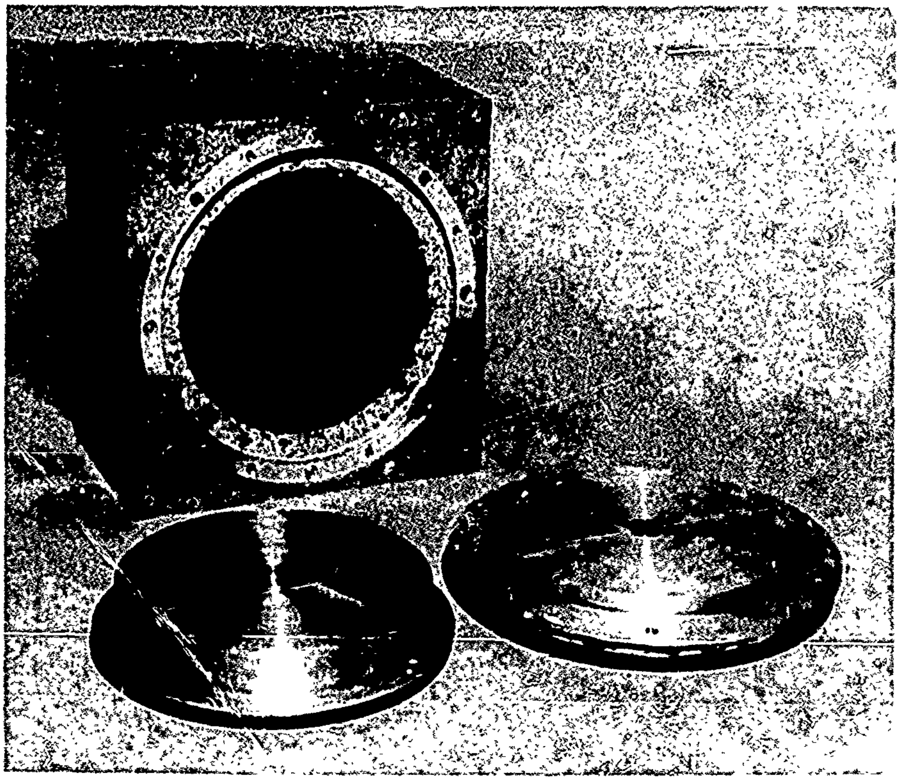
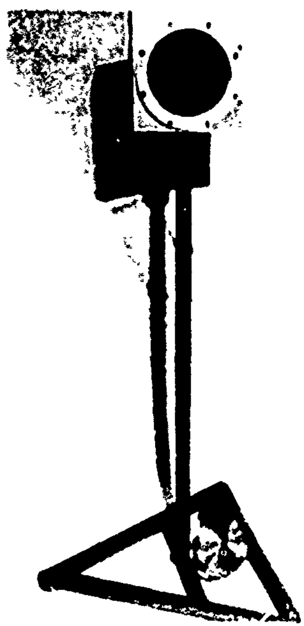


Fig 2 Showing experimental layout used for objective tests



a Artificial head with inserts

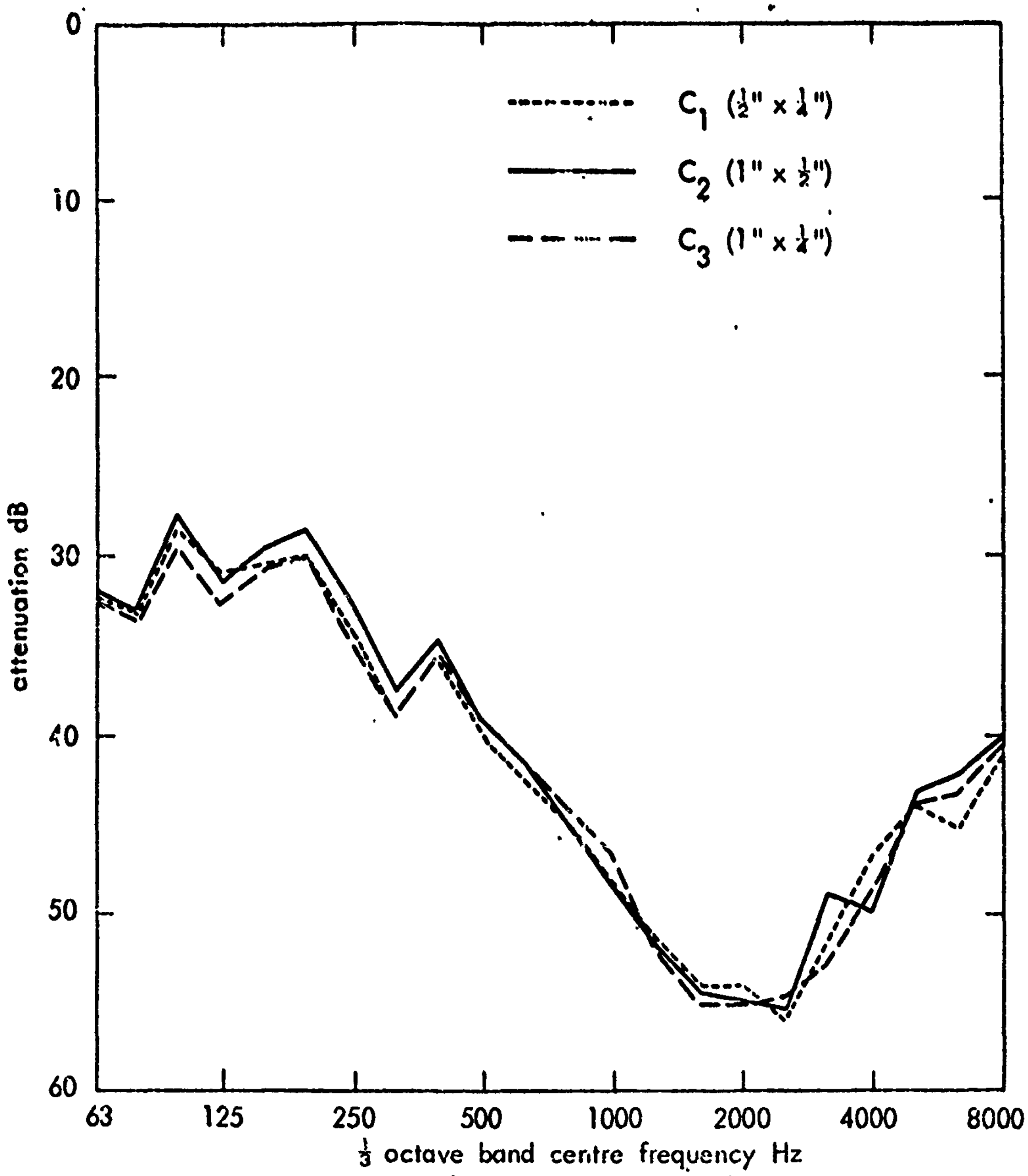


b Vibration isolated tripod

Fig 3a&b Prototype objective test facility

TM FS 379 C16736

Fig 4



FS 379

Fig 4 Attenuation specra-measured using three couplers of different geometries

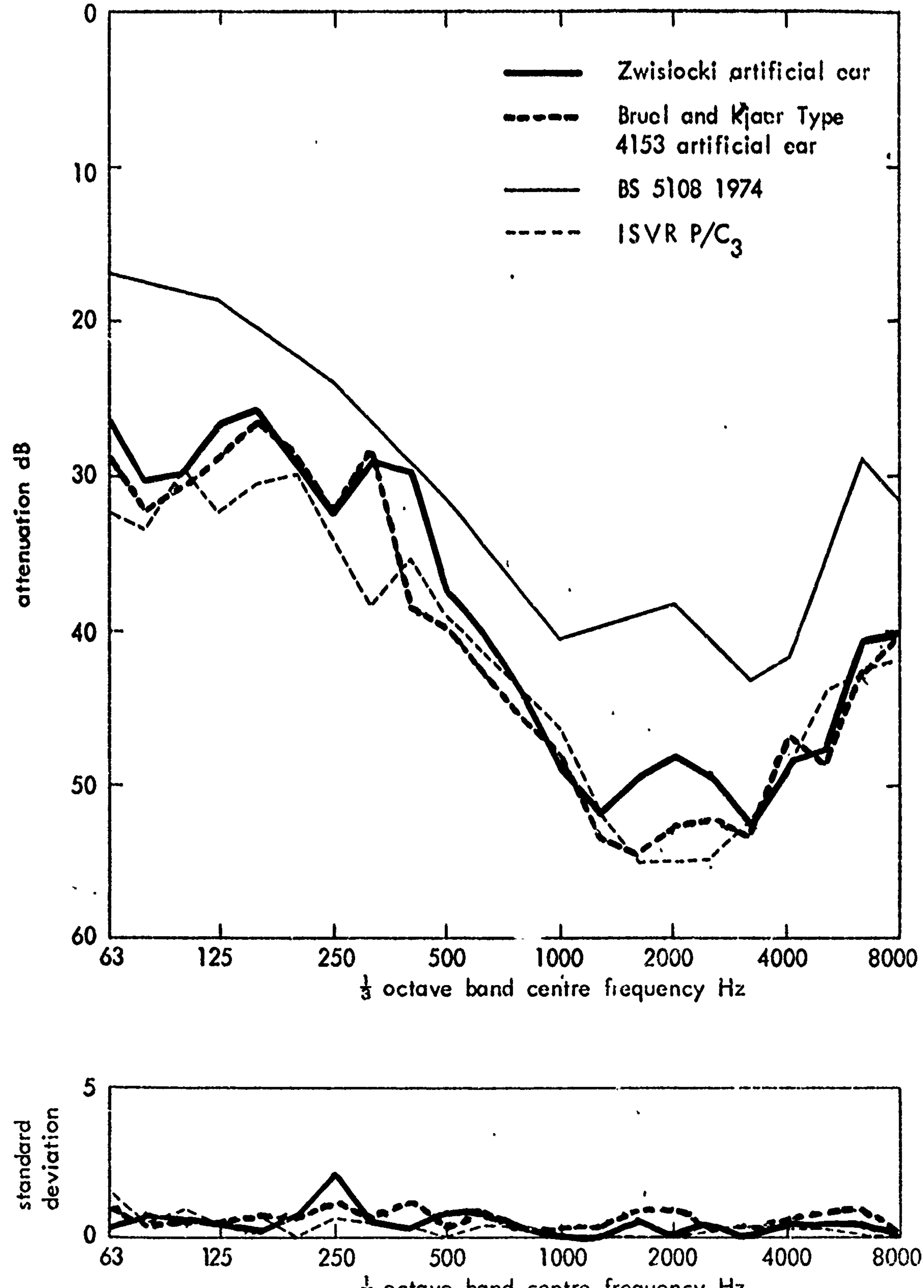


Fig 5 Attenuation spectra as measured by four methods

FS 379

Fig 6

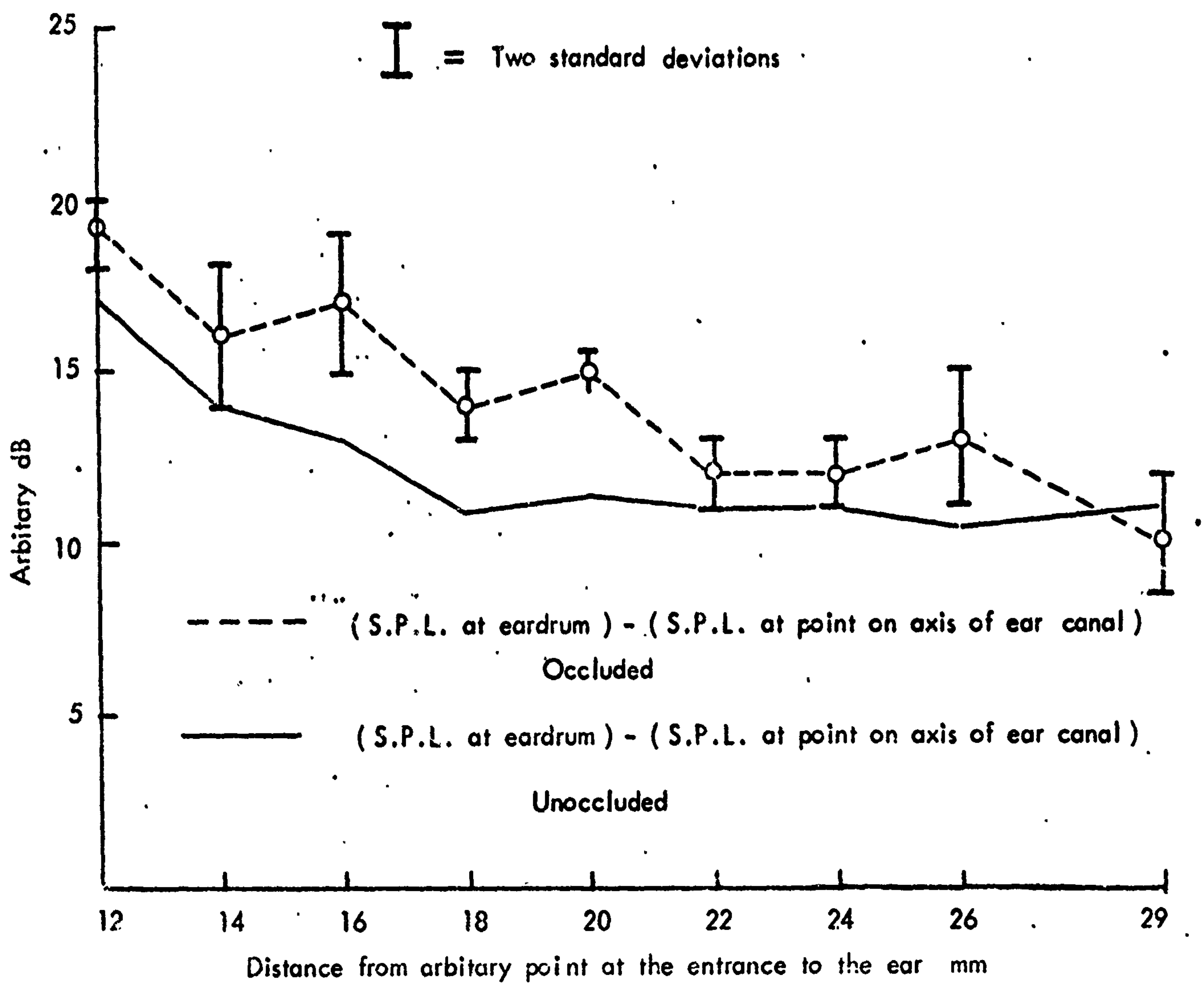


Fig 6 Showing difference in the resonance pattern in KEMAR's ear canal between the occluded and unoccluded states

FS 379

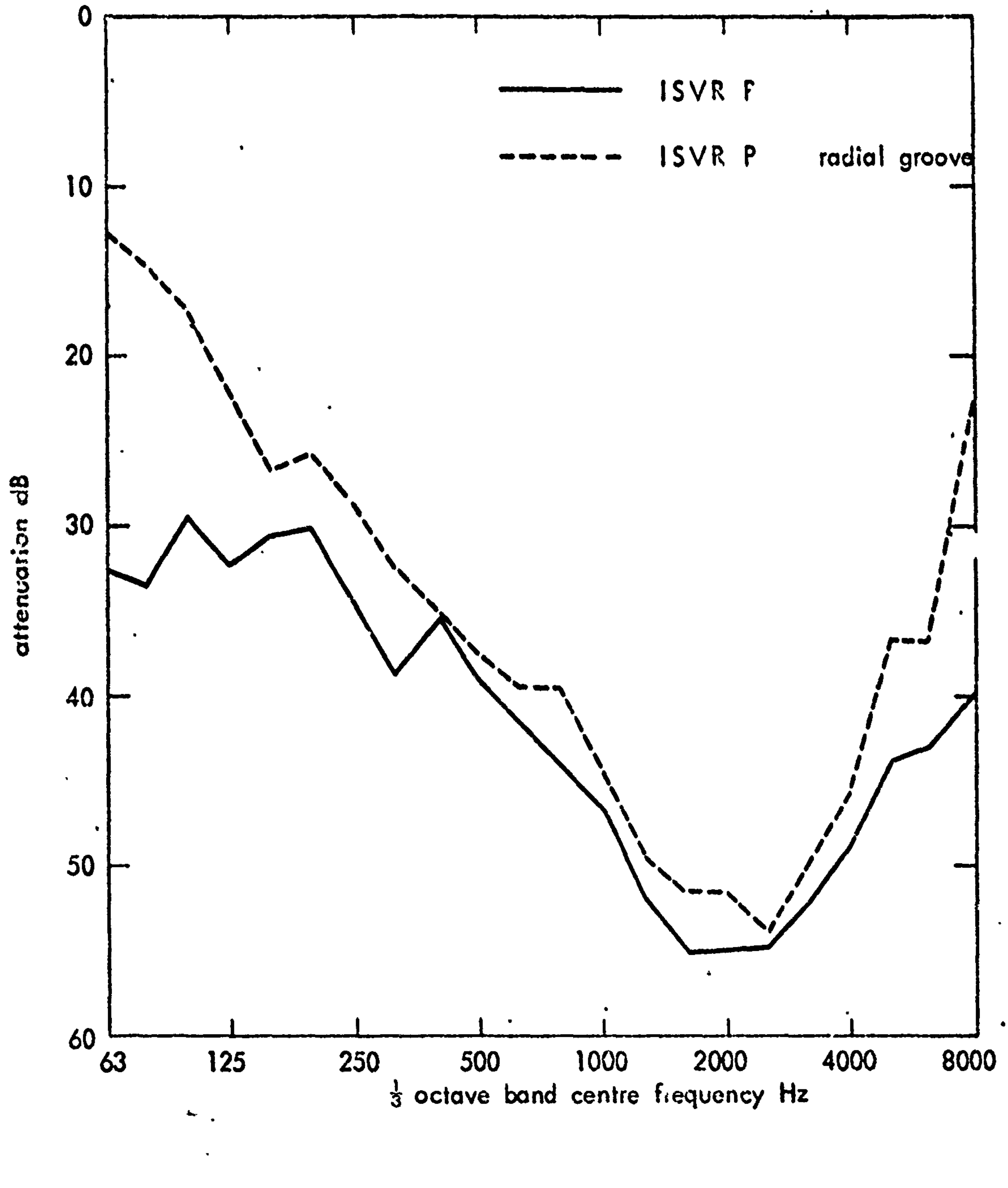


Fig 7 Effect on attenuation of radial groove (liquid-filled cushion)

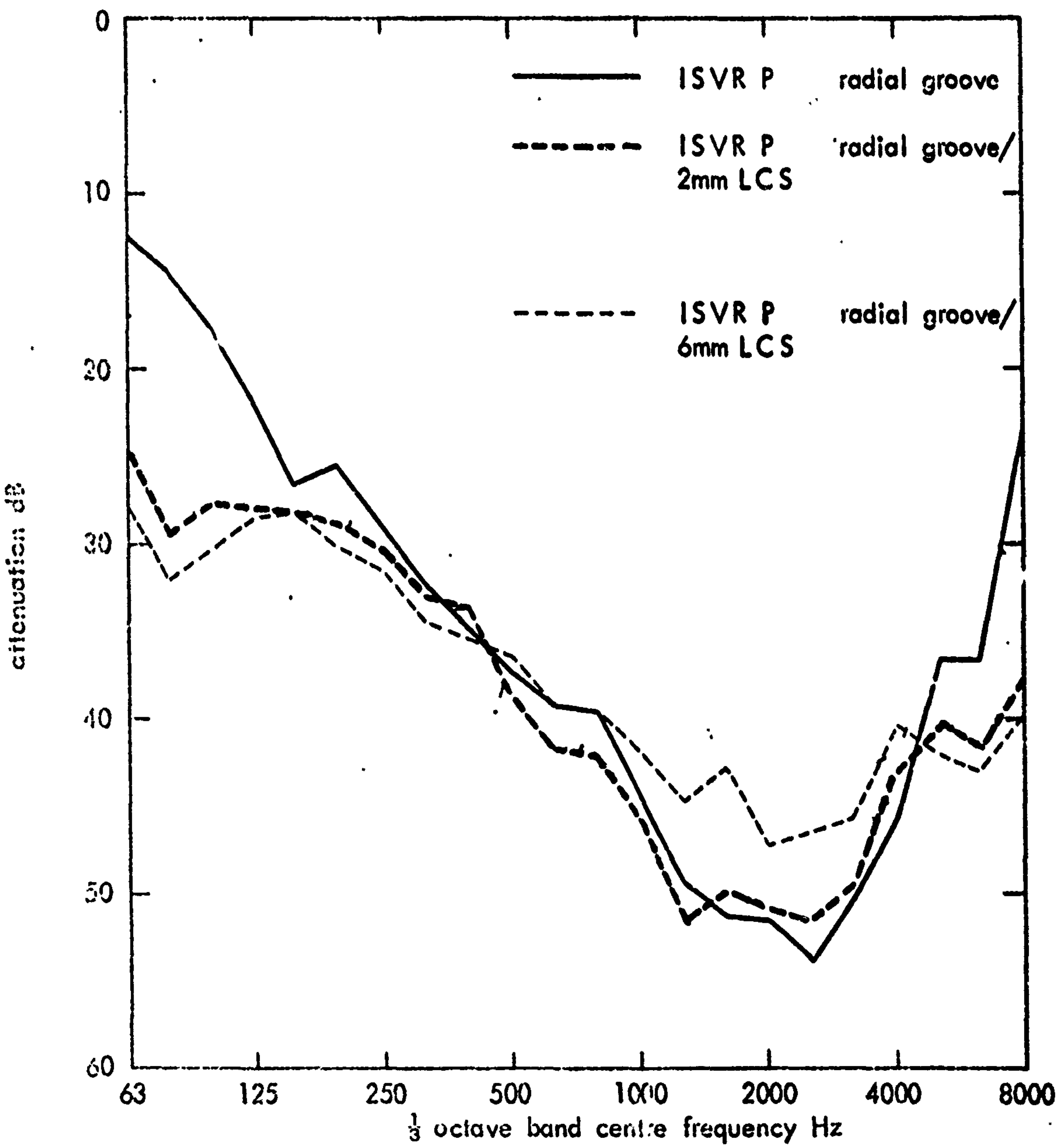


Fig 8 Effect of skin simulant on attenuation (liquid-filled cushion).

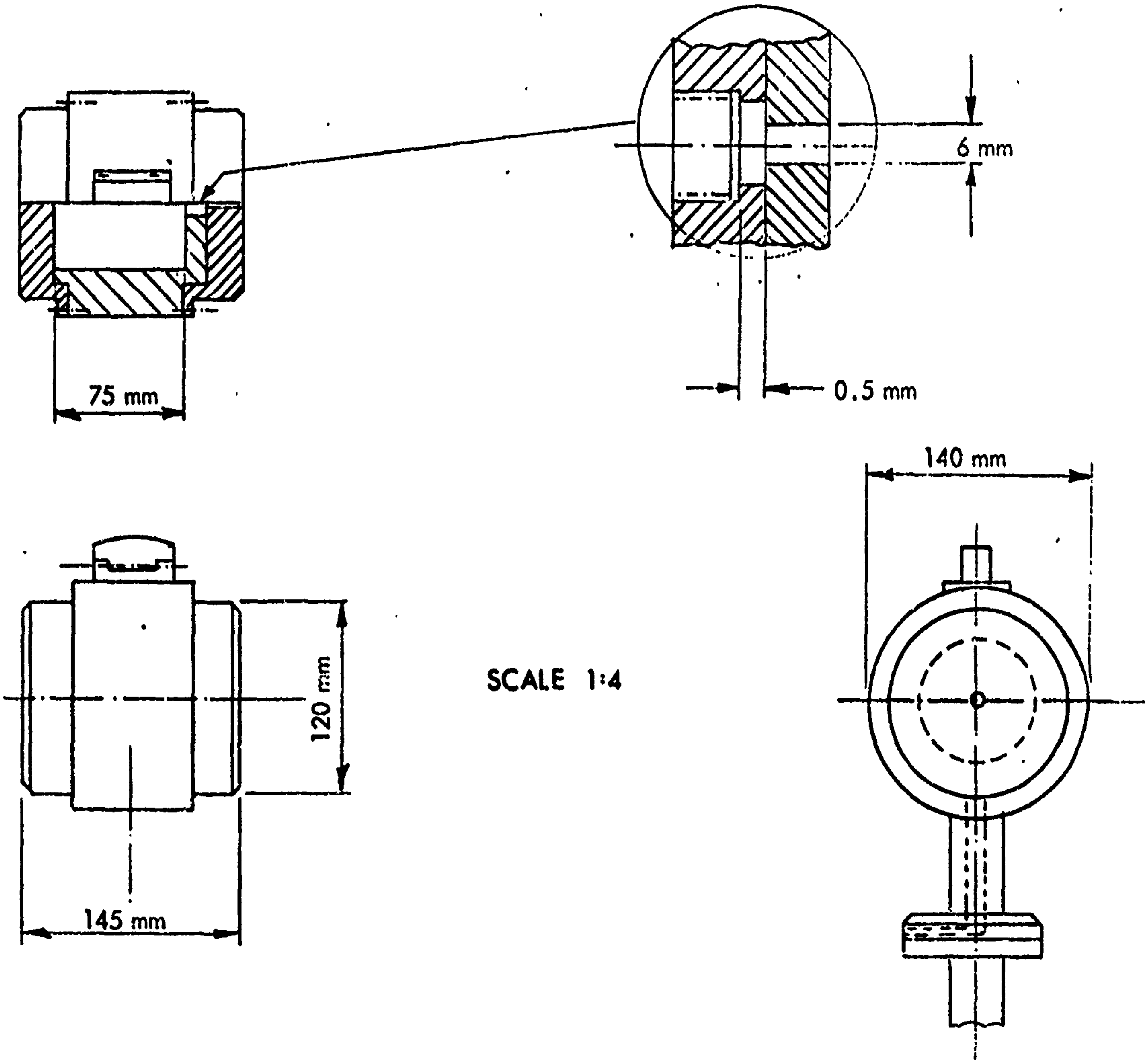


Fig 9 Details of the objective test facility

Fig 10

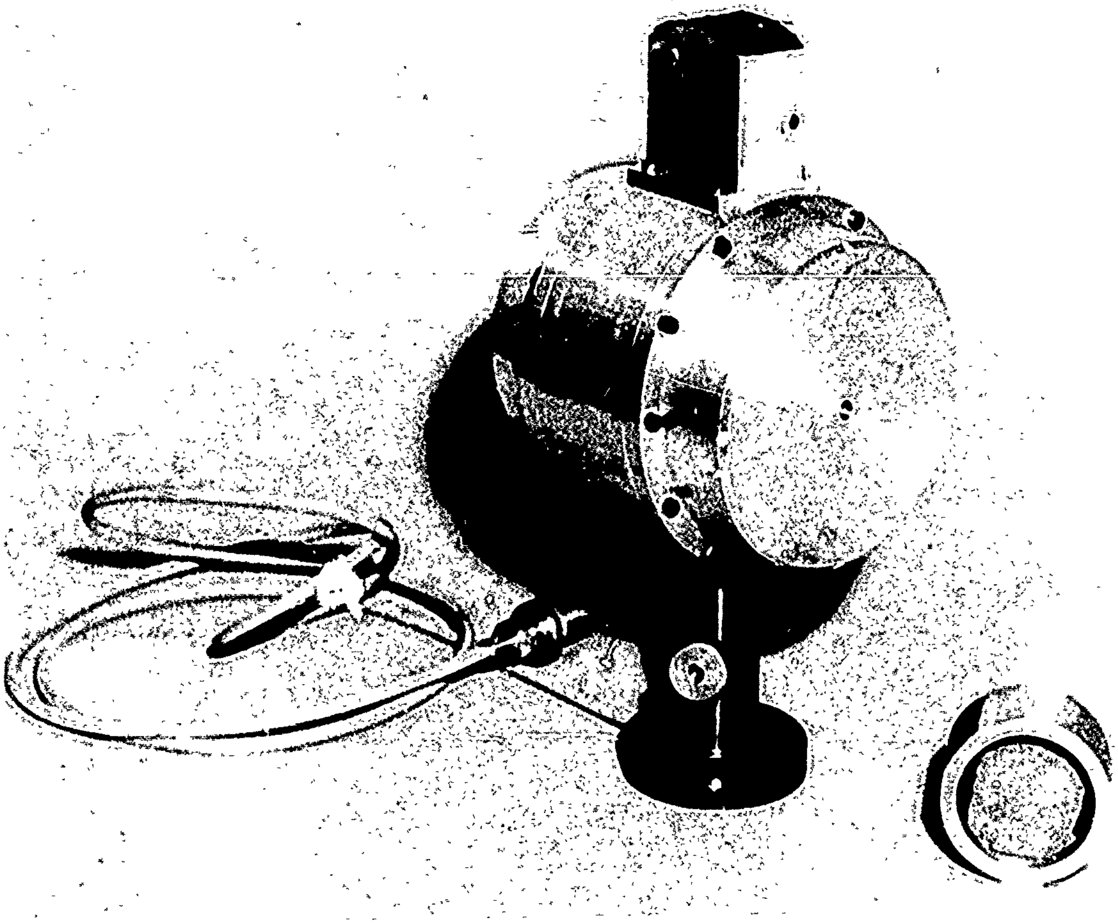


Fig 10 The objective test facility

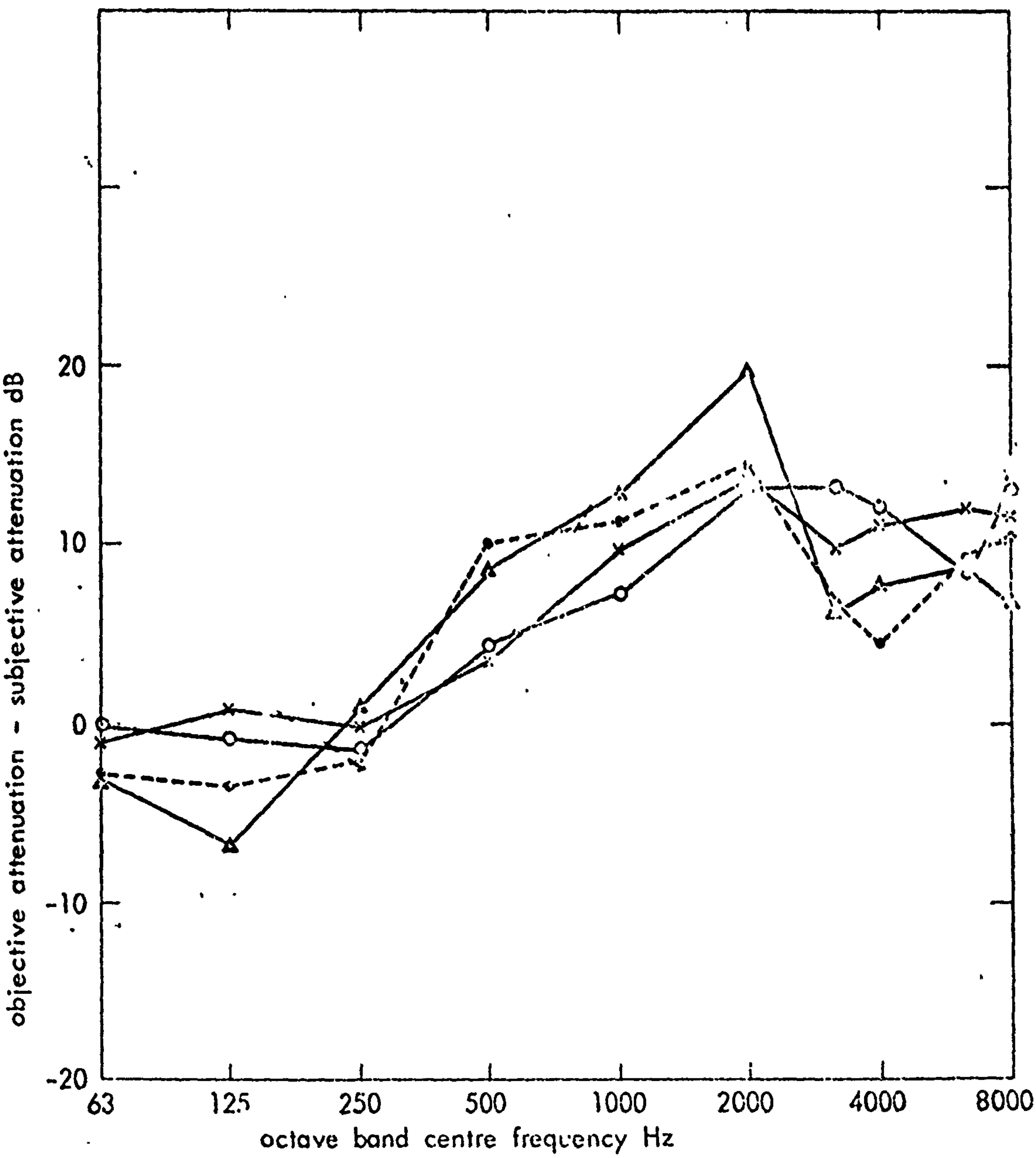


Fig 11 Spectrum of difference betwee i objective and subjective attenuation measurements for earmuffs with foam-filled cushions

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED / UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification/Marking
	RAE TM FS 379	N/A	UNCLASSIFIED / UNLIMITED

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
7673000W	Royal Aircraft Establishment, Farnborough, Hants, UK
5a. Sponsoring Agency's Code	**6a. Sponsoring Agency (Contract Authority) Name and Location**
N/A	N/A

7. Title A test facility for the objective measurement of circumaural hearing protector attenuation.

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference
Second International Symposium on Personal Hearing Protection in Industry. University of Toronto, Toronto, Canada, May 1980

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Chillery, J.A.			February 1981	30	40

11. Contract Number	12. Period	13. Project	14. Other Reference Nos.
N/A	N/A		

15. Distribution statement
(a) Controlled by –
(b) Special limitations (if any) – UNLIMITED

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)
Hearing protector attenuation measurement. Earmuff attenuation measurement. Objective acoustic attenuation measurement.

17. Abstract

The continuing development of the circumaural hearing protector requires control of the quality of this device. Current standard methods of protector attenuation measurement are expensive and time-consuming and wholly unsuitable for the quality control of quantity production. Performance of this task requires an objective test facility or 'artificial head'. This paper describes stages in the development of a facility suitable for quality control work and also useful as a research and development tool.

F5910/1