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# PRELIMINARY REPORT ON THE USE OF THE WIDE ANGLE DIFFUSER IN GROUND MUFFLERS OF THE TYPE USED FOR SILENCING JET AIRCRAFT

by

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# T H E   C O L L E G E   O F   A E R O N A U T I C S

## C R A N F I E L D

A Preliminary Report on the use of the Wide Angle Diffuser in
Ground Mufflers of the Type used for Silencing Jet Aircraft

-by-

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## S U M M A R Y

Experiments with a model wide angle diffuser, in combination
with suitable gauze resistances, fitted to the exit of a high velocity
cold jet show that reductions in total noise level of greater than
30 db. can be achieved; the spectrum being flat.  It is shown that
the wide angle diffuser when fitted to the tail pipe of a jet engine
as a ground muffler need not affect the characteristics of the engine
during 'run up'. Applications of this type of muffler to the silencing
of jet engines during 'run up', jet test beds and exhaust silencing
of internal combustion engines are briefly discussed.

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## Introduction

In recent years considerable attention has been focussed on the problem of reducing the noise produced by jet aircraft when in flight, and while they are being 'run up' prior to take off. The purpose of this paper is to suggest an inexpensive method, involving the use of cheaply constructed portable mufflers, whereby the noise propagated from jet aircraft during 'run up' may be reduced to an acceptable level. The muffler described below might also have an application in the silencing of jet test beds, and in the exhaust silencing of internal combustion engines.

## Some Notes on the Design of Ground Mufflers

The noise intensity produced by the airflow of a jet in the absence of solid boundaries is approximately proportional to a high power of the efflux velocity (ref. I). The object of the ground muffler is to reduce this efflux velocity thereby reducing the noise level. The noise reduction in decibels obtained by a reduction in the efflux velocity from $V_1$ to $V_2$, for a given rate of mass flow, is approximately

$$70 \log_{10} \left( V_1/V_2 \right)$$

since for subsonic jet velocities the noise intensity is approximately proportional to $V^8$. In practice due to the relatively high background noise level, $N_b$, the reduction to the total noise level, $N_1$, of the free jet will be different from the expression above. The actual reduction is approximately given by

$$N_1 - N_b - 10 \log_{10} \left( 1 + 10^{\frac{N_1 - N_b}{10}} \left( \frac{V_2}{V_1} \right)^7 \right)$$

In practical applications the ground muffler must be designed to satisfy certain conditions at the jet pipe exit. The most important of these is that the pressure at the jet pipe exit should be approximately the same as that of the free jet when operating under similar conditions. In addition the muffler must in many cases be readily portable and preferably made of inexpensive materials.

## Description of the Wide Angle Muffler

The wide angle muffler is shown diagrammatically in figure 1. It consists of a wide angle diffuser with wire gauze resistances fitted at selected stations normal to the axis. The purpose of the gauze resistances is twofold, viz.

a) to provide, by selection of the appropriate gauze combination, an overall pressure difference giving a specified pressure at the jet tail pipe

b) to prevent boundary layer separation from the walls of the muffler.

Vortex generators or similar methods of boundary layer control may be used in the initial expansion to assist in the prevention of separation (ref. II).

It should be noted that some results have been published by Lassiter and Hubbard on the effect on the noise intensity of placing single wire gauze screens normal to airflows. They mentioned that the scheme might have an application in the design of mufflers, but do not discuss the use of multi-gauze screen combinations in wide angle diffusers (ref. III).

## Experiments on a Model Wide Angle Muffler

The model muffler consisted of a wide angle, straight sided conical diffuser of cone semi-angle $22\frac{1}{2}°$. It was designed to fit a 1in. diameter nozzle and its overall length was $4\frac{1}{4}$ in. A combination of three gauzes was chosen which gave at the nozzle exit a pressure just above atmospheric when the upstream stagnation to atmospheric pressure ratio. (P) was 2.

For values of P of 1.5 and 2.33 the pressures at the nozzle exit with the muffler in position were 0.96 at. and 1.16 at. respectively.

The sound intensities produced by a 1in. diameter jet of air at values of P of 1.5, 2.0 and 2.33 were measured. All measurements were made at a radial distance of 10feet from the nozzle exit for azimuthal angles increasing by 10 degrees from $10°$ to $170°$ with respect to the downstream direction of the jet. A modified form of the test rig, and noise measuring equipment described in reference IV were used. The measurements were repeated with the silencing device in position. The results are shown in figures 2 (A, B and C) and 3 (A, B and C).

Total head traverses were made $\frac{3}{4}$ in. downstream of the muffler exit for the three values of P used in the noise measurements. The results are plotted in figure 4.

In addition to the tests described above similar measurements were made on modified forms of the muffler. These modifications consisted of the addition of various lengths of perforated, lagged pipe extensions connected to the muffler immediately downstream of the final gauze resistance. The results of these tests are plotted in figures 2 (A, B, C), 3 (A, B, C), 4 and 5.

## Discussion of Model Tests

The results shown in figures 2 (A, B and C) for the plain nozzle and the addition of the wide angle muffler show that appreciable total noise level reductions have been obtained. The reductions in noise level do not, however, agree with the simple calculation based on the reduction in jet efflux velocity.

The noise spectrum measurements, plotted in figures 3 (A, B and C), show clearly that the noise level in the high frequency bands has not suffered the same order of reduction as the noise level in the lower frequency bands.

The distribution of total head at the exit of the wide angle muffler, shown in figure 4, indicates the existence of unfavourable velocity profiles with maxima near the mixing region. Similar measurements on the extended muffler, see figure 4, show that these peaks have been eliminated.

It was assumed that the gauze resistances were generating a source of dipole noise of high frequency which was being propagated along the muffler and into the external field. An extension in the form of a perforated, lagged pipe was added in order to absorb this high frequency noise. The results for the wide angled muffler with a 3ft. extension, plotted in figures 2 (A, B, C) and 3 (A, B, C), show that the total noise level has been further reduced and amounts to a reduction in total noise level, compared with the free jet, of about 30db. The noise spectrum measurements show that the high frequency

content of the noise has been considerably reduced.

In an endeavour to explore the effect of the length of perforated lagged pipe, the initial 3ft. length was reduced in one foot increments. The noise measurement plotted in Figure 5 shows that the muffler is equally efficient for 1ft and 2ft. extensions.

It may be possible to reduce the optimum length of perforated, lagged pipe by using co-axial splitters or similar methods of high frequency noise absorption.

## Application of the Wide Angle Muffler to Full Scale

Some difficulties may arise in the application of the wide angle muffler to the silencing of jet aircraft, but these should not prove insuperable. The porous resistances used in the model experiments, particularly those nearest the jet pipe exit, will need to be constructed from materials designed to withstand both high axial loads and temperature. In this connection it may be found desirable to use porous walls made from ceramics.

## Acknowledgement

This work has been done under a contract from the Ministry of Supply.

## Conclusions

1. Model experiments have shown that considerable reduction in the noise produced by jets with high efflux velocities is obtained by the use of a wide angle diffusor, in which separation of the flow is prevented by the incorporation of suitable combinations of gauze screens. In addition the pressure at the nozzle exit is controlled by the gauze screen combination and can be made equal to the pressure at the exit when there is free flow from the nozzle.

2. The experiments show that the reduction in total noise level, compared with a free jet, is a function of azimuthal angle and varies from 20db. at $15^{\circ}$ to 14 db. at $90^{\circ}$ to the jet downstream direction at a pressure ratio of 2.0.

3. The noise level from the diffuser is further reduced by the addition of a perforated, acoustically lagged pipe extension. In this case the reduction in total noise level, compared with the free jet is 38db. at $15^{\circ}$ and 30 db. at $90^{\circ}$ to the jet downstream direction at a pressure ratio of 2.0. The noise level at all frequencies is approximately constant.

4. The use of the wide angle diffuser is discussed with regard to its use as a ground muffler for the silencing of jet aircraft during 'run up'. In addition this muffler might have an application in the silencing of jet test beds and exhaust silencing of internal combustion engines.

References

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II  SPENCE, A.  Summary of United Aircraft Corporation Reports Nos. R.15064-5, R.4012-3 and 4 on Elimination of Separation by means of Vortex Generators. R.A.E. Tech. Memo. Aero.312.

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IV  WESTLEY, R. and LILLEY, G.M.  An Investigation of the Noise Field from a Small Jet and Methods for Its Reduction. College of Aeronautics Report 53, Jan. 1952.
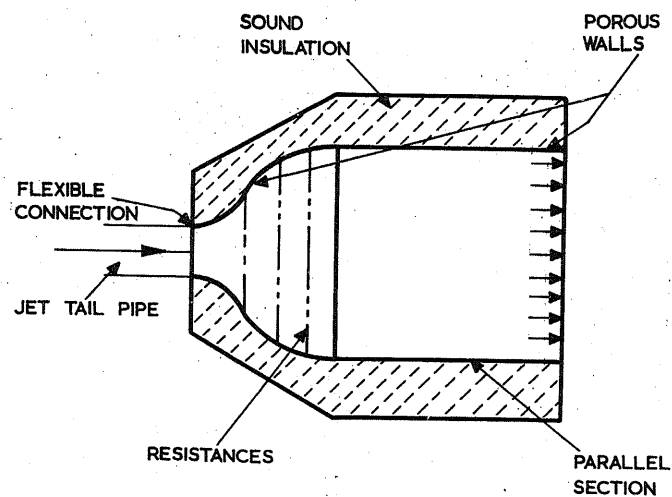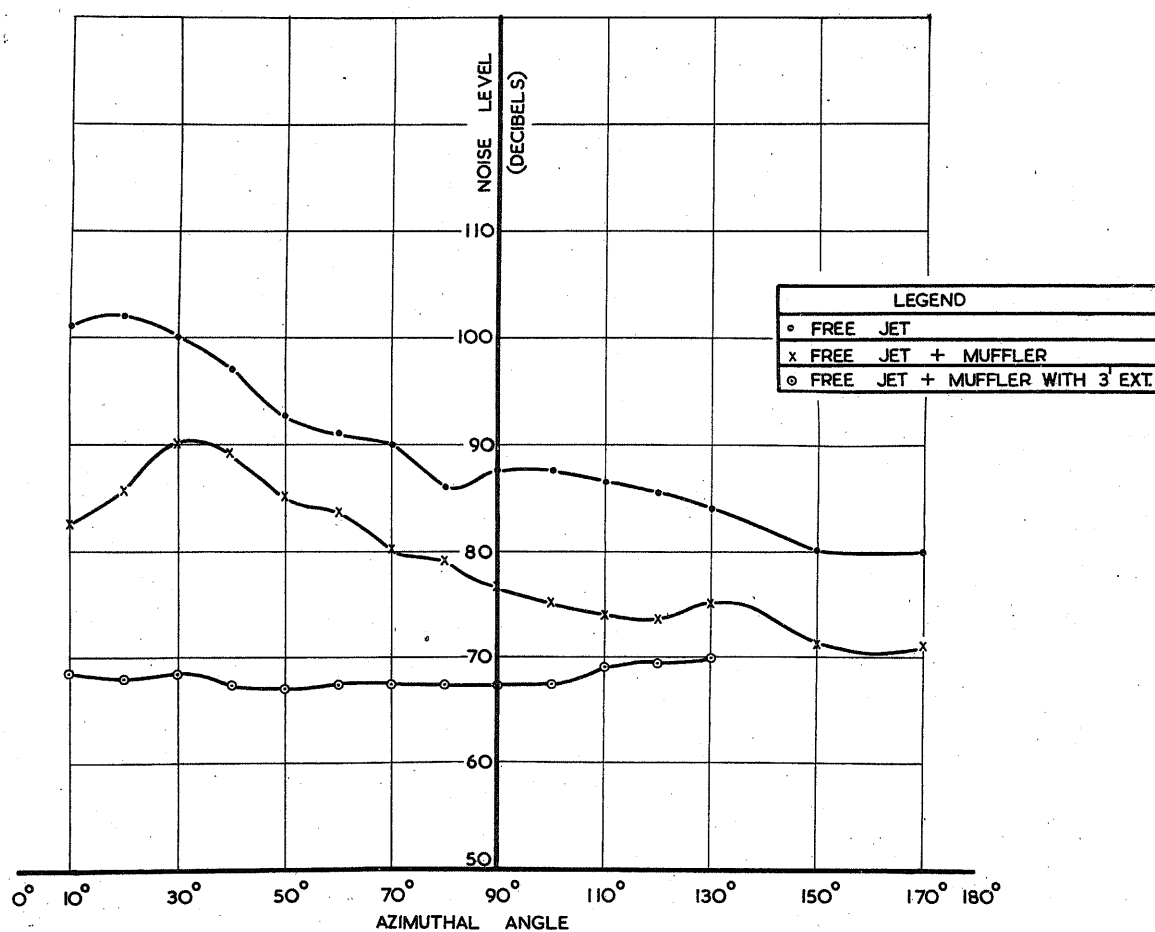
SOUND
INSULATION

POROUS
WALLS

FLEXIBLE
CONNECTION

JET TAIL PIPE

RESISTANCES

PARALLEL
SECTION

THE WIDE ANGLE MUFFLER          FIG.1



| LEGEND |
| --- |
| ○ FREE JET |
| x FREE JET + MUFFLER |
| ⊙ FREE JET + MUFFLER WITH 3' EXT. |

NOISE LEVEL (DECIBELS)

AZIMUTHAL ANGLE

VARIATION IN TOTAL NOISE LEVEL
WITH AZIMUTHAL ANGLE P = 1.5

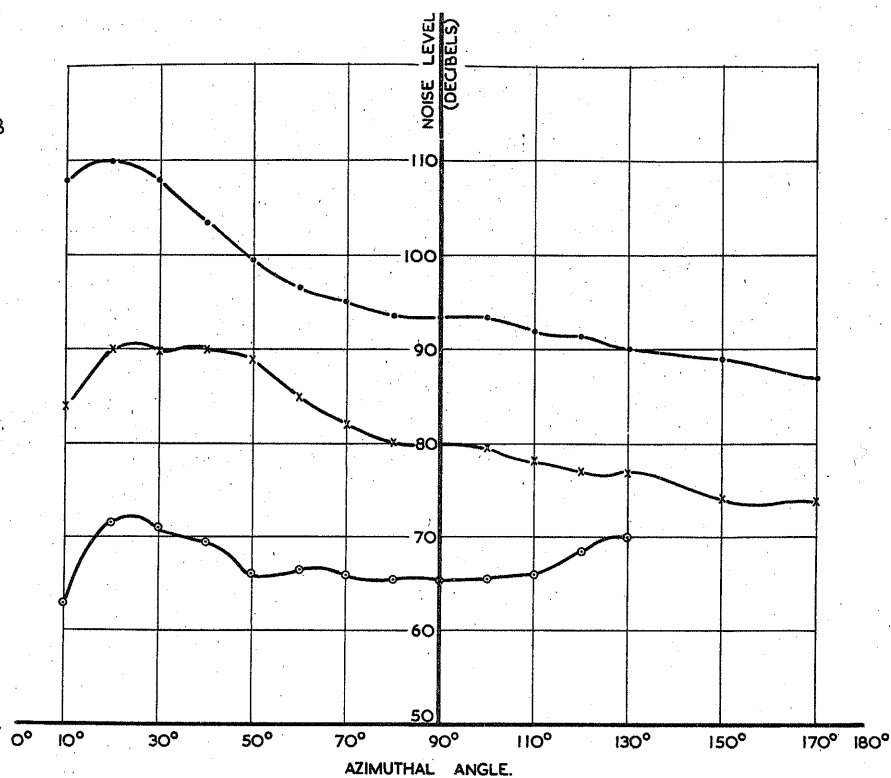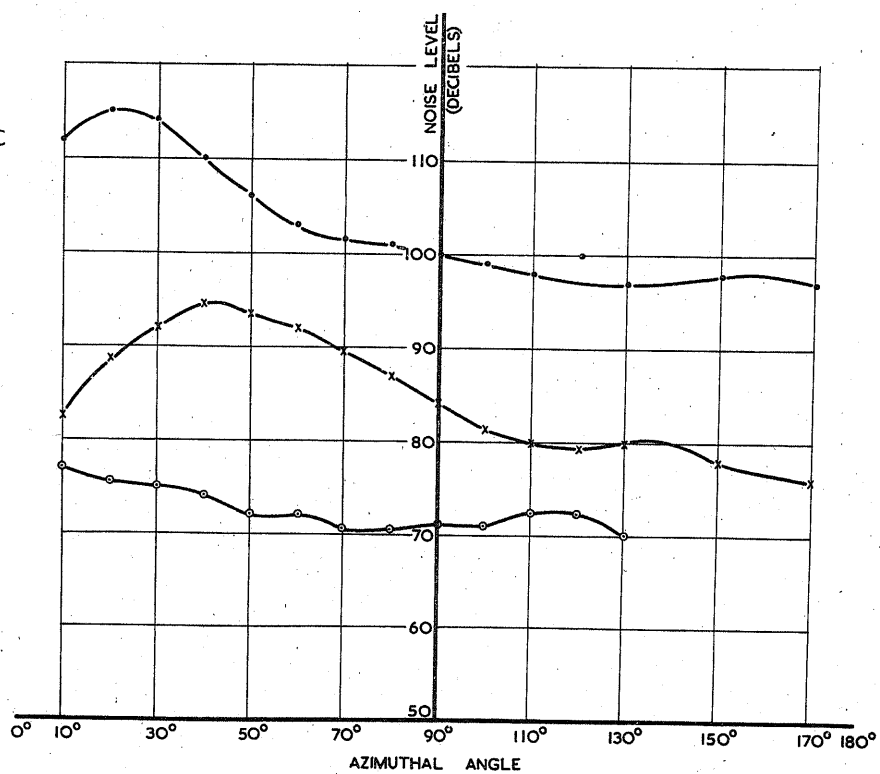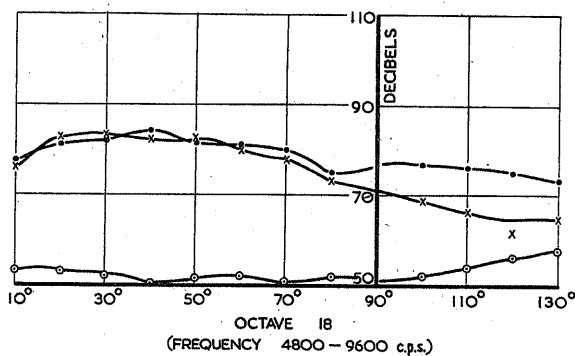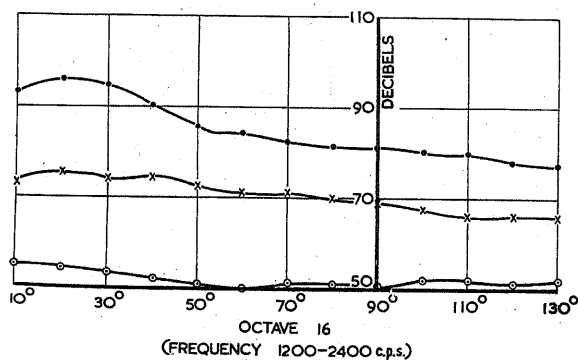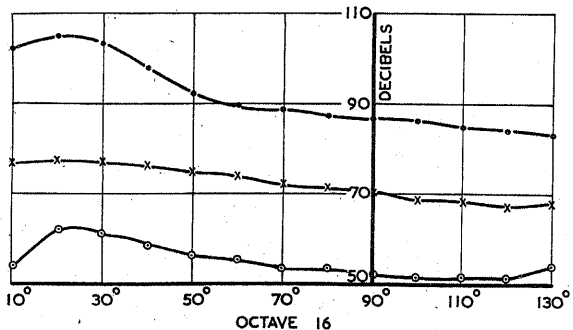(FREE JET WITH AND WITHOUT PLAIN AND EXTENDED MUFFLER)

FIG.2A

FIG.2B



NOISE LEVEL (DECIBELS)

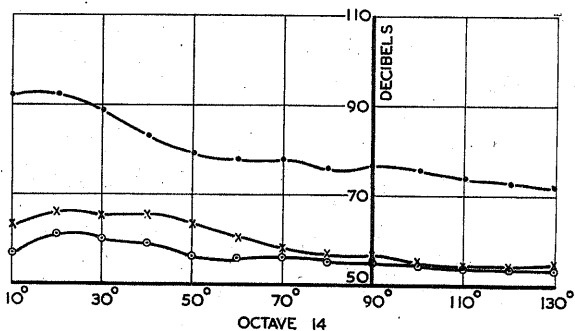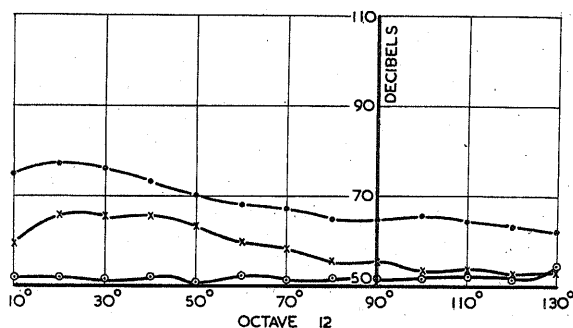AZIMUTHAL ANGLE.

FIG.2C



NOISE LEVEL (DECIBELS)

AZIMUTHAL ANGLE

VARIATION IN TOTAL NOISE LEVEL

WITH AZIMUTHAL ANGLE P=2.33 FIG.2C & P=2.0 FIG.2B

(FREE JET WITH AND WITHOUT PLAIN AND EXTENDED MUFFLER)

OCTAVE 12
(FREQUENCY 75-150 c.p.s.)

OCTAVE 14
(FREQUENCY 300 600 c.p.s.)

OCTAVE 16
(FREQUENCY 1200-2400 c.p.s.)

OCTAVE 18
(FREQUENCY 4800 - 9600 c.p.s.)
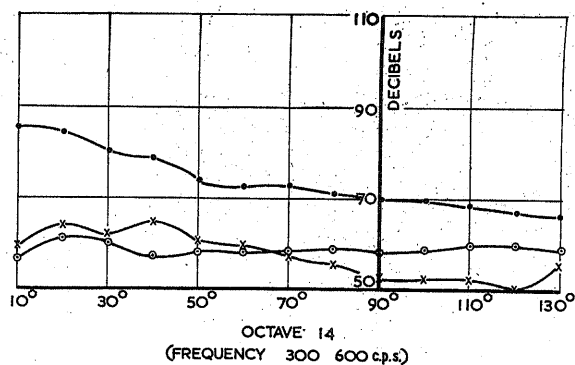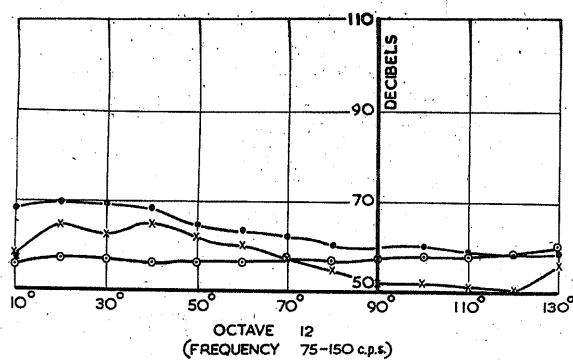
VARIATION IN OCTAVE NOISE LEVEL

WITH AZIMUTHAL ANGLE P = 1.5

FIG.3A

(FREE JET WITH AND WITHOUT PLAIN AND EXTENDED MUFFLER)

OCTAVE 12

OCTAVE 14
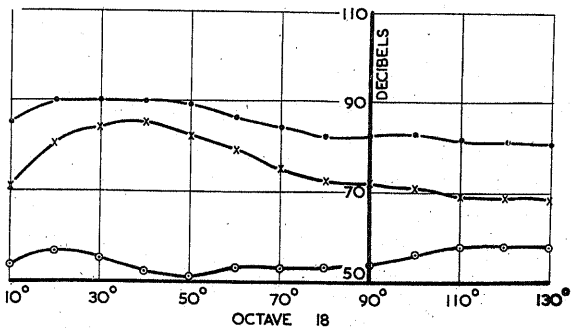
OCTAVE 16

OCTAVE 18

VARIATION IN OCTAVE NOISE LEVEL

WITH AZIMUTHAL ANGLE P = 2.0

FIG 3B

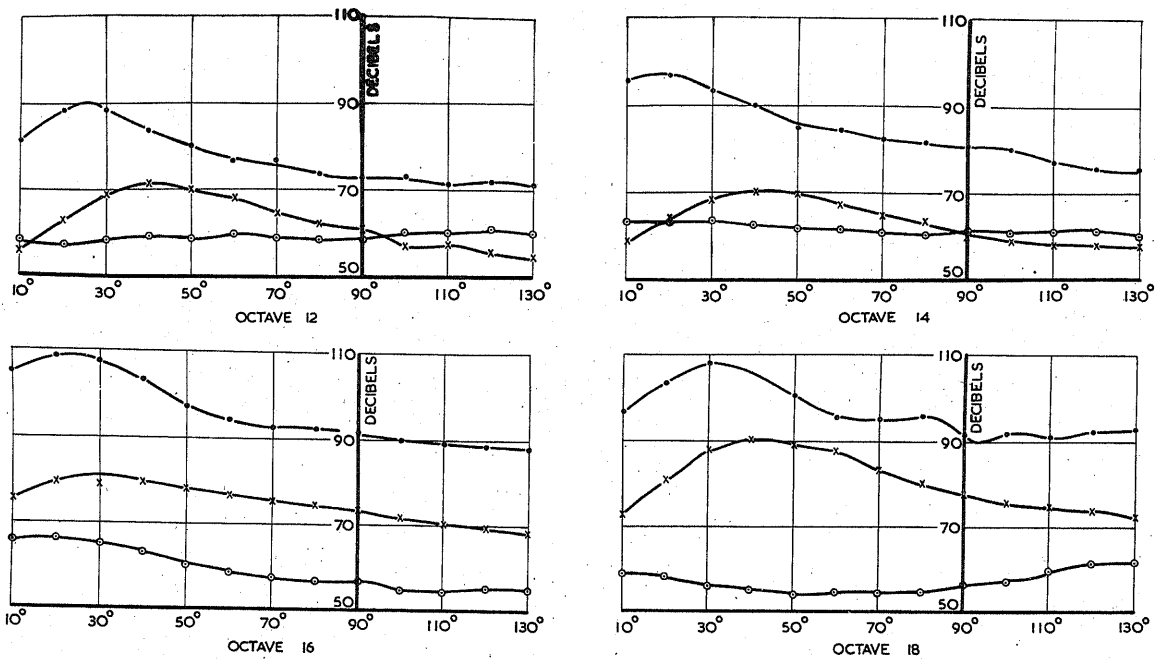(FREE JET WITH AND WITHOUT PLAIN AND EXTENDED MUFFLER)

FIG.3c         VARIATION IN OCTAVE NOISE LEVEL
               WITH AZIMUTHAL ANGLE P=2.33
        (FREE JET WITH AND WITHOUT PLAIN AND EXTENDED MUFFLER)



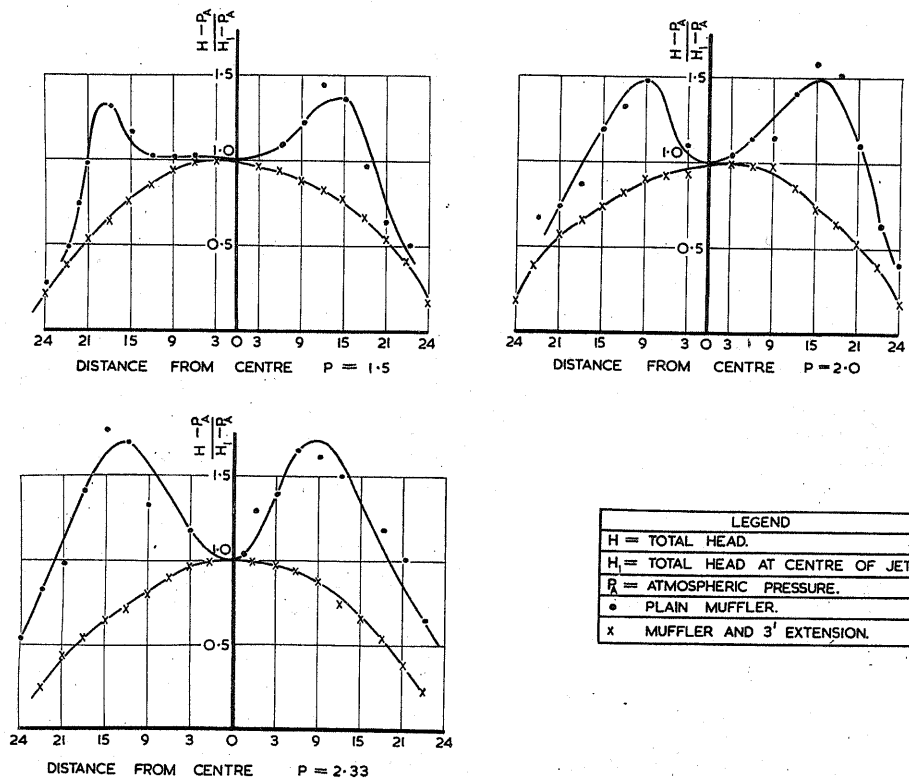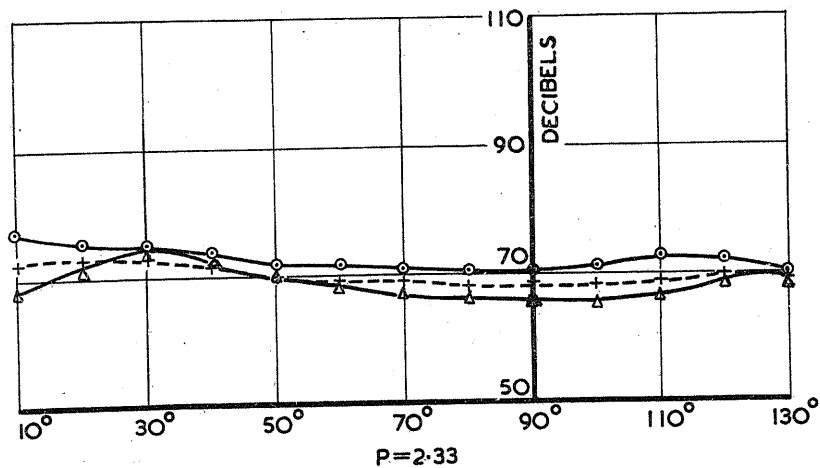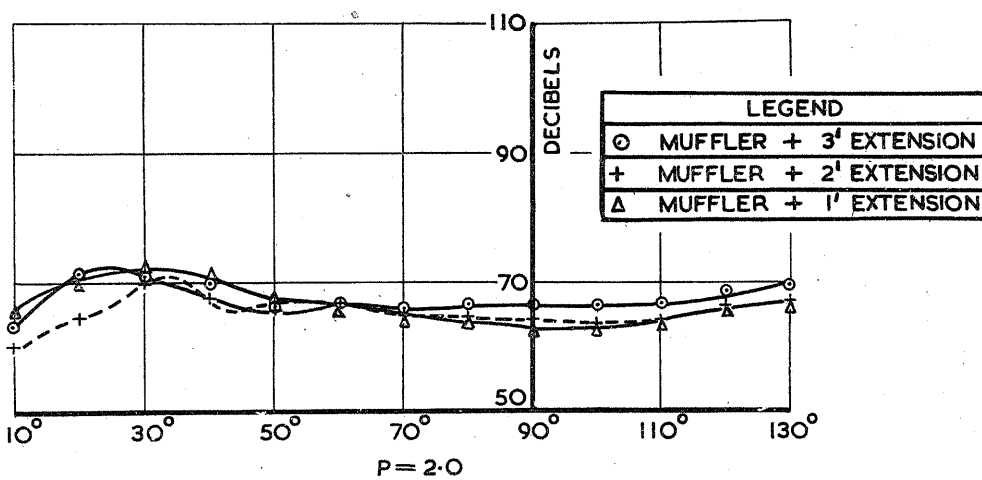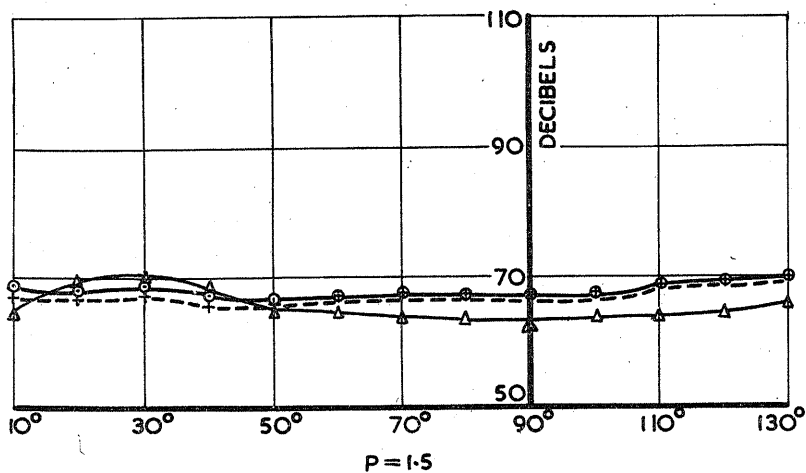| LEGEND | |
|---|---|
| $H$ = | TOTAL HEAD. |
| $H_i$ = | TOTAL HEAD AT CENTRE OF JET. |
| $P_A$ = | ATMOSPHERIC PRESSURE. |
| ● | PLAIN MUFFLER. |
| x | MUFFLER AND 3' EXTENSION. |

FIG.4            DISTRIBUTIONS OF TOTAL HEAD
              DOWNSTREAM OF MUFFLER EXIT
        (PLAIN MUFFLER AND MUFFLER WITH 3 FEET EXTENSION)

VARIATION IN TOTAL NOISE LEVEL
WITH AZIMUTHAL ANGLE
(PLAIN MUFFLER WITH VARIOUS LENGTHS OF PIPE EXTENSION)

FIG. 5