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AERONAUTICAL NOISE: SESSION C: FAN NOISE

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Reduction of fan noise by annulus boundary layer removal.

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1. Introduction.

Much of the noise produced by a subsonic fan is caused by unsteady surface forces, which modulate the steady blade forces and react on the air, producing a propagating sound field (e.g. Refs 1,2). Most of the varying forces are a result of incident flows which vary with respect to the blade row. If the fan has inlet guide vanes, these produce a periodic flow distortion with a period equivalent to the blade spacing. The interaction of this flow field with the blades produces acoustic modes which propagate in a duct as described by Tyler and Sofrin (Ref. 3). Similar effects occur for isolated rotors such as propellers and helicopter rotors (Refs 4 & 5).

When no IGVs are present the noise-producing flow distortions are a result of the turbulent mainstream flow, and blade and annulus boundary layer turbulence and intermittency. If the distortion has a large scale so that several blades pass through each eddy, then tones are produced as for IGV interaction. As the scale becomes smaller the tones vary in frequency about the rotational frequency orders and flows which are completely uncorrelated between blades produce broad band noise. The relative importance of the different sources of distortion depends on the design of the fan and its ducting. Blade boundary layers produce mainly high frequency broad band noise, whereas mainstream and boundary layer fluctuations produce the lower frequency noise. In many cases the annulus boundary layer is the most important source of distortion as this acts on the blade tip region where it is most efficiently converted to noise.

2. Annulus Boundary Layer Bleed.

One method of reducing the effect on the blade forces of the annulus boundary layer fluctuations is to bleed off the annulus boundary layer just upstream of the rotor so that the rotor sees only a thin, even boundary layer starting from the bleed lip. Such a system has been applied to a ducted 1 m. diameter ventilation fan without stators, driven by a 130 kW petrol engine capable of producing a tip speed of 230 m/s with 4 blades and 160 m/s with 12 blades. A radial choke at the duct outlet is used to control the fan loading.

A sketch of the bleed system is shown in Fig. 1. The fan inlet flow passes through a slightly diffusing section leading to a fully annular bleed slot where the boundary layer is diverted into six cylindrical ducts which are sucked by a centrifugal blower ventilating to atmosphere. The blower is capable of removing approximately 5% of the main flow. When not in use, the diffusing section of duct is covered with a thin sleeve providing a cylindrical duct as a reference for bleed tests.

The noise output of the fan has been measured in the duct where the modal content was determined as described in Ref. 6, and in the far field where the free field radiation was measured as described in Ref. 7.

3. Measured Effect of Bleed System.

10 Hz bandwidth analyses of the far field noise with and without the bleed system show that reductions of up to 8 dB are obtained in the tone acoustic powers for both the 4 and 12 bladed fans and up to 5 dB reduction in the broad band noise. Since the full spectra are not suitable for reproduction here, the tone sound powers are shown in Fig. 2 for the 4 bladed fan at 3000 rpm. Although there is considerable reduction for the higher blade passing frequency harmonics, the power in the fundamental increases. Analysis of the modal structure of this tone shows that this is caused by a low order distortion induced by the suction system which has a six lobed suction profile even though the suction slot is fully annular. This could probably be reduced by providing the slot with a large annular plenum chamber to reduce the effect of the six suction pipes.

Fig. 3 shows the variation of tone power level with the percentage of the main flow removed by the bleed system. Except for the fundamental, explained above, the curves show a decrease of sound power with increased suction. For the higher harmonics, this levels off so that no further reduction is obtained after 3½% suction. The lower order harmonics, which are probably caused by distortions of larger spatial scale, are still decreasing at 5% suction.

The variation of overall and tone sound power with speed approximates to a law of tip velocity to the power 5.5 for both 4 and 12 blades, with and without bleed except for the blade passing frequency with four blades which shows no steady trend with speed.

4. Measurement In Duct.

Detailed measurements of the sound field in the duct of the 12 bladed fan have been made at one fan condition. The measured modes in the intake for blade passing frequency (equivalent to 3rd harmonic with 4 blades) are shown in Fig. 4. The modes, measured as described in Ref. 6, are those acoustic components which are phase locked to the rotor and are caused by distortions which are steady with respect to the duct. This constitutes approximately 50% of the total tone power as described in Ref. 1. Fig. 4 shows both a decrease in mode amplitude and a redistribution between modes when the boundary layer bleed is applied.

An attempt has been made to link these measured modes with the aerodynamic measurements of the distortion. Aerodynamic measurements were made by traversing a very small pitot static probe 1 cm. above the suction slot, just ahead of the blading. The circumferential variation of axial velocity was then Fourier analysed to produce the spatial spectrum of the axial flow distortion seen by the blade tips shown in Fig. 5. The modal content of any tone can be constructed by displacing the aerodynamic spectrum by the rotational frequency order and applying the mode attenuation for that particular frequency. The amplitudes are predicted from the steady blade force. The result for blade passing frequency is shown in Fig. 6 together with the measured modes. The two curves show the same general trend supporting the theory that much of the noise is produced by boundary layer fluctuations. It should be noted that no account has been taken of tangential flow fluctuations or of the blading responses in this simple model.

5. Conclusions.

Reducing the flow distortion by bleeding the boundary layer of an isolated fan considerably reduces the radiated noise in agreement with distortion/rotor interaction theory. However, care must be taken to ensure that the boundary layer bleed system does not introduce new distortions.

6. Acknowledgements.

The boundary layer suction system described in this paper was conceived and developed by Mr B. Barry. Mr D. H. Brierley and Miss C. E. Whitfield conducted much of the experimental investigation.

References.

1. BARRY, B. and MOORE, C. J.
Subsonic fan noise.
J. Sound Vib., Vol. 17(2), 1971, pp.207-220.

2. LOWSON, M. V.
Theoretical analysis of compressor noise.
J. Acoust. Soc. Amer. Vol. 57(1) pp.371-385.

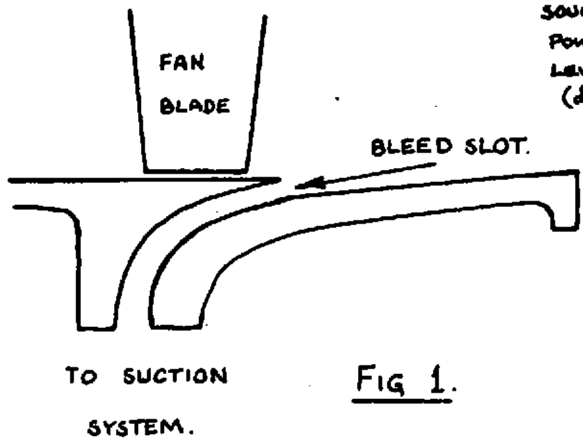
3. TYLER, J. M. and SOFRIN, T. G.
Axial flow compressor noise studies.
SAE Trans. Vol. 70 (1962) pp.309-332.

4. LOWSON, M. V. and OLLERHEAD
A theoretical study of helicopter rotor noise.
J. Sound Vib., Vol. 9(2), 1969, pp.197-222.

5. WRIGHT, S. E.
Sound generation from a lifting rotor generated by asymmetric disc loading.
J. Sound Vib., Vol. 9(2), 1969, pp.223-240.

6. MOORE, C. J.
In duct investigation of subsonic fan 'rotor alone' noise.
J. Acoustic. Soc. Amer. Vol. 51(5), 1972, pp.1471-1482.

7. MOORE, C. J.
A solution to the problem of measuring the sound field of a source in the presence of a ground surface.
J. Sound Vib. Vol. 16(2), 1971, pp.269-282.


FAN
BLADE
BLEED SLOT.
TO SUCTION
SYSTEM.
FIG 1.

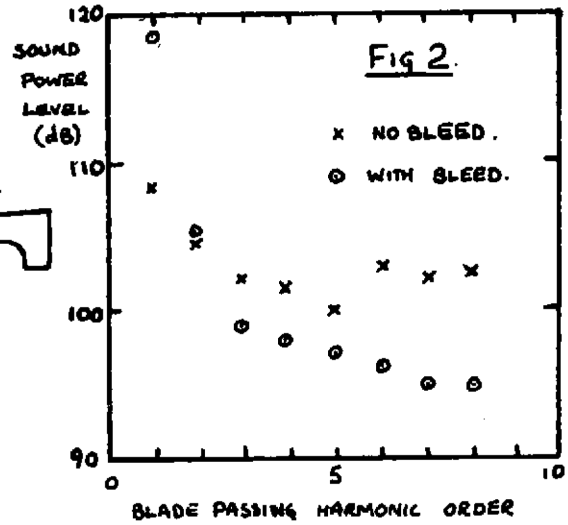


FIG 2.
SOUND
POWER
LEVEL
(dB)
x NO BLEED.
⊙ WITH BLEED.
120
110
100
90
0
5
10
BLADE PASSING HARMONIC ORDER

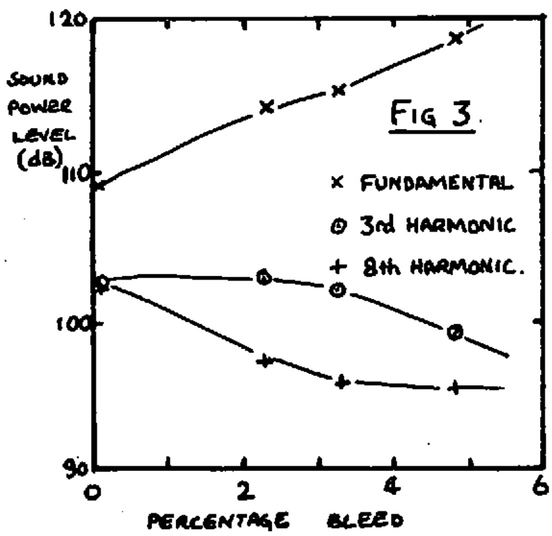


FIG 3.
SOUND
POWER
LEVEL
(dB)
x FUNDAMENTAL
⊙ 3rd HARMONIC
+ 8th HARMONIC.
120
110
100
90
0
2
4
6
PERCENTAGE BLEED

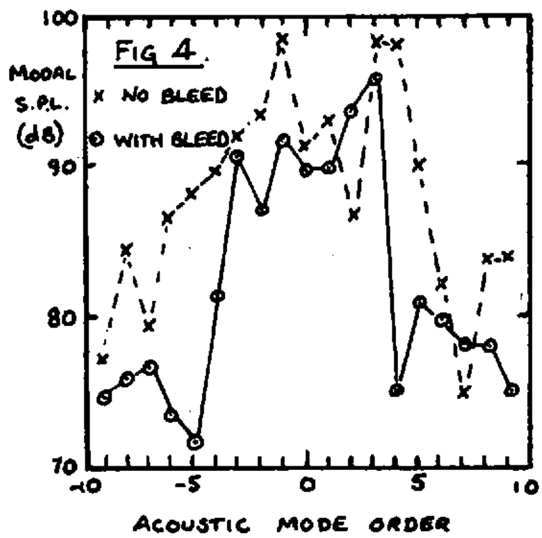


FIG 4.
MODAL
S.P.L.
(dB)
x NO BLEED
⊙ WITH BLEED
100
90
80
70
-10
-5
0
5
10
ACOUSTIC MODE ORDER

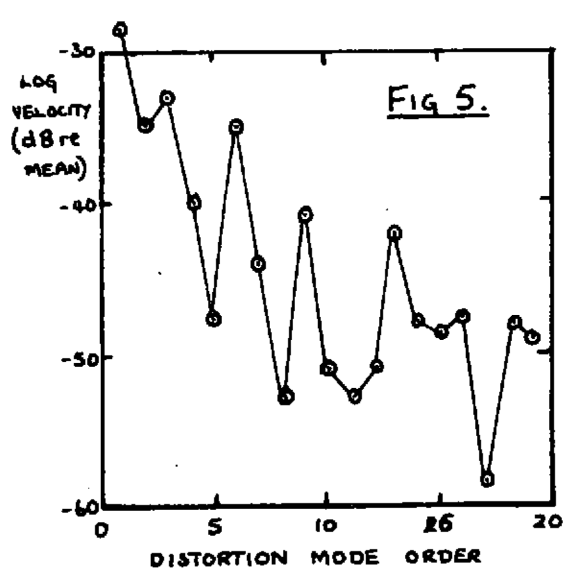


FIG 5.
LOG
VELOCITY
(dB re
MEAN)
-30
-40
-50
-60
0
5
10
26
20
DISTORTION MODE ORDER

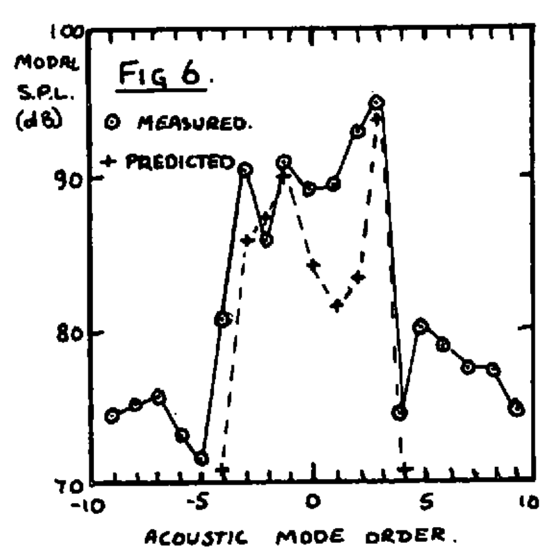


FIG 6.
MODAL
S.P.L.
(dB)
⊙ MEASURED.
+ PREDICTED
100
90
80
70
-10
-5
0
5
10
ACOUSTIC MODE ORDER.