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by

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SOME APPLICATIONS OF HARTMANN-TYPE SOURCES IN AIRCRAFT NOISE RESEARCH

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SUMMARY

A description is given of a Hartmann-type air-jet noise generator which has been developed at RAE to aid in the assessment of airframe shielding effects. In this application, in-flight shielding experiments were performed with a slender-delta research aircraft, the Handley-Page 115, fitted with needle-stabilised generators having 19mm diameter driving jets operated from the HP turbine of the aircraft engine. The acoustic power output of the device was about 1 kW and consisted of a strong fundamental 2.8kHz tone and a few higher harmonics which were easily discernible above engine noise. Comparative wind-tunnel experiments employed quarter-scale versions built to match the tunnel model and these operated at about 11 kHz, the output level being well above tunnel background noise. Calibration in an anechoic room showed the output to be steady and nearly omni-directional.

These devices are rugged, efficient, and relatively simple to construct and operate; they provide a compact, well-defined and powerful sound source of reasonable size which can be easily scaled acoustically and physically.

Text of a paper presented at the Spring Meeting of the Institute of Acoustics, University of Nottingham, March 1975.

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1 INTRODUCTION

Acoustic shielding by the airframe may enable significant reductions of aircraft flyover noise to be achieved and various basic studies of shielding effects have been made at RAE and elsewhere[1,2]. The principle of the method is to find an optimum position for the power plant installation relative to major airframe components, particularly the wings and fuselage, which can result in an appreciable area of acoustic shadow on the ground beneath the aircraft. Such airframe shielding effects can be studied using various facilities including static ground-based rigs, wind-tunnels and other forward-speed facilities, such as linear tracks, whirling arms, high-speed road vehicles, and actual aircraft.

Although full-scale research using aircraft in flight seems the obvious choice on grounds of realism, there are a number of inherent disadvantages which have to be overcome apart from the basic need for good weather for outdoor noise measurements. These are that any major structural alterations to an aircraft to achieve a shielded configuration must receive flight clearance, and the modifications themselves tend to be time-consuming and relatively costly; in all, there is less flexibility in carrying out flight experiments compared to the configuration changes more readily available with ground-based facilities. Moreover, the design and interpretation of flight experiments to evaluate shielding effects is complicated by the complex nature of the engine and other aerodynamic noise sources, and by the fact that the source properties and the propagation of the noise can be affected by the forward motion of the aircraft and its local flowfield.

As an alternative to flight testing, the use of a ground-based forward-speed facility may require care to avoid interference from the spurious noise produced by the drive system. For example, wind-tunnel experiments on shielding effects can be hampered by the tunnel background noise and there are in this case additional problems of simulating engine noise-fields realistically at model scale; it is also necessary to provide an anechoic environment in which to conduct the experiment.

One approach, which forms the basis of this Memorandum, is to use a comparatively simple but powerful auxiliary noise source of known characteristics. This can be used to synthesise that part of the frequency spectrum of interest, and it can also be scaled for both aerodynamic and acoustic reasons, making possible comparisons between flight and wind-tunnel experiments.

A description is given of an air-jet noise generator, based on Hartmann's original design[3], which has been developed successfully for this purpose. Details of the design and performance of the device, which incorporates a stabilising needle to improve the operating characteristics, are given in section 2. In section 3 some applications for the noise sources in-flight and wind-tunnel studies of noise shielding are described.

2 DESIGN AND THEORY OF OPERATION

The basic design philosophy for the acoustic air-jet generator has been described by Hartmann[3]. In its simplest form, the generator consists of a supersonic jet which exhausts into a cavity facing the nozzle. A simplified model for the noise production depends on a normal shock-wave standing some distance ahead of the cavity, this distance being determined by the cavity diameter and the air-supply pressure. When the cavity mouth is positioned to coincide with the periodic structure of the air jet, a system of powerful oscillations of the shock front is set in motion and a continuous train of high-frequency waves are emitted. The frequency and the acoustic power of the generator depends on the diameter of the nozzle, the ratio between nozzle and cavity diameter, the length of the air gap between cavity and nozzle, and the stagnation pressure of the air supply. A particular disadvantage of the device is that very careful adjustment of the air gap and regulation of the air supply is necessary to maintain oscillation and maximum sound output.

Savory[4] found that the stability and output of the basic Hartmann generator could be considerably improved when the cavity was mounted on the end of a thin rod which passed through the jet pipe along its axis. More recently, Brocher et al[5] have given a fluid dynamical explanation of the operation of a modified Hartmann generator in which a thin needle is placed axially in the nozzle cavity only. This causes a basic change in the structure of the flow which is now supersonic into the cavity; their experimental results show that no shock appears in front of the cavity and Mach lines are visible at the cavity entrance. In this condition the jet is fully swallowed and the oscillations, associated with the periodic emptying and filling of the cavity, increase to their maximum intensity. Spillage from around the cavity entrance is reduced and the most noticeable feature, supported by our own experiments, is that the noise source is more stable and the acoustic power output increased.

A useful review of acoustic air-jet generators has been given by Brocher[6]: this includes a discussion of the theory of operation as well as design information.

The two basic features, simplicity and a high acoustic power output, make the modified Hartmann generator a particularly useful source for experiments on aircraft noise. The compactness makes it easy to streamline the unit into an aerodynamic model, causing only a small disturbance to the outside airflow. A compressed-air supply is usually available for wind-tunnel experiments, and for flight experiments gas may be bled from the high-pressure stage of the aircraft's jet engine.

Both large and small versions of the Hartmann noise source have been designed and manufactured by the RAE at Farnborough. Fig 1 shows the general arrangement of a small-scale generator for use in wind-tunnel experiments. High-pressure air exhausts into a cavity whose depth can be adjusted to set the operating frequency. The distance between jet and cavity may also be varied and cavities and needles with different diameters are available. In a calibration experiment in the RAE Anechoic Room, the effects of these parameters were measured to find the optimum configuration, in this application defined as the highest sound output at a frequency of about 11 kHz.

Hartmann's theoretical model for the air-jet sound generator[3] leads to analytic expressions for the power output as a function of input pressure, the frequency as a function of cavity depth and the minimum separation between nozzle and cavity for the source to operate. A comparison is shown in Fig 2a between the calculated and measured fundamental frequency as a function of the cavity depth for the small-scale, wind-tunnel noise source. This configuration, whilst not adjusted to the final operating condition, illustrates that the frequency obtained is close to the theoretical prediction, and that the noise source can operate over a significant frequency range, from 5.5 kHz to at least 10.0 kHz in this case. In other configurations, the generator can be tuned to 12.5 kHz but at these higher fundamental frequencies the actual sound output begins to decrease. Also shown in Fig 2b is the theoretical variation of acoustic power level with the pressure of the air supply, together with the 11.2 kHz operating point as used in the wind-tunnel experiments. The output is significantly less than predicted and the efficiency, defined in terms of the power required to maintain the jet, was measured as 0.3%, compared with a theoretical value of 2.5% with an air-supply pressure of 5.5×10^5 N/m^2. If the supply pressure is reduced to 2×10^5 N/m^2, as it was for the larger noise sources mounted on the aircraft, then the theoretical efficiency is doubled to 5%. The theoretical minimum cavity-to-nozzle separation for this small-scale noise source is 8.5 mm at 5×10^5 N/m^2 pressure. The noise of the small source, when tuned to a frequency of 8 kHz, was analysed on a narrow-band heterodyne analyser and the frequency spectrum is shown in Fig 3. The tone is very clearly defined and, together with some higher harmonics, is at least 30 dB above the level of the background noise of the jet exhausting into the cavity. The waveform at distances of up to nearly 5 m from the source was sinusoidal and thus free of distortion caused by non-linear propagation.

The other important practical characteristic of the noise source is its directivity pattern in both the horizontal and vertical planes. Ideally, the source should be omni-directional and Fig 4 shows the distribution, measured for the small-scale source in both planes and for the large-scale aircraft noise source in the horizontal plane. In both cases the noise sources incorporate an axial stabilising needle, and the sound output is quoted as the Sound Pressure Level (SPL) at an arbitrary distance for both the large and small sources at their operating frequency. For the model source, the total polar variation is within 5 dB in the horizontal plane and within 8 dB in the vertical plane. In the latter case, the presence of the backplate can in certain directions give rise to reflection interference and shielding effects which probably explains the low sound level at the 0° and 180° positions. Also shown is the directivity pattern for the large-scale noise source on the aircraft, where the total variation in the horizontal plane is about 5 dB. The noise output power of the large-scale source, with a cavity diameter of 25 mm, a nozzle diameter of 19 mm and a cavity depth of 22 mm, was about 1 kW or about 25 times more than that of the model source.

In both cases, the modification of Hartmann's original design for an air-jet generator provides a useful and reasonably omni-directional noise source. The generator can be tuned over a wide frequency-range, and the tone is relatively pure though with clearly defined higher harmonics. Moreover, the total sound output is generally more than sufficient for the source to be detected above any interfering background noise such as that of a wind-tunnel, or say the engine noise of a jet aircraft. The source sound energy can, in any case, be increased or decreased by a simple adjustment of the pressure of the air supply; this has relatively little effect on the emitted sound frequency.

4 APPLICATION TO FLIGHT AND WIND-TUNNEL EXPERIMENTS

The modified form of Hartmann noise source incorporating the stabilising needle has found useful application in both full-scale flight experiments and in model-scale wind-tunnel tests to assess the potential for reducing aircraft noise by using the airframe to shield the engine noise. Some early flight studies were made using the Handley-Page 115 slender-delta research aircraft (Fig 5). Originally built to provide information on the low-speed handling qualities of slender-winged aircraft, it subsequently lent itself well to these acoustic studies through having a relatively simple planform shape amenable to diffraction calculations, and a large wing area affording a high degree of shielding. Matched Hartmann noise sources were mounted above and below the aircraft wing and they produced tones that were clearly discernible above the noise of the Viper jet engine. At the same time, the noise sources provided a simulation of the subjectively important discrete-tone features which characterise some turbo-fan engine noise spectra. The installation of the Hartmann source on the engine nacelle above the wing is also shown in Fig 5.

The aircraft flew at nominally constant height over an array of six microphones laid out on a concrete runway surface at right angles to the flight-path. The Hartmann sources were tuned to a frequency of 2.8 kHz and were individually controlled from a switch in the cockpit. The aircraft made a series of passes at constant speed, first with the upper source operating, then with the lower. The noise signals were recorded on analogue magnetic tape and subsequently processed using a Fourier Analyser. In this analysis each recorded signal was broken down into blocks corresponding to a 0.1 s sample. The digitised data were transferred to a disc store and then sequentially analysed into a narrow-band spectrum with constant 10 Hz bandwidth for each data block. Each spectrum was searched to find the peak intensity corresponding to the fundamental of the noise source. Integration over 50 Hz either side of the peak value then gave a measure of the sound level due to the source.

Fig 6 shows the variation with time of the frequency of the Hartmann source at two microphone positions; one directly under the aircraft (M1) and the other the most offset (M6). Only the upper source is in operation. The classic Doppler shift of frequency can be seen. The aircraft velocity calculated from this Doppler shift is 83.8 m/s, compared with a velocity of 82.3 m/s measured by a kinetheodolite system tracking the aircraft. At the microphone position directly under the flight-path, the tone from the upper source could be tracked as the aircraft approached and receded but was lost completely for a period of 2 s when the aircraft was overhead. At the offset microphone position the tone was tracked throughout the fly-past. This provides strong evidence that wing or airframe shielding could be a powerful technique for reduction of aircraft perceived noise especially for the rather idealised case here of a simple compact noise source situated fairly close to the shielding surface.

Following these flight experiments comparative measurements were made at model-scale in the RAE 24ft Acoustic Wind Tunnel Facility and the test installation is illustrated in Fig 7. Although it is relatively difficult to provide a truly anechoic environment in the test-section of a wind-tunnel[7], data analysis is simplified because the experiment is static, and the tests can be made in any aircraft attitude. A quarter-scale model was used and, in order to preserve acoustic similarity, the frequency of this model-scale noise source needed to be four times the value in flight. In fact, the model source was tuned to 10 kHz, compared with 2.8 kHz in flight, this being a compromise between maximising sound output and achieving the correct scaled frequency. Fig 8 shows a frequency spectrum for the HP 115 model in the wind-tunnel with the Hartmann source in operation, at a tunnel speed of 36.6 m/s, compared with the background noise level for the empty tunnel at the same speed. Although the model and microphone supports can be seen to cause an increase in the level of the broad-band background noise, the output of the Hartmann source, when analysed on a third-octave analyser, is some 40 dB above the tunnel and rig noise at the operating frequency. This output was sufficient to allow the noise field under the model to be measured, and hence the degree of shielding within the acoustic shadow, formed by the aircraft's wing, to be evaluated. In order to reject unwanted tunnel background noise, the signal from the traversing microphone (Fig 7) was filtered with a heterodyne analyser tuned to the source frequency with a 316 Hz bandwidth. Results from the wind-tunnel were then compared with the flight-test results, in order to assess the relative merits of full-scale and model-scale experiments[1].

In other applications, wind-tunnel experiments have employed Hartmann sources mounted on models of the BAC 111 and VC10 for investigating the refraction of engine noise by the vortices produced by the wing and flap system, as well as airframe shielding effects: some related RAE work is described in Ref 2. A further flight study using Hartmann generators mounted on an HS 125 aircraft to provide a more representative swept-wing layout has also been undertaken by HSA Ltd (now British Aerospace) with Government funding.

4 CONCLUDING REMARKS

Noise generators of the Hartmann type, especially those incorporating a stabilising needle to improve output and steadiness, have found useful application to both flight and wind-tunnel studies of noise shielding and flow-field refraction effects produced by airframe components. They provide a compact, well-defined source of reasonable size which can be easily scaled acoustically and physically. The high acoustic output has a particular benefit in overcoming background noise problems.

The devices are rugged, efficient, and relatively simple to construct and operate: the output frequency may be altered over a wide range by a simple adjustment of the depth of the resonant cavity, and the output power by adjustment of the air-supply pressure. Tests in an anechoic room have shown the output to be steady and nearly omni-directional.

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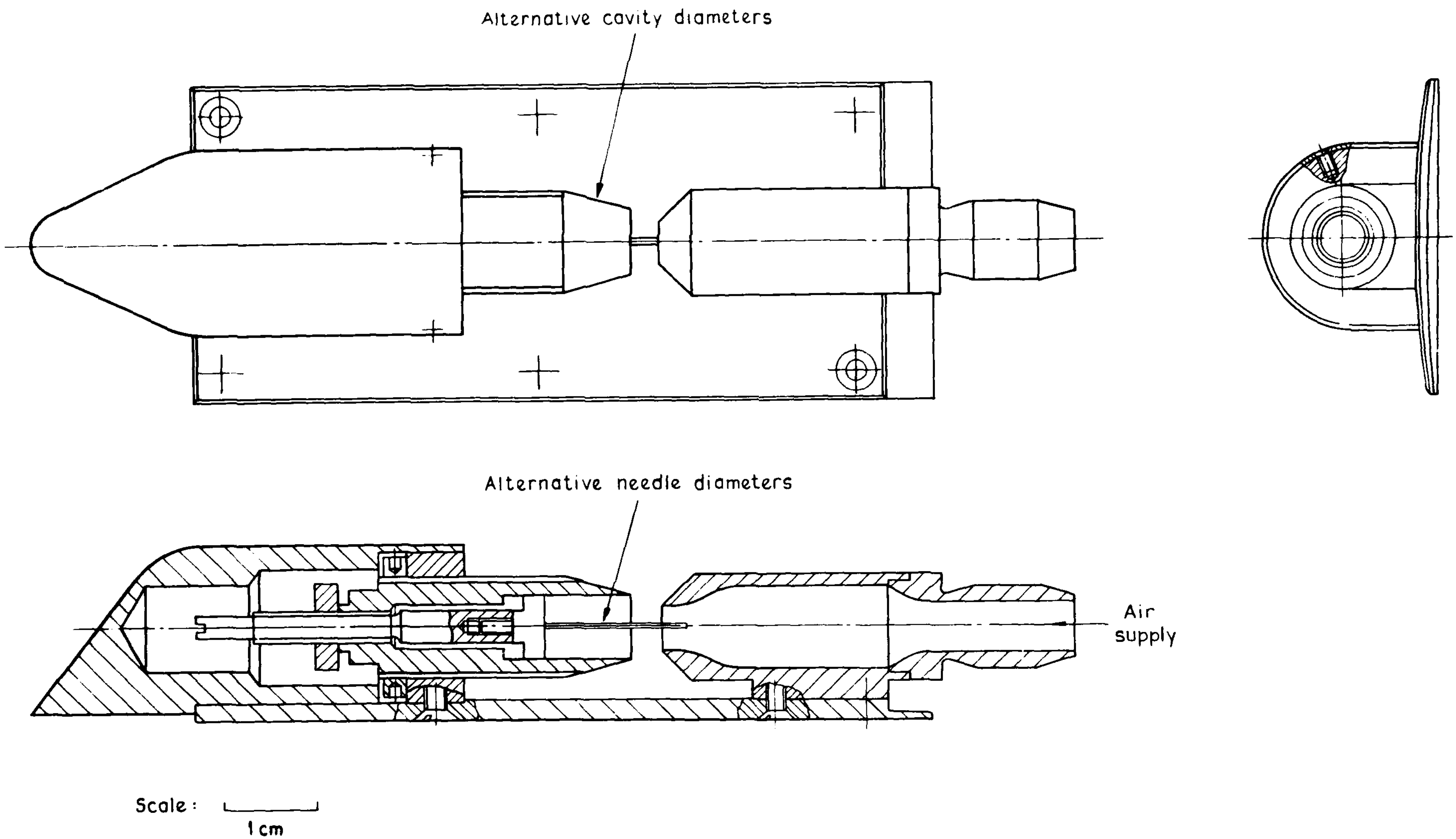
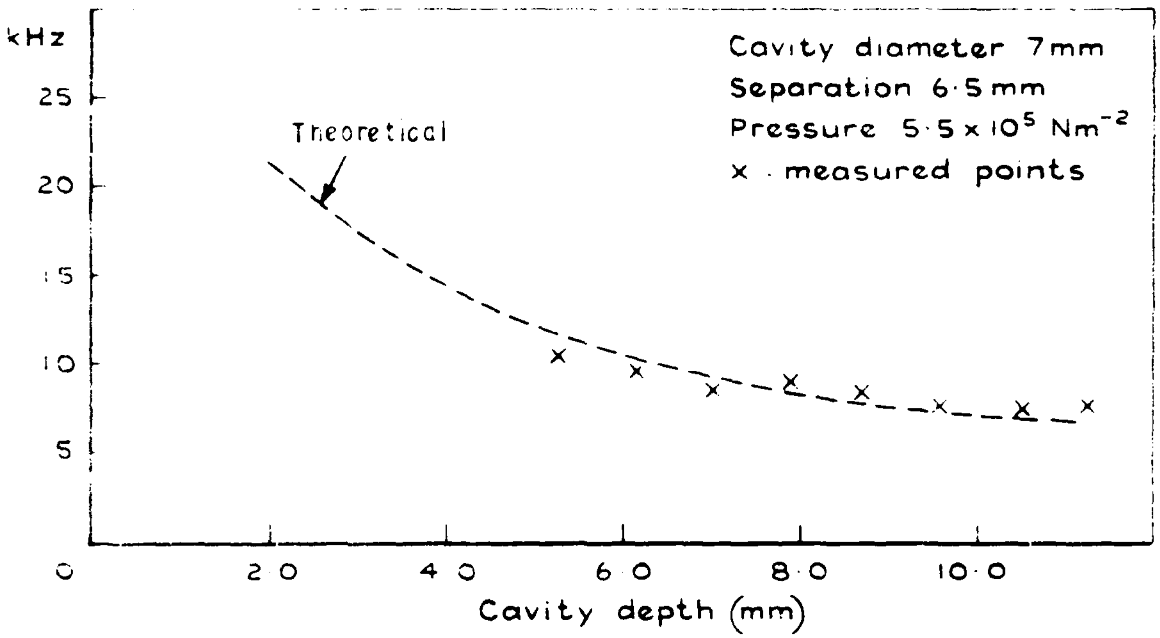


Fig. 1 Assembly of small-scale needle-stabilised Hartmann noise source

Fig. 2 a & b



a Source frequency for cavity depth

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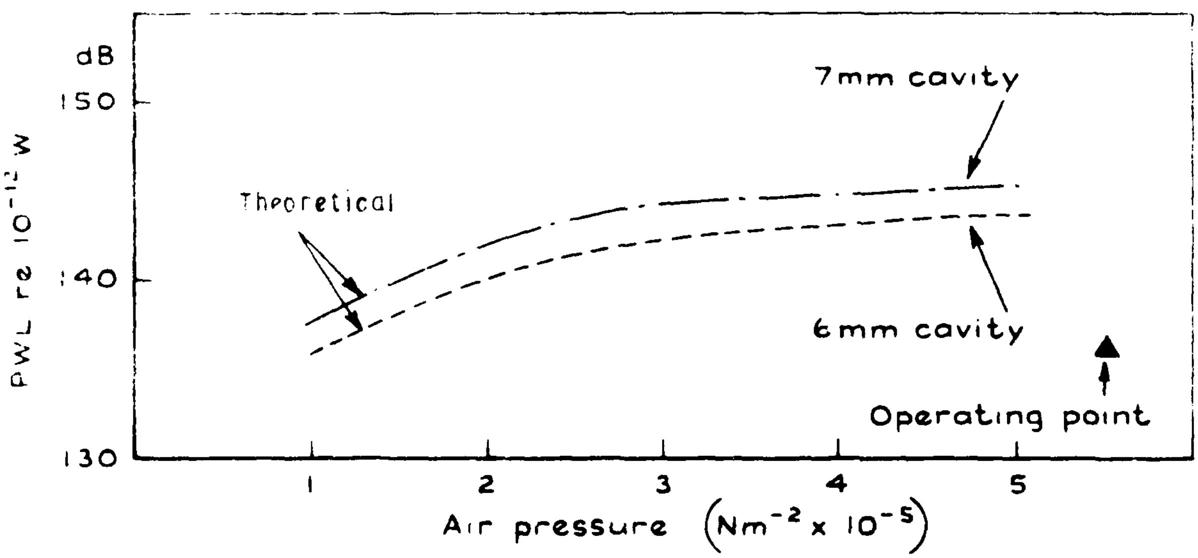

b Acoustic power output for nozzle pressure

Fig. 2 a & b Performance of small-scale noise generator

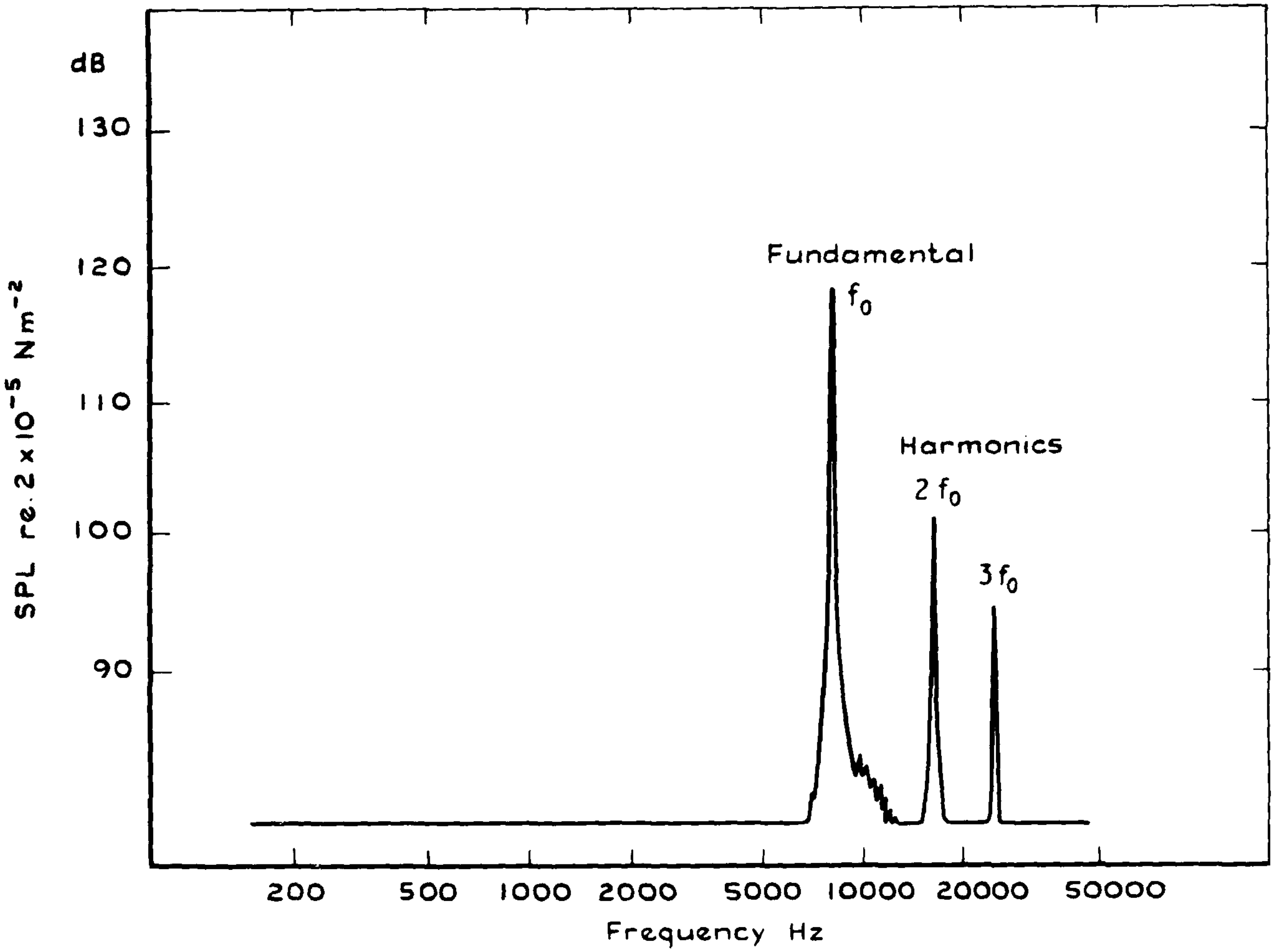

Fig. 3 Frequency spectrum of small-scale noise generator

Fig. 3

Fig. 4

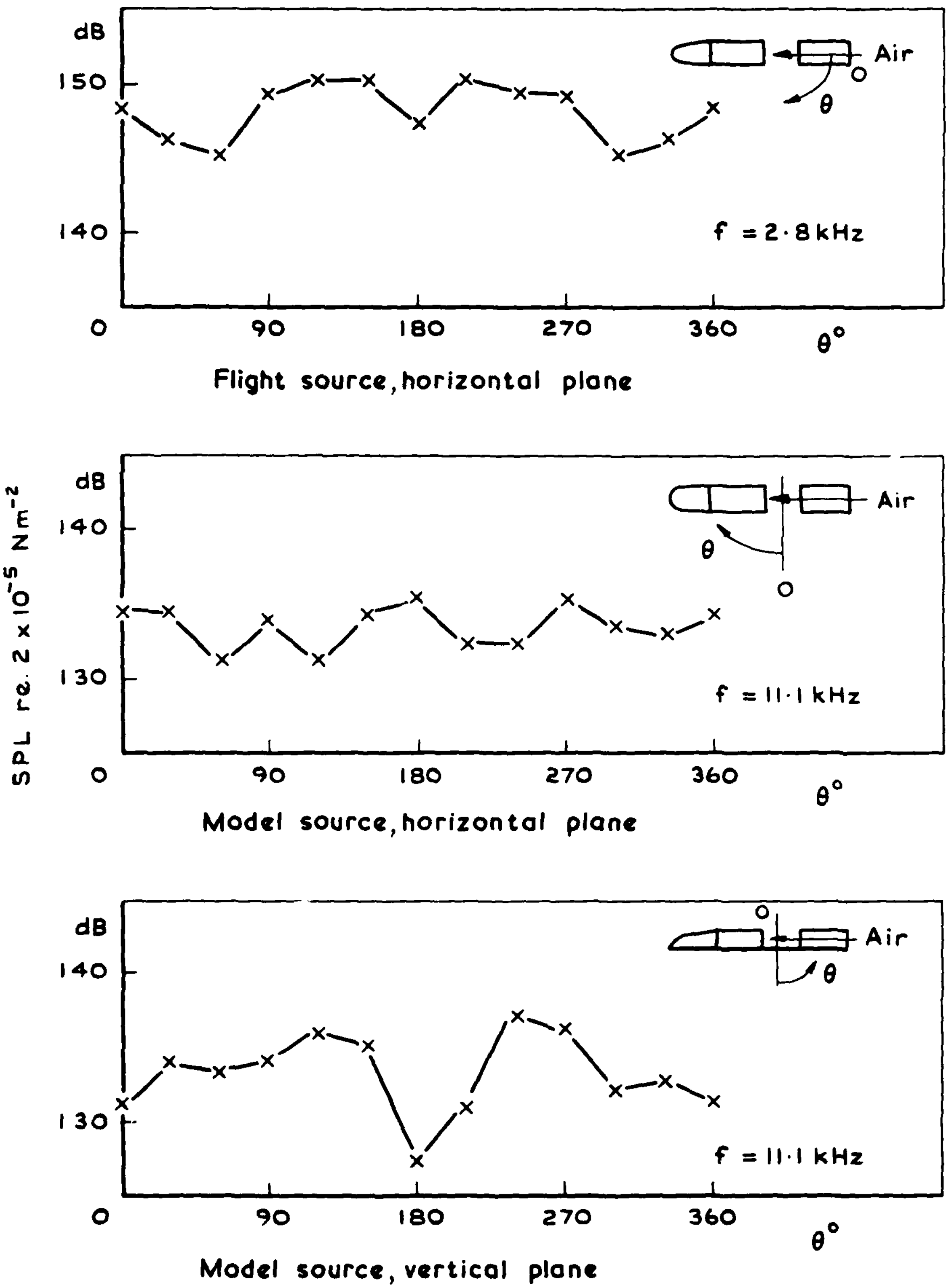

Fig. 4 Directional characteristics of sources

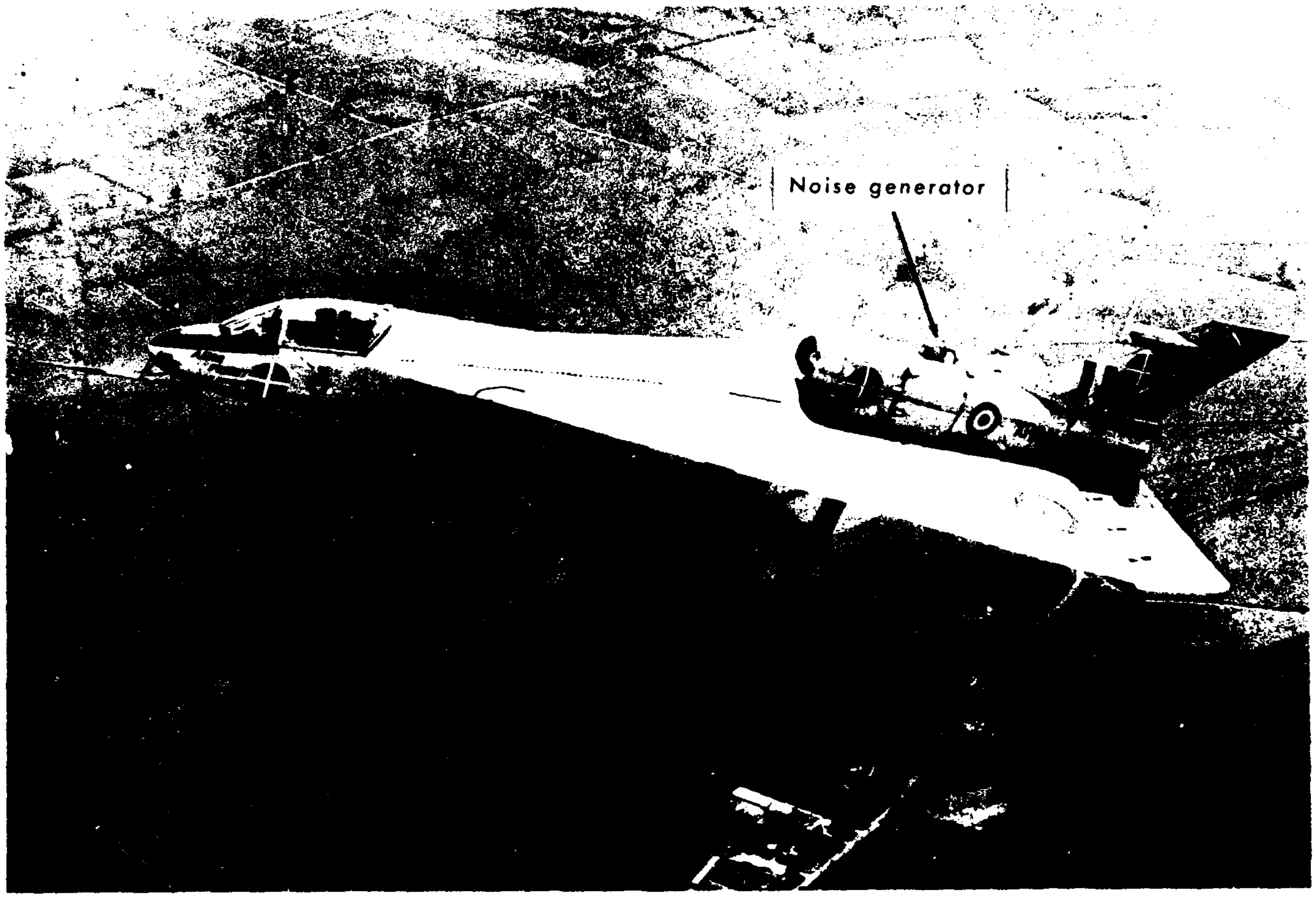

Fig 5 The Handley-Page 115 slender delta research aircraft

Fig. 6

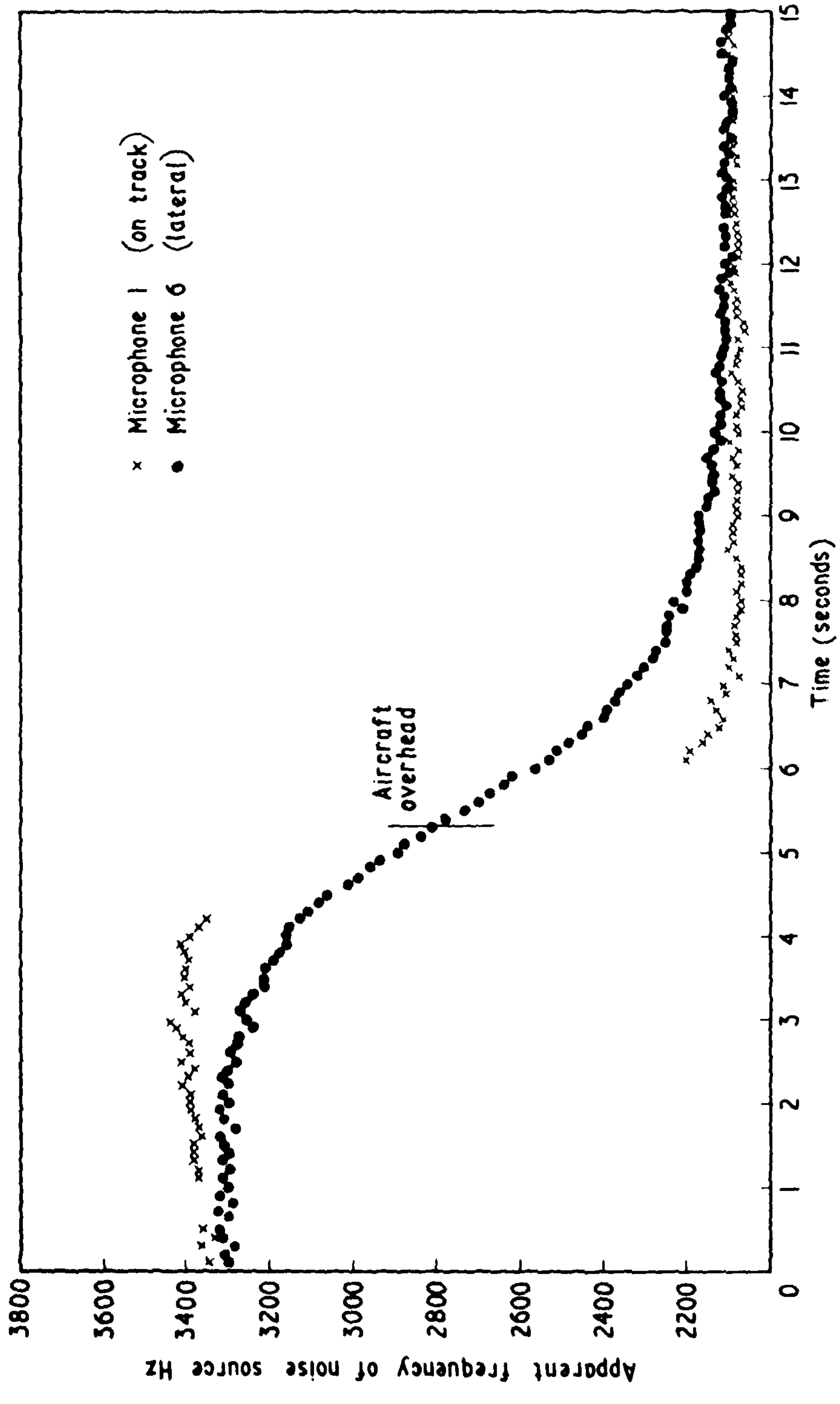

Fig.6 Frequency time-histories during flyover

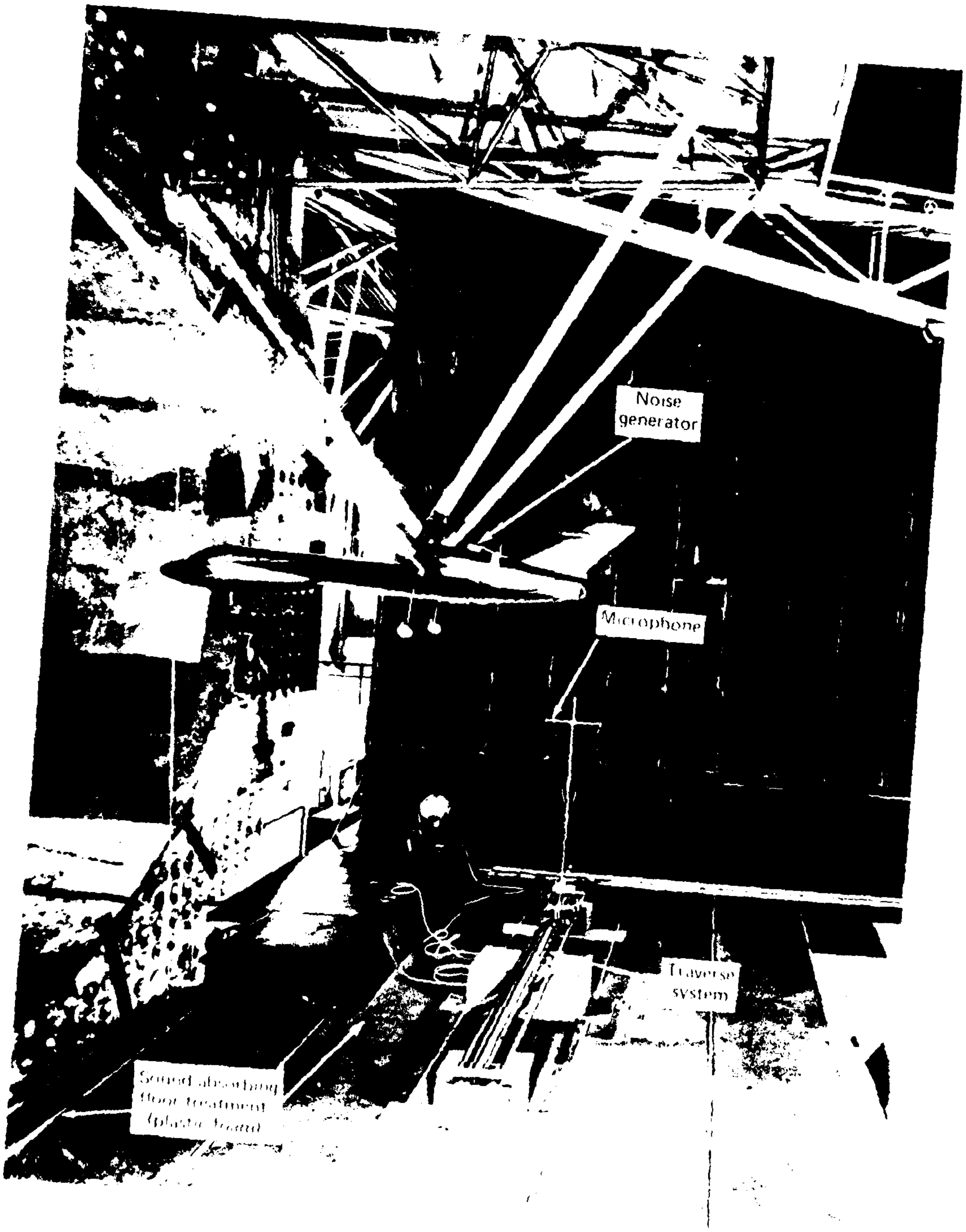

Fig 7 HP 115 model installed in the RAE 24ft diameter wind tunnel

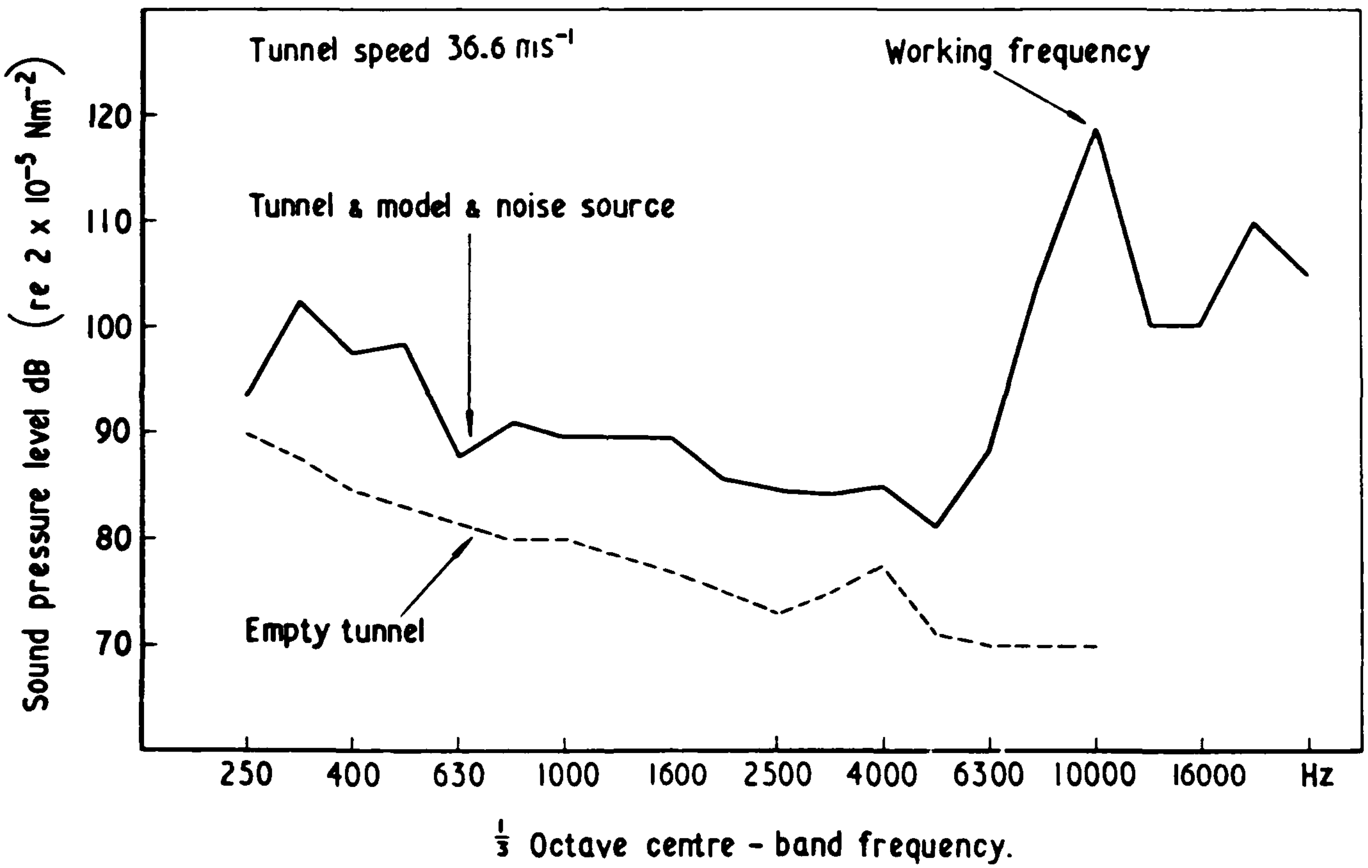

Fig.8 Relative noise levels for wind-tunnel model experiments

REPORT DOCUMENTATION PAGE

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17. Abstract

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