Measurements of Plane-Wave Noise Radiating from a Jet Nozzle

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Theme

IT is well known that the exhaust noise produced by gas turbine aero-engines does not reduce in flight according to the expected behavior of jet noise obtained from flight-simulation experiments.[1] However, it is also known that engines contain internally-generated sources of noise which radiate from the engine exhaust and, as one step towards the solution of the flight problem, it is clearly desirable that the far-field radiation characteristics of internal noise should be able to be quantified, both statically and in flight. The present study is restricted to the consideration of plane-wave radiation.

Contents

The static and the flight-simulation experiments were conducted with the test rig, detailed in Fig. 1, installed in an anechoic chamber. The internal noise required to propagate through the test (primary) nozzle was generated by a loudspeaker in the plenum chamber. A simple hydrogen-burning combustor was incorporated to enable hot jets to be tested, by fitting four small tubes, used for both fuel injection and flame stabilization, across the jet-pipe.

The secondary nozzle, used to simulate the effect of flight on the noise radiation from the primary nozzle, gives a secondary-to-primary area ratio which is satisfactory for the simulation of flight on jet noise[2] and which should therefore be adequate for internal noise.

The limited speaker power (100 W) required the use of tones for the internal noise to be easily distinguished from the jet noise in the far field. The cut-off frequency of the first jet-pipe mode was calculated to be always greater than 4 kHz so that by choosing tone frequencies of 1 kHz and 2.5 kHz, the internal noise was arranged to propagate down the jet-pipe in the form of plane waves.

The far-field noise measurements were made using a 6 mm microphone traversed at a polar distance of 2.1 m from the primary nozzle. Narrow-band analysis (80 Hz bandwidth) of the recorded microphone data was carried out using a Hewlett-Packard type 5451A fast Fourier analyzer. The frequency transforms calculated for each 0.2° of the traverse were averaged over $\pm 5°$ of arc every 10°.

When there is no jet flow, the polar field shapes of the plane-wave tones exhibit little directionality, but there is a marked trend giving higher rear arc levels and lower forward arc levels as the jet velocity is increased. For cold (unheated) nozzle flows, results for the two test frequencies have been obtained up to a jet Mach number (M_j) of 0.95 and a flight Mach number (M_a) of 0.15; some of the measured field shapes are shown in Fig. 2.

The tone levels measured with jets heated to $T_j = 830$ K showed considerably more scatter, as much as 2 dB. Comparisons with the cold jet results were able to be made at jet velocities of 148 m/sec and 324 m/sec. The tone field shapes were seen to be very similar at the same frequency and indeed, at these low velocities, are similar to those of jet noise at the same Strouhal number.

In Ref. 3, Crow presents experimental evidence demonstrating a large amplification of a tone radiating from a jet exhaust when the tone frequency corresponds to a Strouhal number (fd/V_j) of about 0.3. This observation has been related to a characteristic frequency of instabilities of the jet shear layer. But the present results are not uniquely dependent on this Strouhal number and show no evidence of the tone amplification observed by Crow.

Flight simulation tests were only conducted using cold jets. Since the noise was measured outside the secondary airstream, corrections are required to be made for the propagation of the tone through the shear layer of the secondary jet and for the convection of the tone by the secondary flow so that the measured results can be presented as 'true' flight data (equal to the sound pressure level that would be measured at the corresponding sound emission angle if the nozzle were to be moving through still air at the same polar distance from the microphone). These corrections have been derived from a theory of Jacques[4] which treats sound propagation through a cylindrical shear layer assumed to have zero thickness.

The effects of flight on the tone radiation, over a range of jet velocities and at flight speeds equal to about one-sixth of the jet velocity, are also shown in Fig. 2. There can be seen to be little change at 90° to the jet axis. The tone levels are reduced in the rear arc by flight and increased in the forward arc.

The radiation of sound from a semi-infinite cylindrical duct with a jet-like flow has been studied theoretically by Munt.[5] The theory is applicable to jets at ambient temperature and can be used to predict the radiation of internal noise in flight

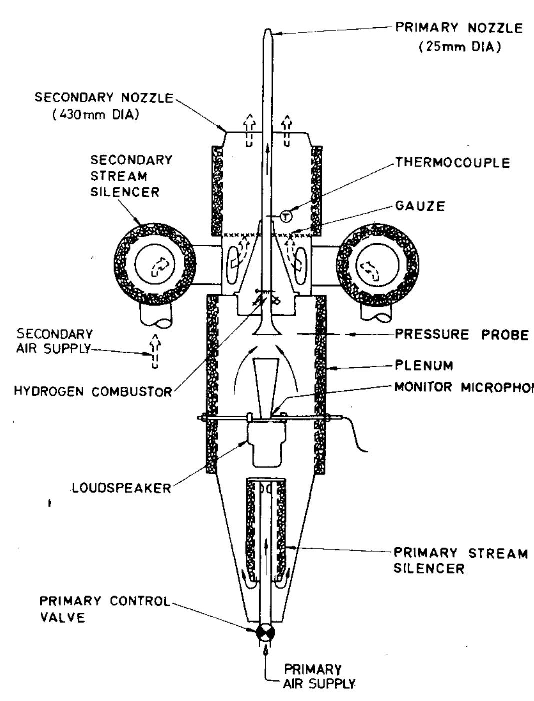

Fig. 1 A diagram of the test rig.

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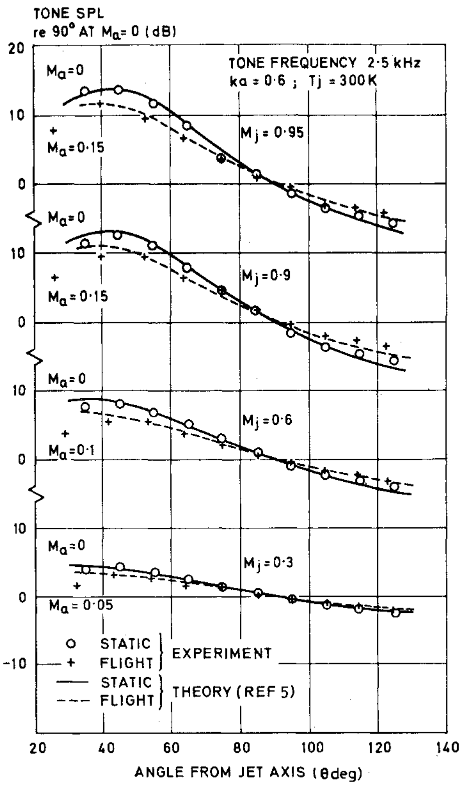

Fig. 2 Comparisons of experimental and theoretical flight effects.

as well as statically. An unstable portion of the noise field arising from Helmholtz shear-layer instabilities is predicted to occur at angles less than a critical angle. For the experiments described here, this is generally less than 40° to the jet axis. Hence most of the field of practical interest can be predicted by neglecting the uncertainties introduced by instabilities.

The theory shows that the radiated field shapes depend on the jet velocity and on the product, ka, of the wave number and the radius of the duct. Taking the duct radius as that of the nozzle, the field shapes relative to the 90° level measured statically for the two plane-wave frequencies of this study have been evaluated for a range of jet and flight velocities to give the curves shown in Fig. 2. Over most of the noise field, the agreement between the theoretical and experimentally derived results can be seen to be excellent. The discrepancies occurring at low angles to the jet axis need not necessarily indicate limitations in the theory but could be attributable to imperfections in the shear-layer corrections arising from the increased shear-layer thickness.

This encouraging result represents a step forward in the prediction of internal noise radiation.

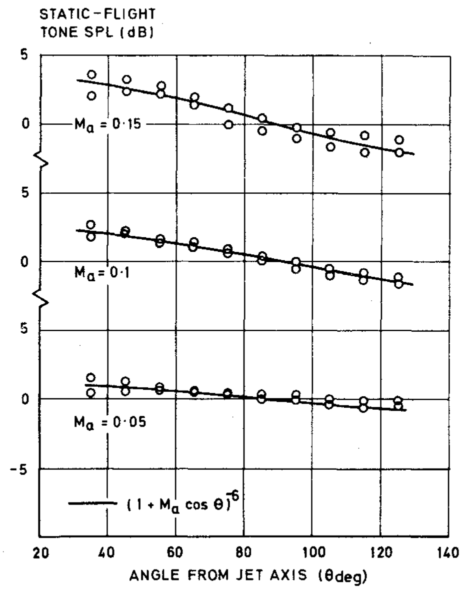

Fig. 3 A correlation of static-to-flight changes.

In an attempt to correlate the static-to-flight changes in a simple manner for prediction purposes, the available data have been plotted in Fig 3 at constant flight Mach numbers. The data collapses reasonably well and, as a simple working hypothesis, an aircraft Doppler-type term of the form $(1 + M_a \cos \theta)^{-n}$ was fitted to the results. The best fit was obtained with $n = 6$, although a value of $n = 4$ has often been suggested from general theoretical considerations.

Acknowledgments

References

[1] Bushell, K.W., "Measurement and Prediction of Jet Noise in Flight," AIAA Paper 75-461, Hampton, Va., 1975.

[2] Way, D.J. and Cocking, B.J., "The Use of Co-flowing Airstreams for the Simulation of Flight Effects on Jet Noise," National Gas Turbine Establishment, Pyestock, Farnborough, Hampshire, UK, NGTE Report to be published.

[3] Crow, S.C., "The Predictability of Jet Noise," Boeing Commercial Airplane Company, Seattle, Wash., Jan. 1972.

[4] Jacques, J.R., "The Noise from Moving Aircraft; Some Relevant Models," PhD thesis, Cambridge University, Cambridge, England. Aug. 1975.

[5] Munt, R.M., "The Interaction of Sound with a Subsonic Jet Issuing from a Semi-Infinite Cylindrical Pipe," Mathematics Dept., University of Dundee, Scotland, May 1976.