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MILITARY AIRCRAFT SOURCE NOISE

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Historically civil aircraft have been required to meet ever tightening international standards, and as a result the noise levels for new civil aircraft entering service have dropped by almost 20dB as shown in figure 1. This was initially due to the change from turbo-jets (or low-bypass ratio engines) to the modern high-bypass ratio engines such as the RB211, JT9 and CF6. The impetus behind the development was primarily for greater propulsive efficiency but the associated move towards lower specific thrusts, that is thrust provided by greater mass flows and lower exhaust velocities, reduced the dominance of the jet mixing noise and this trend is evident from figure 2. Further advances in noise reduction technology, driven by tighter legislation and coupled with the gradual retirement of the older and noisier jets, has thus significantly improved the noise climate around civil airfields.

Unfortunately, the trend for high-performance combat aircraft is towards engines of high specific thrust to give the aircraft increased agility and to enable them to operate at high flight speeds. A measure of this growing disparity between civil and military aircraft noise in the airfield environment is demonstrated by the fact that civil aircraft can be up to 20dB quieter than a military aircraft of the same weight. They are not, however, capable of the same missions.

Although military and civil aircraft engines share many common noise sources the sources which dominate differ. Some of these sources are more amenable to treatment than others and thus, depending upon their nature and the engine application, significantly different noise levels are produced. The low-bypass-ratio engine is a high specific-thrust engine and typical of those fitted to most modern combat aircraft. Its noise is dominated by the jet noise whereas that of the high-bypass-ratio engine with its lower specific-thrust tends to have all the sources roughly of equal magnitude.

In order to understand the various problems associated with military aircraft noise, it is best to start with a brief description of the main noise sources involved.

Jet mixing noise is the source synonymous with the public's image of jet aircraft and is generated by the high-velocity gases from the engine shearing and mixing with the surrounding atmosphere. The sources are external to the engine forming a region approximately 10 nozzle diameters long. The noise is highly sensitive to changes in the exhaust velocity. At very high velocities an additional source starts to appear when the eddies in the mixing region radiate noise as miniature "sonic booms".

The jet mixing noise associated with high-bypass-ratio engines behaves in a similar manner, but is complicated by the two concentric exhaust streams which aerodynamically interact to modify the noise source regions. Shock cells which are formed in the engine exhaust when the jet is under-expanded, that is, when the exhaust flow becomes supersonic relative to the local conditions. These cells produce two different forms of acoustic radiation; shock cell screech and shock associated noise.

Shock cell screech is generated by the oscillation of the train of shock cells due to positive acoustic feedback around the jet. Although exhibited strongly by model jets as intense tones, especially when cold, this mechanism is not so dominant with the turbulent hot flow from real engines.

Shock associated noise is the open loop equivalent of screech whereby broadband noise is generated by turbulence in the jet producing pressure pulses as it passes through the shock cell structure. It is dependent on pressure ratio, as can be seen from figure 3 which shows the variation of noise intensity with a Mach number function.

Reductions in both shock noise sources can be best achieved by using a matched convergent-divergent nozzle to correctly expand the exhaust gases and prevent formation of the shock cell train. Complete elimination is unlikely with full-scale engines, even with an active variable nozzle system, since the mchanical difficulties make it virtually impossible to achieve perfectly expanded flow over a wide range of pressure ratios. However useful reductions may be possible and although these nozzles are heavy and complicated by the requirement for area variability for reheat, they also offer potential improvements in performance.

Flight has little direct effect on the source strength, although as the flight speed increases more of the noise radiates forward of the aircraft by a phenomenon known as convective or Doppler amplification. All sources in motion undergo this process but it tends to be identified more with sources which are directly linked with the motion of the aircraft.

Although airframe noise is not an engine source it is a potentially important mechanism. It is a general term and covers the noise generated by the airframe and deployed structure, such as the landing gear and flaps, which generate extra turbulence. This noise is not likely to be a problem with combat aircraft in airfield operations due to their low speed and small physical size, but will contribute in high-speed, low-altitude operations, especially when fitted with external stores and munitions.

At very low altitudes and high speeds, the noise is also felt, as the lift pressure pulse due to the aircraft presence passes. This results in sub-audible pressure fluctuations.

The installation of an engine into an airframe can cause substantial changes in the apparent behaviour of the engine sources. Four fundamentally different types of mechanism can be present. Firstly, there is acoustic interaction, which in its simplest form is reflection from the adjacent aircraft structure such as the undersurface of a wing, but can also occur as scattering of the acoustic wave by an edge. Secondly, noise can be generated by the presence of a surface close to, but not actually in, the jet flow. This is because the surface in the near-field inhibits the normal cancellation processes that occur when the sound propagates into the far-field. Thirdly, noise will be generated by the jet if it impinges upon a surface such as the wing-flaps.

Finally, the noise from a jet will be increased in flight due to flight stream turbulence entering the jet. Figure 4 shows the results from research tests on a model of a military trainer aircraft operated both statically, that is with no forward motion, and at a modest simulated flight speed. Statically the effects are small, but in flight substantial increases are observed at large angles from the jet axis, while in the rear arc the full flight reduction for clean jets is almost achieved. This forward arc increment is likely to increase with flight speed and thus become significant with combat aircraft operating at high subsonic flight speeds.

Turning to the applications, since the spectrum of military aircraft types and their associated missions are considerably more diverse than their civil counterparts, it is best to consider the problem under four main headings. First, support aircraft, second, combat aircraft in the airfield environment, third, combat aircraft training at low-level, and finally, special category aircraft.

In general the requirements of support aircraft, such as tankers, AWACs, cargo etc, mirror their civil counterparts. The technology improvements made in the civil sector to reduce fuel consumption, life-cycle costs and emmissions (smoke), and improve reliability, are all features that are of importance to the military operators. In addition these improvements have gone hand in hand with noise reductions brought about by the legal requirements to meet international noise regulations. Thus, available in todays market place are engines having all the necessary attributes for military use without the need to provide significant development funding.

Apart from the capital expenditure, which could be offset in some measure by reduced fuel and life-cycle costs, in principle there is no technical reason why the noise of support aircraft should not be significantly reduced. In some notable cases this has already been done and probably the best example is the USAF re-engining of the Boeing KC-135 tankers. The fitting of CFM-56 turbo-fan engines has reduced the noise by 17 EPNdB (a footprint reduction of 98%) and produced an aircraft with increased range and no smoke. Other examples are the use by the USAF and RAF of modified civil airliners as tankers and general transports.

With combat aircraft in airfield environments it is evident that jet and shock noise are by far the most dominant sources in terms of level, and probably cause the most complaints from the public. Unfortunately they are also the most difficult group of sources to silence even though the problem has been studied for many years.

A closely parallel problem was the Concorde with similar exhaust conditions where, in spite of an extensive research programme, no simple universal silencer was found.

The most successful silencing technique employed during flyover and approach was a modification of the engine control system enabling the final nozzle to be enlarged, thus passing more mass flow and reducing the jet velocity for a given thrust. The extent to which this latter technique can be generally applied depends on the characteristics of the particular engine involved, but could offer small benefits with minimal hardware changes.

For the next and future generations of super-sonic transports (SSTs), meeting the noise certification targets is one of the most critical questions that must be answered. On-going research has produced several new ideas and developments of existing techniques.

While with some schemes the principle reductions are in shock noise, other schemes, such as mixers with downstream line ejectors, reduce both jet mixing and shock noise and thus offer significant potential for commercial SSTs applications.

A measure of variable geometry is vital in the design to permit the silencer to be stowed for supersonic cruise and thus minimise cruise thrust losses. However, for combat aircraft the thrust loss, weight and mechanical complexity are likely to be unacceptable.

Future work is focussing on the use of variable cycle engines which enable gross changes in the engine cycle and geometry to be achieved. This form of engine is equivalent to having the benefits of a high-bypass ratio engine in the airfield environment and a high-specific thrust mode for supersonic operation.

However for military applications the necessary compromises may not be acceptable and, unless the engines offer significant advantages elsewhere, the massive allocation in both money and manpower is unlikely to be committed on military noise grounds alone.

As well as direct reduction in source noise through engine design, improvements in airframe performance through increased lift/drag ratios do offer significant advantages. During take-off the extra lift for a given drag, and hence engine thrust, will result in the aircraft climbing more steeply, thus reducing its noise impact on the ground.

In source noise terms the noise from combat aircraft operating at low-altitude and at high subsonic speeds is complicated by the high flight speeds. Virtually all the knowledge that has been acquired over the last 30 years has been concerned with civil operations around airports and hence flight speeds have been limited to 0.3 Mach. At higher speeds around 0.7 Mach, typical of training missions, the sources of noise involved are known but not which ones are dominant. Figure 5 illustrates the scale of the problem and the current state of our understanding based upon the simple extrapolation of existing data. Some of these sources may be ammenable to treatment, but it critically depends on which are dominant.

Schemes for reducing jet and shock noise such as ejector mixers, which appear attractive at the lower speeds, may not be suitable for these higher speed operations. However other schemes such as increasing nozzle area could be beneficial, but only to a limited extent and then depending upon which sources dominate.

But even before a start can be made on assessing what noise reduction methods may be possible, the breakdown of the sources needs to be known and their characteristics understood. In the past flight tests investigating military noise had been aimed at providing information for noise zoning and community responses, and are inadequate to identify the sources which requires carefully structured and controlled flight tests.

Therefore, the first priority is for a series of dedicated flight tests to provide the necessary information. Judgements can then be made as to future research programmes aimed at investigating potential silencing methods and techniques.

Finally, combat aircraft that have the capability of vertical take-off and landing (VTOL), such as the Harrier, do have a serious noise problem. Studies of future designs have taken noise as a prime factor because of the problem of structural fatigue and, to a lesser extent, the ground crew environment. Fortunately for the community their ability to take-off and land vertically does mean that the noise can be confined within the airfield/operations boundary.

CONCLUSION

A start has been made on the reduction of military aircraft noise with the recognition that there is a problem. However, to reduce the impact on the community needs a positive commitment by all parties to consider noise in all aspects of its activities; from the initial design studies for new engines/aircraft, right through to their operational use. Technology is available, and being applied, for some classes of aircraft. Unfortunately the performance requirement and mission flexibility of combat aircraft invalidates the application of existing technology.

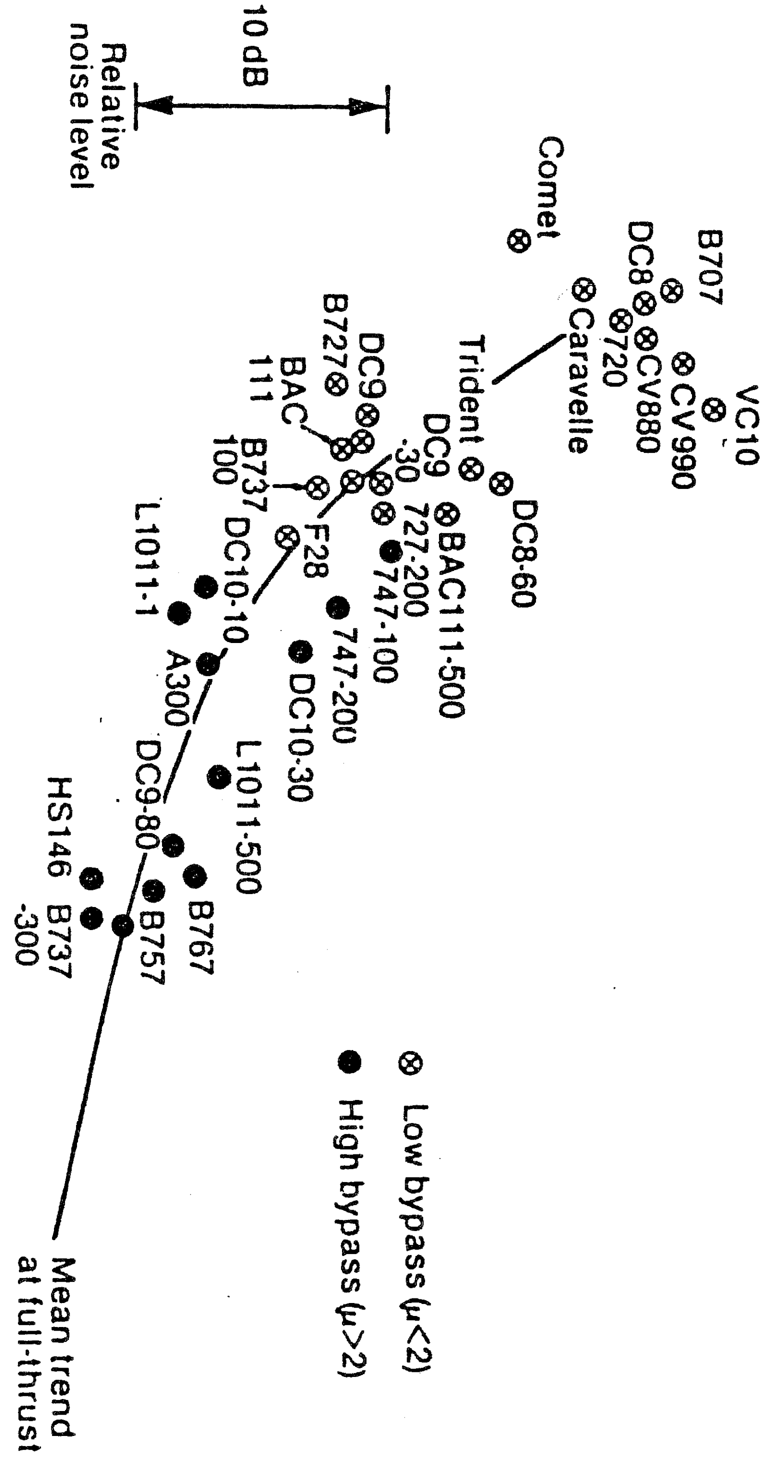
10 dB
Relative noise level
Comet
B707
DC8
720
Caravelle
VC10
CV990
CV880
Trident
DC8-60
DC9
DC9 -30
B727
BAC 111
B737 100
BAC111-500
727-200
747-100
F28
DC10-10
L1011-1
747-200
DC10-30
A300
L1011-500
DC9-80
B767
B757
HS146
B737 -300
Low bypass (μ<2)
High bypass (μ>2)
Mean trend at full-thrust
1960
1970
1980
1990
ENTRY INTO SERVICE DATE

Figure 1

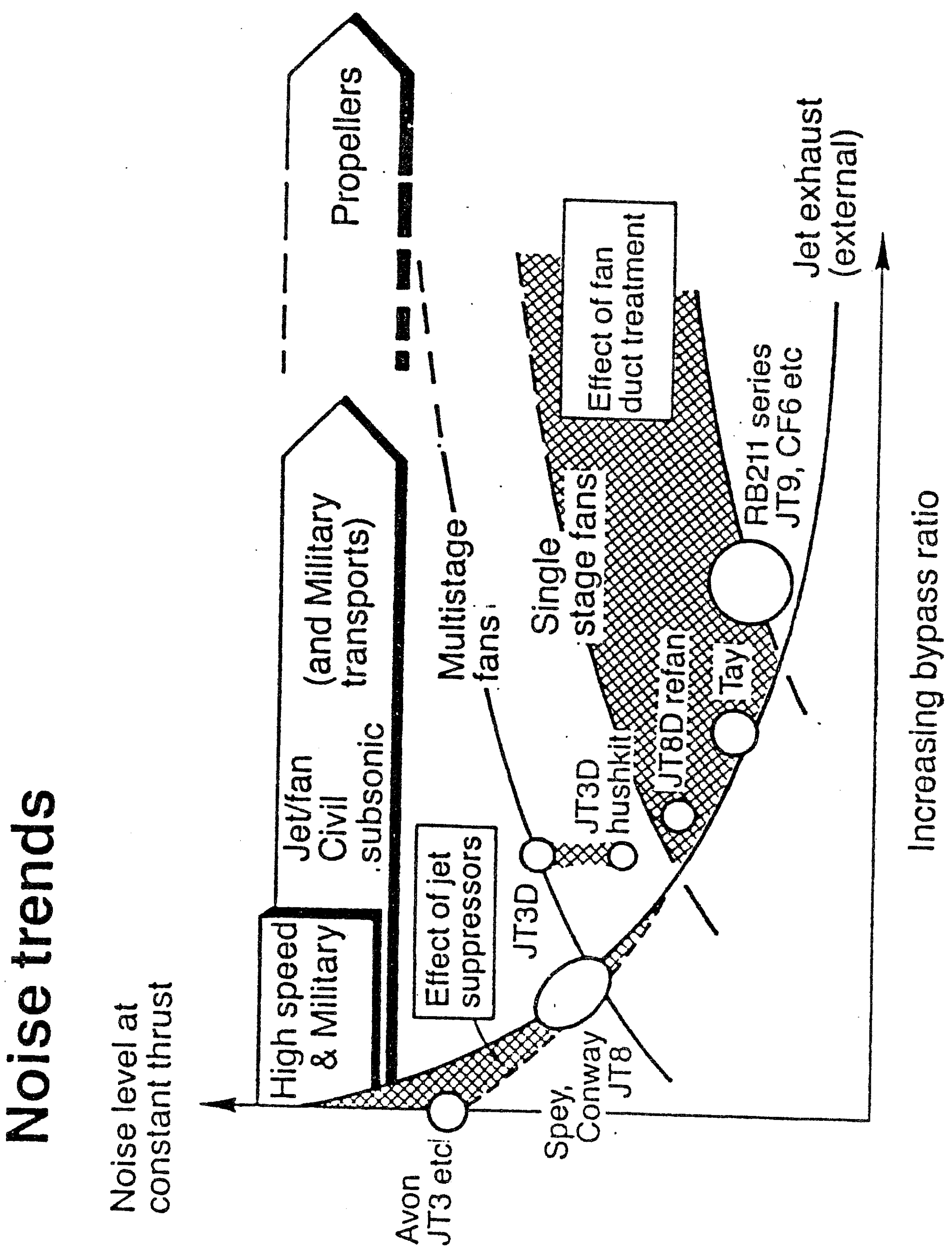
Noise trends
Noise level at constant thrust
High speed & Military
Jet/fan Civil subsonic
(and Military transports)
Propellers
Effect of jet suppressors
Multistage fans
Single stage fans
Effect of fan duct treatment
JT3D
JT3D hushkit
JT8D refan
Tay
RB211 series JT9, CF6 etc
Jet exhaust (external)
Increasing bypass ratio
Avon JT3 etc
Spey, Conway JT8

Figure 2

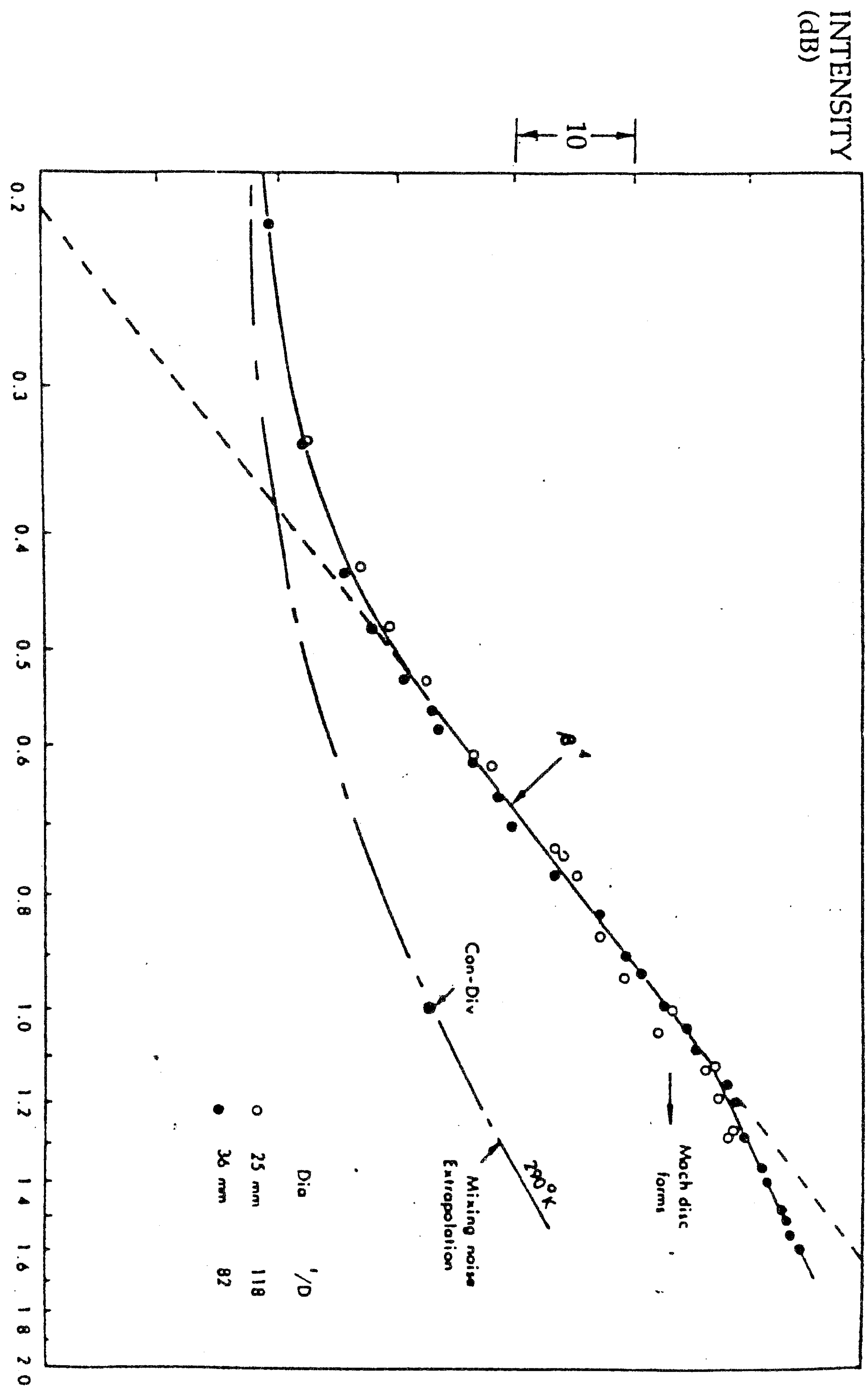
INTENSITY (dB)
10
0.2
0.3
0.4
0.5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\beta = \sqrt{M^2 - 1}$
β^4
Con-Div
Mach disc forms
290°K
Mixing noise Extrapolation
Dia
l/D
o 25 mm 118
● 36 mm 82

Figure 3

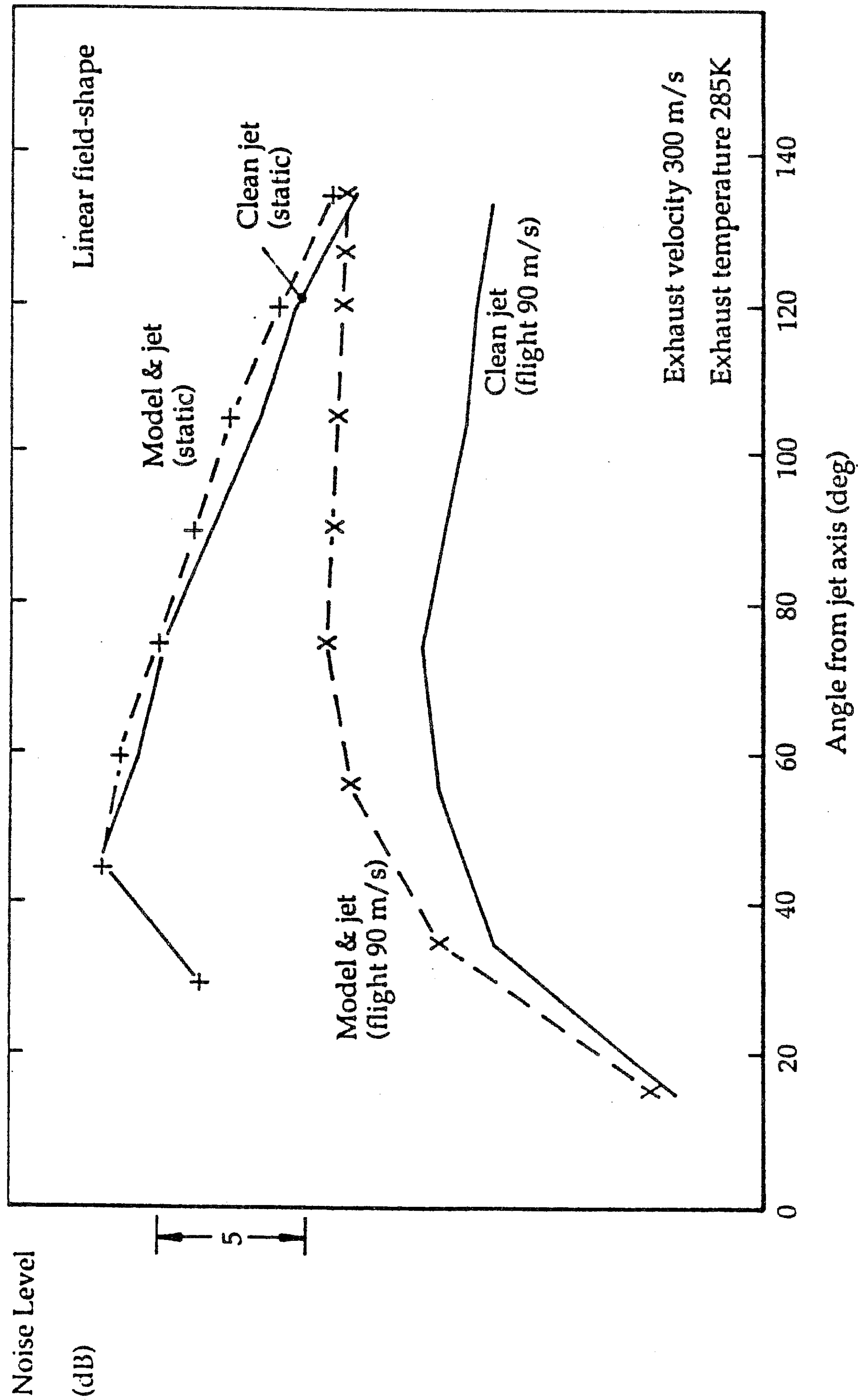
Linear field-shape
Clean jet (static)
Model & jet (static)
Model & jet (flight 90 m/s)
Clean jet (flight 90 m/s)
Exhaust velocity 300 m/s
Exhaust temperature 285K
0
20
40
60
80
100
120
140
Angle from jet axis (deg)
Noise Level
(dB)
5

Figure 4

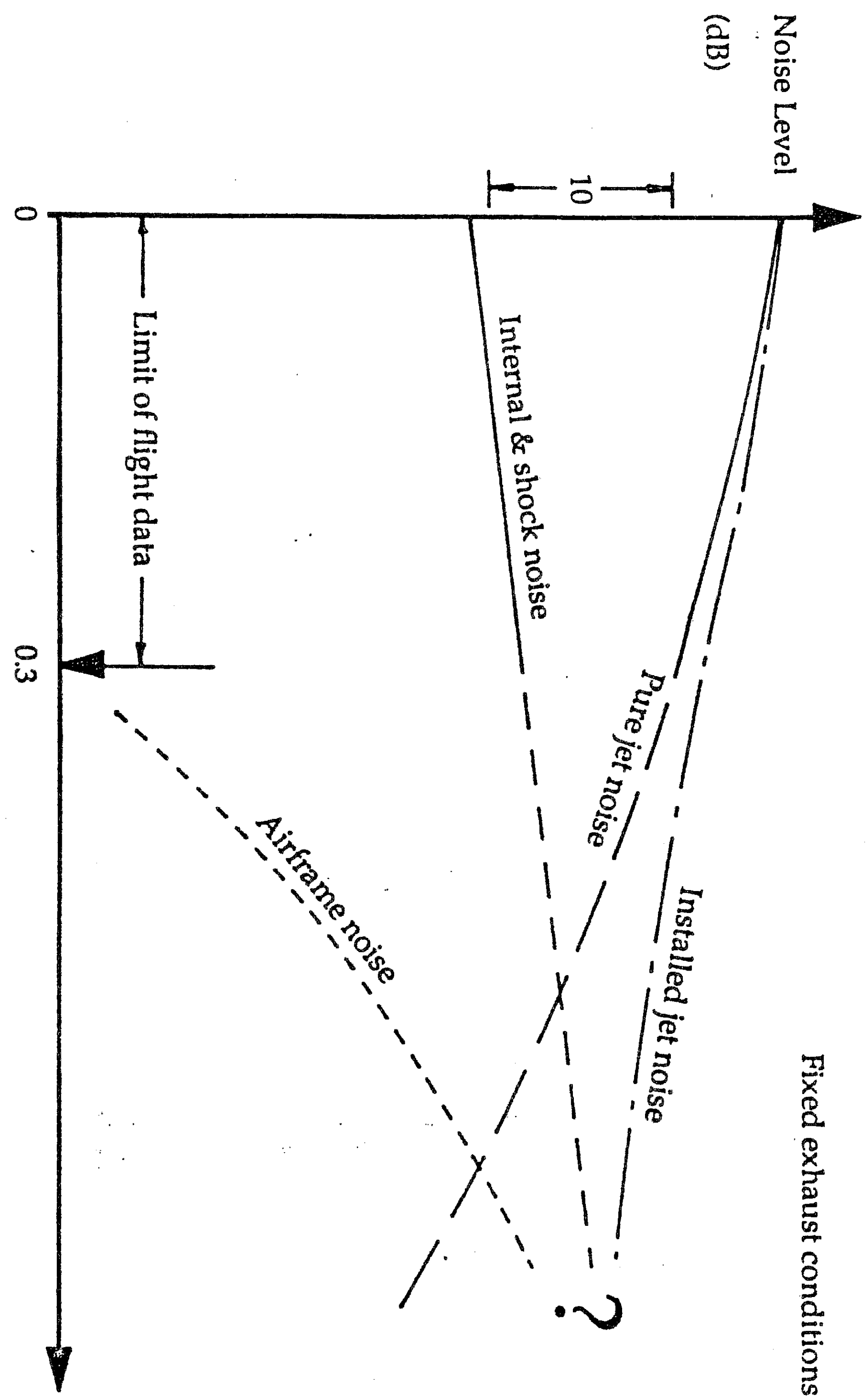
Noise Level
(dB)
10
0
0.3
Limit of flight data
Internal & shock noise
Pure jet noise
Installed jet noise
Airframe noise
Fixed exhaust conditions
?
Flight Mach Number

Figure 5