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Workshop Summary

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1982

NOISE MEASUREMENTS IN WIND TUNNELS –

WORKSHOP SUMMARY

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Ames Research Center

This paper summarizes the technical content of the NASA Ames Research Center "Workshop on Aero-acoustics Tunnel Testing Techniques" held in March of 1979. In reviewing the progress made in acoustic measurements in wind tunnels over the 5-yr span of the workshops, it is evident that a great deal of progress has been made. New, specialized facilities have been brought on line, special measurement techniques have been developed, and corrections have been devised and proven. This new capability is in the process of creating a new and more correct data bank on acoustic phenomena, and represents a major step forward in acoustics technology.

Additional work is still required, but now, rather than concentrating on facilities and techniques, researchers may more profitably concentrate on noise-source modeling, with the simulation of propulsor noise source (in flight) and of propulsor/airframe airflow characteristics. Recent promising developments in directional acoustic receivers and other discrimination/correlation techniques should now be regularly exploited, in part for model noise-source diagnosis, but also to expedite extraction of the lone source signal from any residual background noise and reverberation in the working chamber and from parasitic noise due to essential rigs or instrumentation inside the airstream.

In 1974 and again in 1976, the NATO Advisory Group for Aerospace Research and Development sponsored workshops on the measurement of noise in ground-based facilities. These workshops, organized by Professor John Williams and Mr. R. Westley, provided a useful exchange of information among the participants and provided material for AGARD-AR-83 and AGARD-AR-105. The majority of the discussions at these workshops were on the measurement of noise and the simulation of flight effects on noise in wind tunnels.

In March of 1979, NASA Ames Research Center (ARC) sponsored and organized a subsequent "Workshop on Aero-acoustics Tunnel Testing Techniques." This workshop, which was organized similarly to the AGARD Workshops, focused on aeroacoustic wind tunnels and the techniques used for noise measurements in these facilities. Professor John Williams chaired the workshop.

This paper will summarize the technical content of the ARC workshop and present the important acoustic parameters of wind tunnels used for noise research. The list of workshop papers is presented in appendix A and a list of attendees is in appendix B. Appendix C is a list of papers on the workshop subject that have been published since AGARD-AR-105 was published. Copies of vugraphs were distributed to the meeting attendees and are available from ARC.

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SUMMARY OF WORKSHOP TECHNICAL CONTENT

The discussions of the workshop will follow the general topical outline of the agenda, but will be in a different order.

Facility Development

Facility developments seem to have taken two paths. One taken by those who have no wind-tunnel-type facilities resulted in new, specially designed open-throat wind tunnels with the test sections surrounded by anechoic chambers. The second approach was to modify existing wind tunnels (open and closed throat) or anechoic chambers to make them acceptable for noise research on the effect of flight. Most Government agencies (RAE, NGTE, NASA, etc.) have followed this second path because of the plethora of such facilities at the aeronautical establishments. The ensuing discussion will examine examples of each approach.

New open-throat wind-tunnel facilities – Some examples of the new facilities are the French CEPRA 19 and German-Dutch DNW wind tunnels in Europe, and the Boeing, Douglas, and General Electric facilities in the United States. While all designs are different in dimension and detail, the basic concepts are as illustrated in figure 1 (from Paper 15). The noise measurements outside the flow are one factor that is inherent in open-throat wind tunnels. Another factor is the necessity for noise data corrections for the alterations in the signature, due to transmission through the shear layer. Of course, if the jet is large compared to the chamber, the user may choose instream measurements. (These corrections will be discussed in a later section.) Reliable near-field measurements well inside the airstream can also be important (discussed later). One of the major questions with open-throat wind tunnels is that of flow quality. Figures 2 and 3 (from Paper 14) show the mean flow velocity profile and the RMS turbulence level in the Boeing Wind Tunnel. The flow quality and turbulence levels of open-throat wind tunnels are not quite as good as for the best closed test section wind tunnels used for aerodynamic investigations. They are adequate, however, provided the effects of unsteady flow at very low frequency are of no concern.

Another basic parameter in acoustic wind tunnel performance is the background noise. Figure 4 (from Paper 14) shows a requirement based on specific engine performance, but this level is rather high and would limit the type of testing that could be done in the facility. Figure 5 (from Paper 16) shows what can be done by very careful design of a wind tunnel for noise research. With the background noise shown, research on a low-level noise contributor such as airframe noise should be practical.

It is apparent from the workshop that a number of high quality, open-throat wind tunnels for acoustic testing have been or are about to be brought on line since the last AGARD Workshop. These facilities have test airstreams as large as 8 m square and include national facilities such as the DNW tunnel and the industry-owned facilities such as the G.E., Boeing, and Douglas tunnels. The ability to test small-scale acoustic models has taken a quantum leap in these last few years, stimulated by the previous exchanges on aeroacoustic techniques provided by the AGARD Workshops.

Modified wind tunnels – Some of the facilities modified for acoustic and wind-tunnel testing include the NGTE Anechoic Chamber, RAE 24-Foot and 1.5-Meter Wind Tunnels, the Boeing 9- by 9-Foot Wind Tunnels, and the NASA V/STOL, 7- by 10-Foot Wind Tunnel, and 40- by 80-Foot Wind Tunnel. Since some of the recent and most thorough work has been done on the RAE 1.5-Meter Wind Tunnel and the Ames 7- by 10-Foot Wind Tunnel, the characteristics of these two facilities will be discussed.

Figure 6 (from Paper 20) shows the circuit of the RAE 1.5-Meter (5-ft) Wind Tunnel before internal modification to simulate a possible practical solution for modifications of the RAE 24-Foot Wind Tunnel, and figure 7 shows the circuit after the modification. The drive system with a new quiet fan was moved from near the test section to the back leg to provide more distance from the test arena and space for the splitters to control fan noise propagation. Figure 8 shows that the alterations to the 1.5-Meter Wind Tunnel reduced noise as much as 25 dB and 15 dB over the practical frequency range for the same speed. Alternatively, this provides double the test speed for the original background noise. These are, of course, drastic modifications to the tunnel, but it would still be much less costly to correspondingly modify the 24-ft tunnel than to build a new large facility.

The NASA Ames 7- by 10-Foot Wind Tunnel Circuit is shown in figure 9. Treatment was added to the circuit cross legs to control fan noise, and the test-section walls were made removable so that the test section could have closed hard walls, closed acoustically absorbent walls, or three walls open. This modification is not as drastic as the modifications to the RAE 1.5-Meter Wind Tunnel, but the original NASA Ames wind-tunnel background noise level was lower than the original RAE wind-tunnel noise level. Figure 10 shows the effect of the circuit treatment on the in-stream noise with the hardwall test section. This background noise level is expected to be less with a treated test section wall. Figure 11 shows the background noise level with the test section open, along with similar data from two smaller anechoic wind tunnels. The measurements arena in the 7- by 10- is not treated whereas they are treated in the other two wind tunnels. It appears that the 7- by 10- will be reasonably competitive with other acoustic wind tunnels. The turbulence level in the 7- by 10- is shown in figure 12 with open and closed test sections and the 40- by 80- levels are included for comparison. The modifications do not appear to have seriously hampered the flow quality.

These two cases of wind-tunnel modifications show that aerodynamic wind tunnels can be modified into facilities acceptable for most noise measurements. However, the modified tunnels are not likely to be as good as new custom-built facilities such as the NSRDC facility because of the lower contraction ratio, higher circuit speed past the acoustic treatment, lack of ground insolation, etc., common to the older wind tunnels.

Measurement Techniques

Noise measurement in wind tunnels may be either in the flow or out of the flow. It is in principle a simple procedure to correct the measurements for the flow effects with the microphone in the flow. But the effect of the noise transmission through the shear layer of an open-throat wind tunnel to a microphone outside the tunnel flow is a complex problem involving refraction of the sound wave and correction for different frames of reference. Much research has been devoted to the development of suitable corrections. The workshop results on problems of inflow noise measurements will be discussed first, then progress on corrections for noise transmission through shear layers will be reviewed. An adequate signal-to-noise ratio is necessary to make quality noise measurements. When the signal-to-noise ratio is not adequate, methods of improving this ratio must be applied. These techniques can often be used to locate noise sources as well. Some methods and their effects on signal-to-noise ratio will be discussed at the end of this section.

Noise measurements with microphones in the flow – With the microphone in the flow, the correction to the measured pressure is a simple correction for the downstream convection of the sound wave and a spherical-spreading correction for the difference in distance. The disadvantage of inflow measurements is that the flow over the microphone and its support produces noise which is likely to define the background noise level that the microphone measures at the lower frequencies. Papers 3 and 4 discussed this problem and paper 3 gave a quantitative idea of the 0.63 cm (1/4 in.) microphone noise resulting from the turbulent flow in a tunnel. Figure 13 relates turbulence to noise at 91 m/sec (300 ft/sec) wind-tunnel speed at different frequencies, though it ignores the effect of turbulence scale on microphone response. A value of approximately 0.2% in a 1/3 octave band turbulence level is about as high as is acceptable for measurements with the microphone in the flow. Figure 14 shows the corresponding effect of turbulence at different wind-tunnel airspeeds. Within the designated ±7 dB range of scatter, these results reasonably agree with Owen's measurements at RAE, referred to previously in AGARD-AR-105, though the RAE results consistently exhibited the influence of turbulence scale. Additionally, it can be strongly argued that the fluctuations v and w in the lateral velocity components are the major cause of spurious noise at the microphone, rather than the longitudinal component used in the foregoing graphs. Fortunately, having a microphone in the flow also means that it is nearer to the noise source and even with the microphone self-noise there may still be an acceptable signal-to-noise ratio. Even when the microphone may be in the near field for an extended source, in a case where microphones must be in the flow and noise source is at a low level, discrimination techniques (discussed later) can be used to remove the random pressure fluctuations.

Corrections for shear layer transmission – Use of an open-throat wind tunnel with microphones outside the stream for noise measurements implies that the data must be corrected for the effect of the transmission through the shear layer and for the effect of the microphones and the noise source being in different frames of reference. Figures 15 and 16 (from Paper 10) describe the corrections geometrically and figures 17 and 18 (also from Paper 10) give examples of the correction. The shear layer correction gives the most difficulty and includes both amplitude and angle corrections. Recent experimental work, shown in Papers 11 and 12, has greatly increased the confidence level in the corrections. Experiments on the acoustic transmission through shear layers established that the Amiet correction method is adequate in most cases. The measurements obtained by these methods thus have gained considerable stature in the acoustic research community and the experimental approach is generally accepted, even though correction methods may differ from one installation to another. Of course, good experimental practice dictates that the use of large corrections should be minimized or subjected to extra checks.

Discrimination against unwanted noise – For low level signals or where the signal-to-noise ratio is not adequate for quality noise measurements, techniques for discrimination against the noise sources that intrude on the source of interest may be used. Many of the techniques amount to a form of directional microphone (microphone arrays, correlation microphones, acoustic mirrors, etc.) and thus can serve the dual purpose of locating noise sources as well as discriminating against other noise sources. Figure 19 depicts one such device, the acoustic mirror (from Paper 1). Paper 5 provides figure 20 on the correlation microphone. Another approach to the same problem is to move into the geometric near field of the noise source of interest and then correct for near-field effects (using the multiple sideline techniques described in Paper 6 and fig. 21, for example). In the years since the last workshop, these techniques have seen considerable use and refinement, and the use of some of them has become standardized by the developers. The acoustics research community accepts some of these methods, thus considerable progress has been made in the use of measurement techniques to allow the measurement of a particular noise while in the presence of other noises. In the last 3 years, progress has been made in the use of and confidence in these techniques.

Scaling and Modeling

A principal problem encountered by many researchers on the effect of flight on aircraft noise is the need to scale selected elements of the noise source rather than work with the actual engine. This problem is not new; aerodynamicists have had the problem of scaling propulsion systems for scale model testing over the time span of powered aviation, and there are still spirited debates over the advantages of various techniques. Several papers were given at the workshop discussing acoustic experience with this problem.

The consensus of these papers was that, where the noise source was adequately modeled and the data processed to account for all differences, small-scale results could give an accurate description of jet noise flight effects in particular. For example, figure 22 shows small-scale results with a simulated JT8D engine in the Boeing 9- by 9-Foot Wind Tunnel compared to a full-scale JT8D engine whose noise characteristics were measured in the Ames 40- by 80-Foot Wind Tunnel. The agreement, as shown by a comparison of velocity exponents, was excellent. On the other hand, where results from a clean 15 cm (6 in.) jet nozzle, obtained in the 40- by 80-Foot Wind Tunnel and an F86 airplane with a J47 engine were compared, they were not similar (fig. 23) in the forward quadrant. This discrepancy is believed to be caused by large internal noise sources in the J47 engine which were not simulated on the model. This and other evidence indicate that scale models can and should be used in the estimation of flight effects on noise. However, a great deal of care must be taken in interpreting the results and modeling the engine to avoid misleading results, particularly in respect to possible installation effects.

Comparison of Wind-Tunnel and Flight-Noise Results

The title of this session is misleading; the outcome was somewhat disappointing because only one paper dealt with that topic. The other two papers included a report of work to modify flow conditions in static facilities to more closely resemble those in flight, and a comparison of model data from two facilities.

Paper 27 compares results obtained from a 7.5 cm (3 in.) model on the Rolls Royce Spin Rig with results from a 6 in. nozzle in the Ames 40- by 80-Foot Wind Tunnel (fig. 24). The largest discrepancy in the results is between the conical nozzles. This is, of course, important because it shows discrepancies in the suppression effectiveness of the nozzles between the two tests. For both nozzles, the Ames data have a lower sound pressure level than the Rolls Royce data, which are in the opposite direction for internal noise, reverberation, or background noise problems in the Ames test rig. The Ames conical nozzle results also agree well with other conical nozzle results; therefore, it is believed that the problem lies with the spin rig data jet model installation effects. This has since been clarified by work at NGTE and Rolls Royce.

Paper 25 described the development of a turbulence control inlet. The purpose of this inlet was to reduce turbulence associated with the test site while testing a fan under static conditions, and thus make the test closely represent flight conditions. Some of the sources of turbulence for static testing are shown in figure 25 (from Paper 25). The importance of removing this turbulence is shown in figure 26. While the simulation of flight conditions by the turbulence control inlet can be questioned because of different streamlines and boundary-layer growth in the engines, control of the turbulence provides a major improvement and is strongly encouraged for future tests.

Paper 26 was the only paper in the workshop that covered the very difficult task of comparing flight effects as measured in a wind tunnel with those measured in flight. In this case, since the "model" was a JT8D engine, most of the questions of modeling and scaling were removed and the basic question of whether or not the wind tunnel gave the right answers could be addressed. As would be expected, there were some adjustments that had to be made to the data because of different engine models, inlet configurations, and flight conditions. The summary of the comparison is found in figure 27. The agreement is excellent regardless of whether the ground-based estimate is done on an incremental basis or an absolute basis. While the figure shows only an EPNL comparison, the comparison is correspondingly good for directivity and spectra. It is thus confirmed that ground-based facilities can give the correct answer for flight effects if the model used faithfully represents the flight source. Indeed, this may be the most difficult problem in applying small-scale results to obtain flight estimates.

CHARACTERISTICS OF ACOUSTIC WIND TUNNELS

The wind tunnels used for acoustic studies vary from small, quiet wind tunnels especially constructed for the task, to large wind tunnels such as the Ames 40- by 80-, that may require special techniques to record the acoustic data. Since there are so many facilities, it may be possible to select a facility best suited for a given noise measurement task. Table 1 is a cross section of wind tunnels in use for noise research and development. While not all are included, the table presents characteristics of representative facilities. The facilities considered are evident from the table and reflect the information provided by the workshop attendees at the time. A more complete list of aeroacoustic facilities constructed in Great Britain, West Germany, France, and the Netherlands has now been prepared jointly by RAE/NGTE, DFVLR, ONERA, and NLR under the auspices of the "Aircraft Noise Section" of the Group for Aeronautical Research and Technology in Europe (GARTEur-5).

CONCLUDING REMARKS

In reviewing the progress made in acoustic measurements in wind tunnels over the 5-yr span of the workshops, it is evident that a great deal of progress has been made. New, specialized facilities have been brought on line, special measurement techniques have been developed, and corrections have been devised and proven. This new capability is in the process of creating a new and more correct data bank on acoustic phenomena, and represents a major step forward in acoustics technology.

Additional work is still required, but now, rather than concentrating on facilities and techniques, researchers may more profitably concentrate on noise-source modeling, with the simulation of propulsor noise source (in flight) and of propulsor/airframe airflow characteristics. Recent promising developments in directional acoustic receivers and other discrimination/correlation techniques should now be regularly exploited, in part for model noise-source diagnosis, but also to expedite extraction of the lone source signal from any residual background noise and reverberation in the working chamber and from parasitic noise due to essential rigs or instrumentation inside the airstream.

Most useful was the stimulating exchange of up-to-date information on the substantial advances and continuing work on problems during the three-year period since the last workshop.

Ames Research Center
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Moffett Field, California 94035, March 11, 1982

APPENDIX A

WORKSHOP ON AEROACOUSTIC TUNNEL TESTING TECHNIQUES

AMES RESEARCH CENTER

MARCH 15-16, 1979

AGENDA*

March 15, 1979

OPENING REMARKS . . . . Dr. Roberts

Paper No. MEASUREMENT PROBLEMS AND TECHNIQUES

1. Noise Source Location Using the Acoustic Mirror Technique . . . . Dr. F. R. Groshe
2. A Directional Microphone for Measurements . . . . Dr. R. Schlinker
3. Evaluation of Flow Noise Floor Characteristics . . . . K. J. Young
4. Contribution from UTIAS . . . . . Prof. Richarz
5. The Correlation Microphone System of the Measurement of Airframe Noise . . . . Warren F. Ahtye
6. The Multiple Sideline Technique for Source Location and Extrapolation of Near-Field Measurements . . . . F. G. Strout
7. Transducer Microphone Correlations for Airframe Noise . . . . Prof. Meecham
8. Helicopter Noise Testing Techniques . . . . D. Hoad
9. Wind Tunnel Testing to Determine Impulsive Noise Characteristics of Helicopter Rotors . . . . H. Sternfield
10. Open Jet Refraction and Scattering of Sound . . . . Dr. R. Schlinker
11. Aeroacoustic Corrections for Testing Small Models in an Open Jet Anechoic Flow Facility . . . . Dr. J. Yu
12. Experimental Verification of the Free-Jet Flight Simulation Correction Procedure for Acoustic Data . . . . Dr. H. Plumbee
13. Partial Acoustic Treatment . . . . . M. Falarski

QUIET FACILITY DESIGN

14. Boeing Quiet Relative Velocity Facility . . . . W. G. Harris
15. Evolution of a Forward Motion Simulator for the MDC Anechoic Chamber . . . . J. H. Brettnacher
16. Aeroacoustic Aspects of the German Dutch Wind Tunnel . . . R. Ross
17. Acoustic Features of 40x80/80x120 . . . . P. Soderman
18. Jet Noise Testing Capabilities at NLR . . . . W. B. DeWolf
19. Contribution from UTIAS . . . . . Prof. Richarz
20. Acoustic Modification to the RAE 24-Foot and 1.5-Meter Wind Tunnels . . . . Prof. J. Williams
    a. Working chamber treatment
    b. Fan design consideration
    c. Circuit treatment
    d. Aerodynamic implications

MARCH 16, 1979

SCALING AND MODELING

21. Comparison of 9x9 Wind Tunnel Model and 40x80 Engine Flight Effects Data for the 727/JT8D Baseline . . . . C. L. Jaeck
22. Model of Study Underwing Engine Installation Effects on Noise Radiation . . . . R. Schofield
23. The Simulation of Engine Exhaust Noise at Model Scale . . . . D. J. Way
24. Comparison of F-86 and 40x80 Model Data for a Uniform Flow Jet . . . . F. G. Strout

COMPARISON OF WIND TUNNEL AND FLIGHT NOISE

25. An Inflow Turbulence Reduction Structure for Scale Model Fan Testing . . . . E. B. Smith

*Vugraphs were distributed at the meeting.

APPENDIX B

ATTENDANCE LIST FOR

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APPENDIX C

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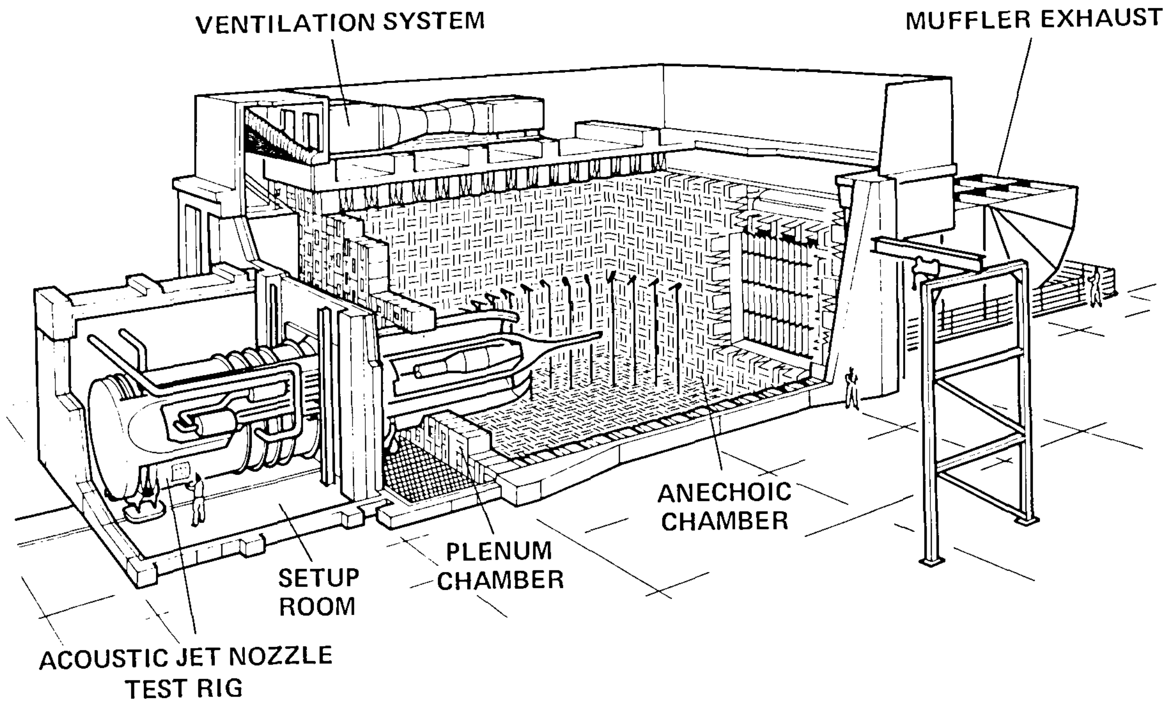
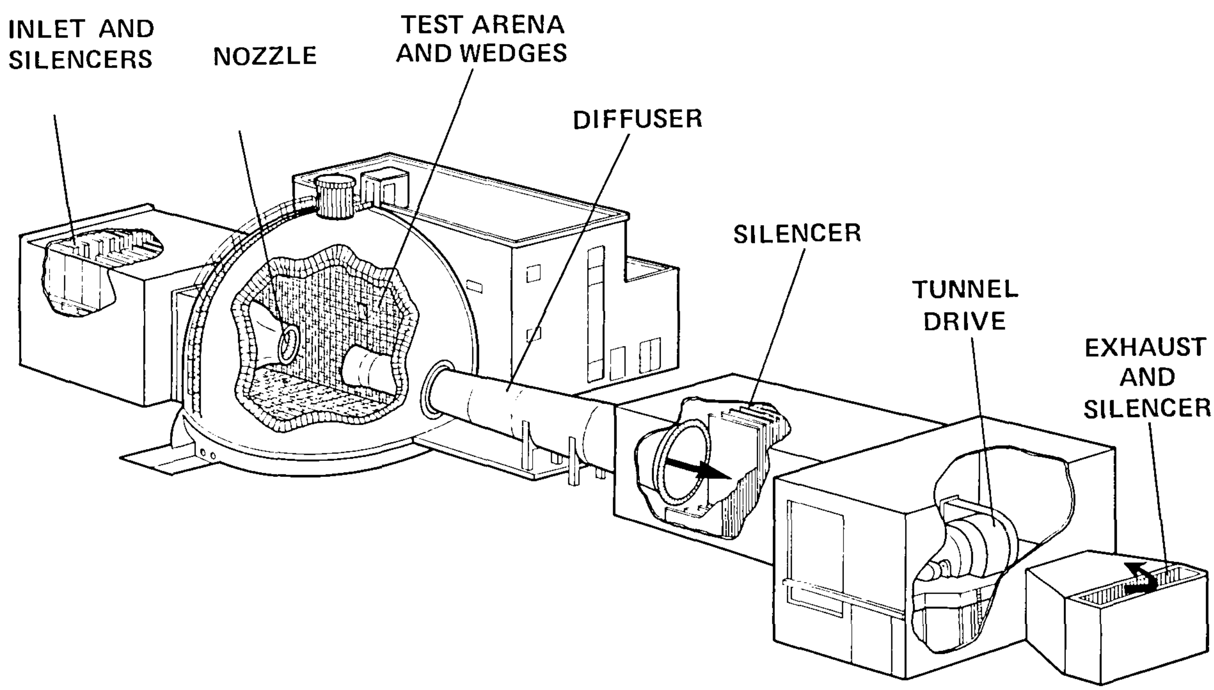
TABLE 1.– SOME WIND TUNNELS USED FOR NOISE MEASUREMENTS

Wind Tunnels	Test section				Working chamber			Tunnel circuit			Comments
	Size	Maximum speed, m/sec	Turbulence, %	Type	Treatment	Minimum anechoic, Hz	Background Noise	Type	Drive	Treatment	
European											
RAE 24 ft	7.3 m diam	50	0.3	open	wedges	20C	75 dB @ 1 kHz 30 m/s	closed	electric	none	Anechoic chamber added only.
RAE 1.5 m	1.5 m diam	55	0.2	open	foam sheet	500	75 dB @ 1 kHz 50 m/s	closed	electric	splitters	Modified aerodynamic tunnel, as model for possible 24 ft tunnel conversion.
DNW	8x6x20 m	110	–	open	wedges	–	54 dB @ 1 kHz 50 m/s	closed	electric	corners	Wind tunnel just coming on line, background noise estimated.
CEPRA 19	2 m diam	100	–	open	wedges	200	–	open	electric	splitters	
North American											
Boeing 9 by 9 Ft.	2.7x2.7x4.3 m	97	0.14	closed	absorbent walls	200	100 dB @ 1 kHz	once through	turboprop	panels & splitters	
Boeing Vertol	6.1x6.1x13.7 m	120	0.09	closed	none	–	91.5 dB @ 1 kHz	closed return	electric	none	Used for measurement of harmonic components only.
G.E. Anechoic Free Jet Facility	1.2 m diam	140	–	open	wedges	160	–	open jet	plant air	–	Dual flow, heat air capability. Acoustic mirror and laser velocimeter available.
Lockheed Open Jet Anechoic Wind Tunnel	0.71 m diam	100	–	open	wedges	200	58 dB @ 1 kHz	open	jet	extensive	Optional 0.76x1.07 m rectangular test section available.
UTIAS Anechoic Wind Tunnel	1 m diam	100	.2-.3	open	wedges	180	55 dB @ 1 kHz 55 m/s	open jet	electric	splitters	
NASA 40 by 80	12x24x24 m	100	0.19	closed	panels on 1/3 test section	–	86 dB @ 1 kHz 46 m/s	closed return	electric	none	Full permanent acoustic treatment is being added to test section.
NASA 7 by 10	2.1x3x4.3 m	100	0.26	optional	commercial tile	–	62 dB @ 1 kHz open throat, 35 m/s 80 dB closed hardwalls @ 1 kHz 56 m/s	closed return	electric	panels in cross legs	Can be operated with closed test section and acoustically hard and soft walls or open test section.
NASA ANRL Anechoic Flow Facility	1.22 m diam	120	0.25	open	wedges	125	42 dB @ 1 kHz 45.7 m/s	open jet	electric	vanes & baffles	
NASA V/STOL Wind Tunnel	4.4x6.6 m	103	–	optional	foam panels	250	80 dB @ 1 kHz 42 m/s	open jet	electric	none	

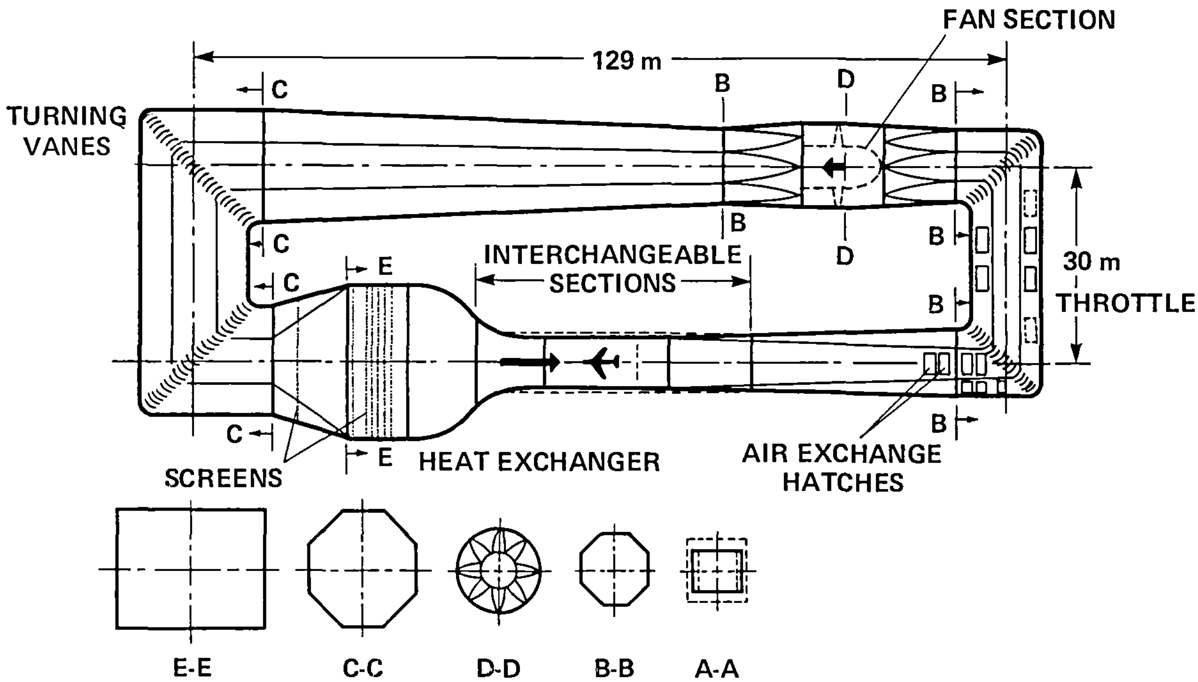


(a) McDonnell-Douglass facility.

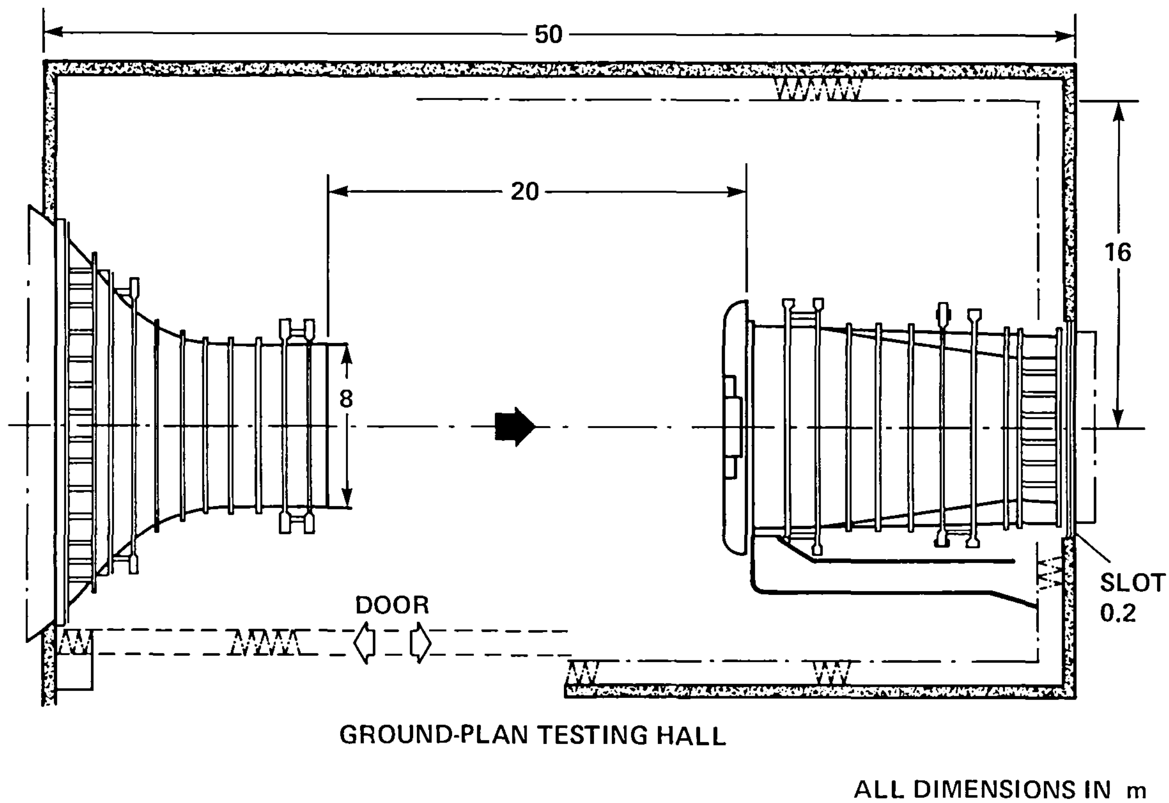


(b) French Cepra 19 facility.

Figure 1.– Anechoic acoustic test facilities.



(c) German-Dutch wind-tunnel circuit.



(d) German-Dutch wind-tunnel test arena.

Figure 1.– Anechoic acoustic test facilities.

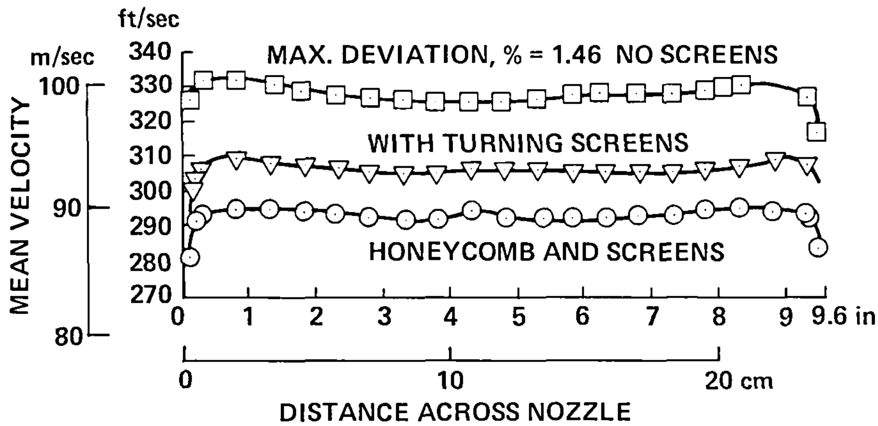


Figure 2.– Mean velocity profiles at nozzle exit of open-throat wind tunnel.

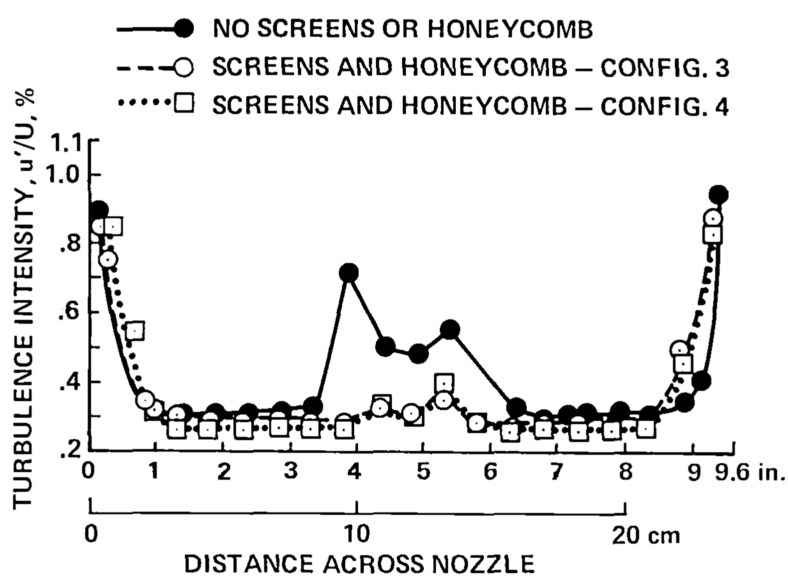


Figure 3.– Turbulence intensity profile at nozzle of open-throat wind tunnel.

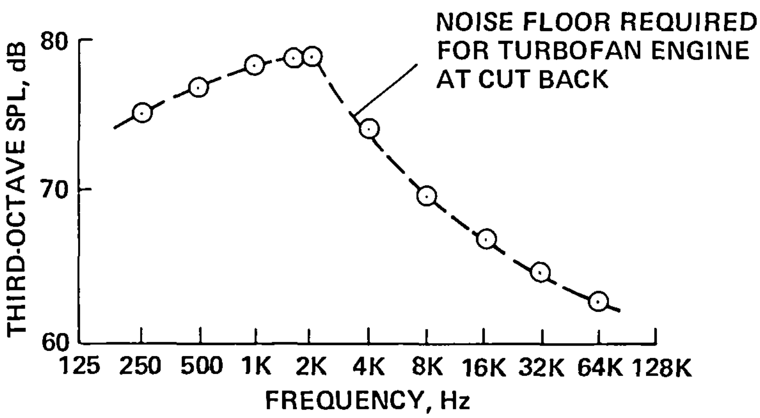


Figure 4.— An example of wind-tunnel background noise requirement.

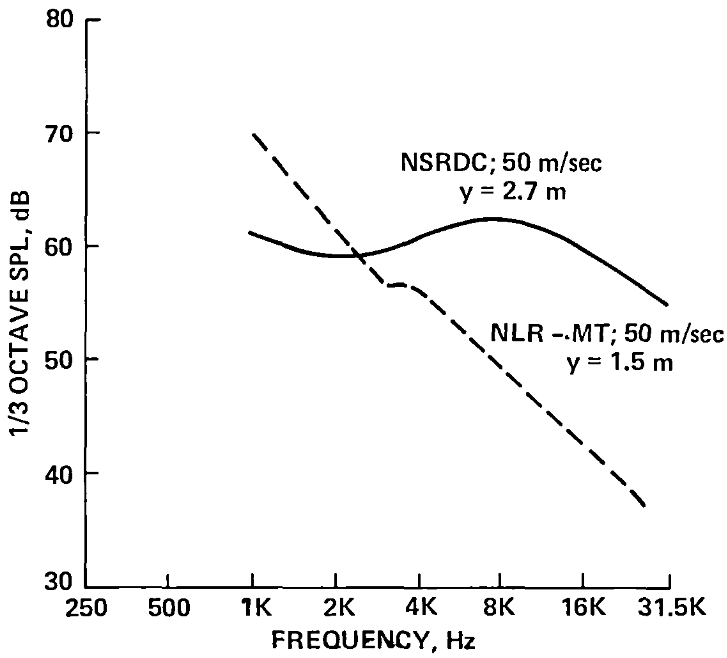


Figure 5.— Background noise in different tunnels.

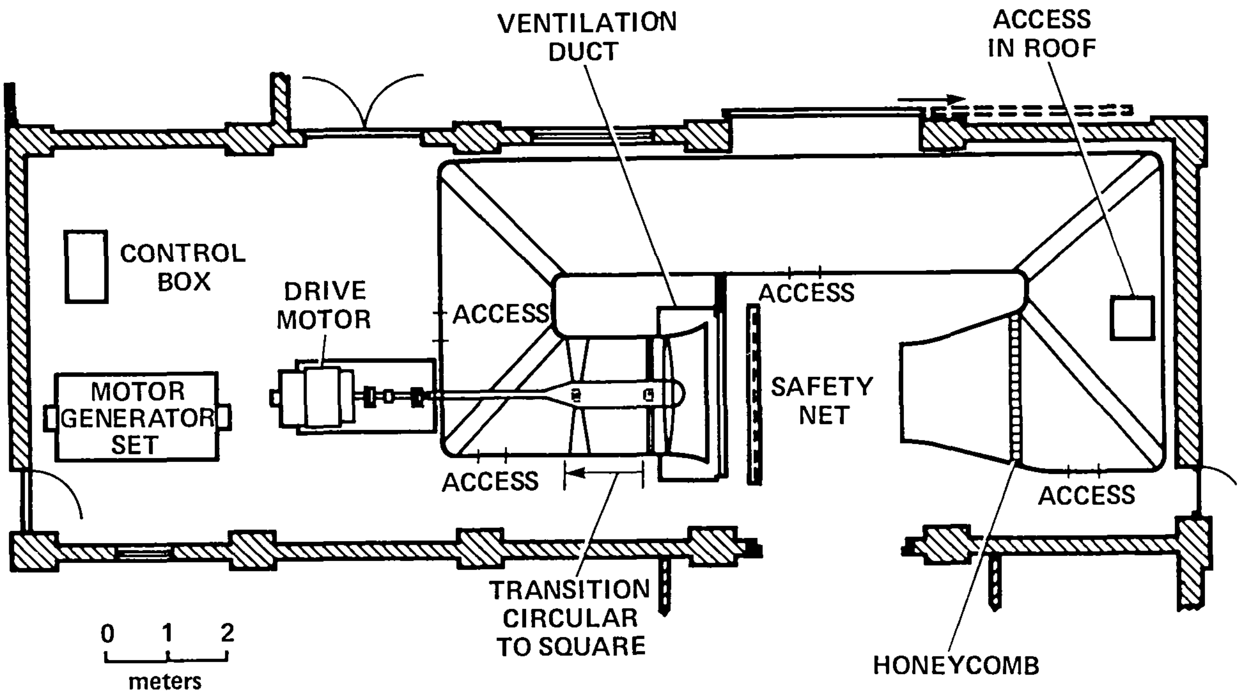


Figure 6.– Original circuit of 1.5 m tunnel.

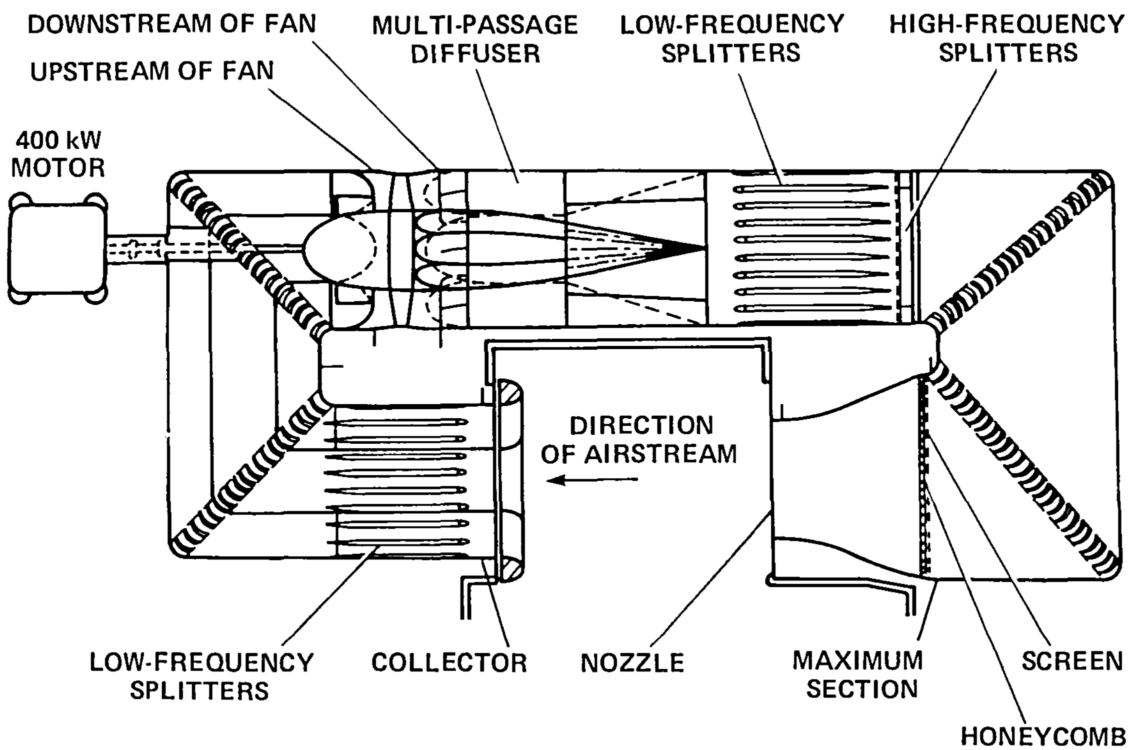


Figure 7.– 1.5 m aeroacoustic wind-tunnel internal details.

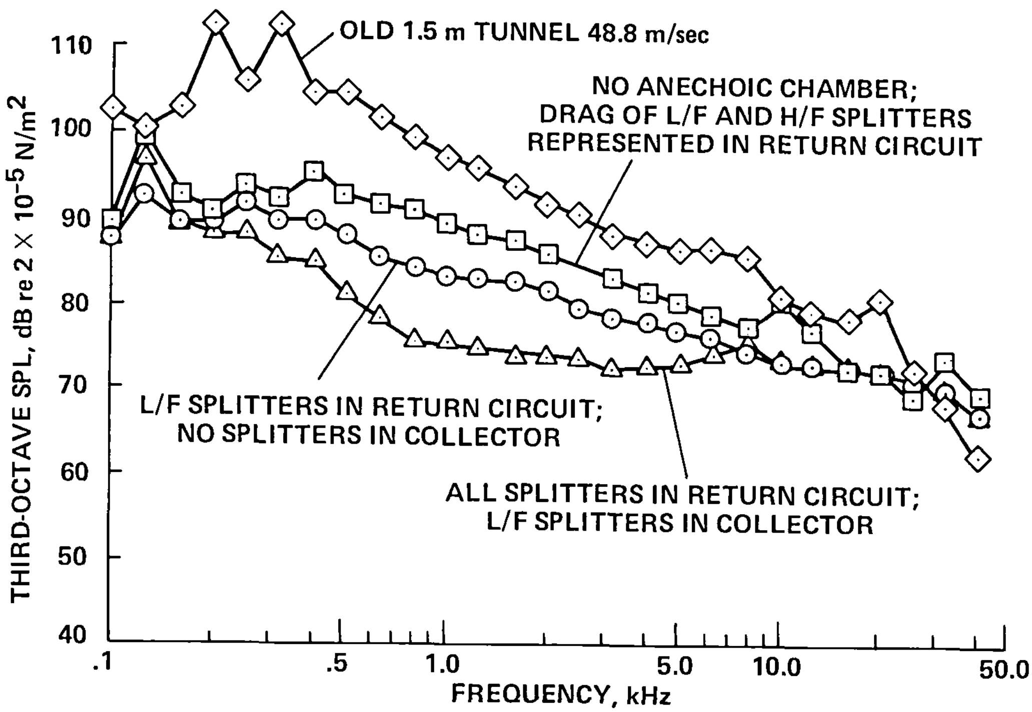


Figure 8.– Improvements to acoustic performance obtained from modification to facility; U_0 = 50 m/s; X/R = 1.30; Y/R = 0; Z/R = 0; RAE 1.5 m tunnel.

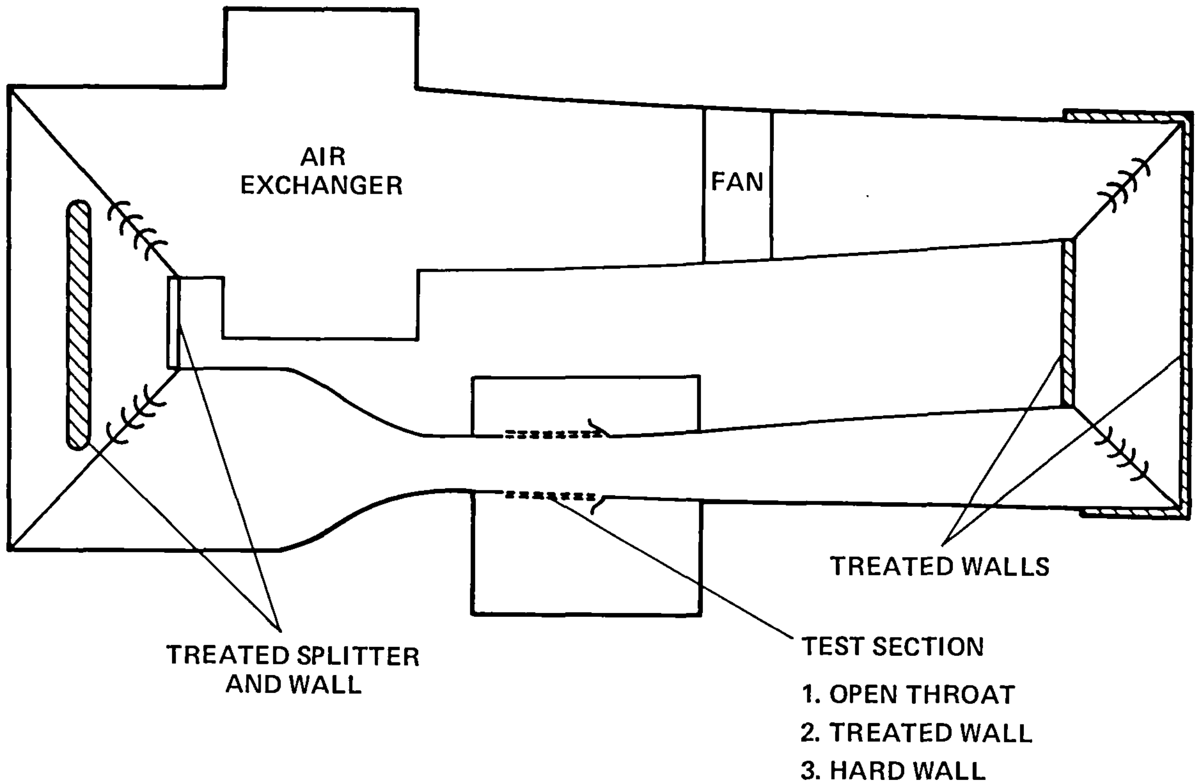


Figure 9.– NASA Ames 7- by 10-Foot Wind Tunnel.

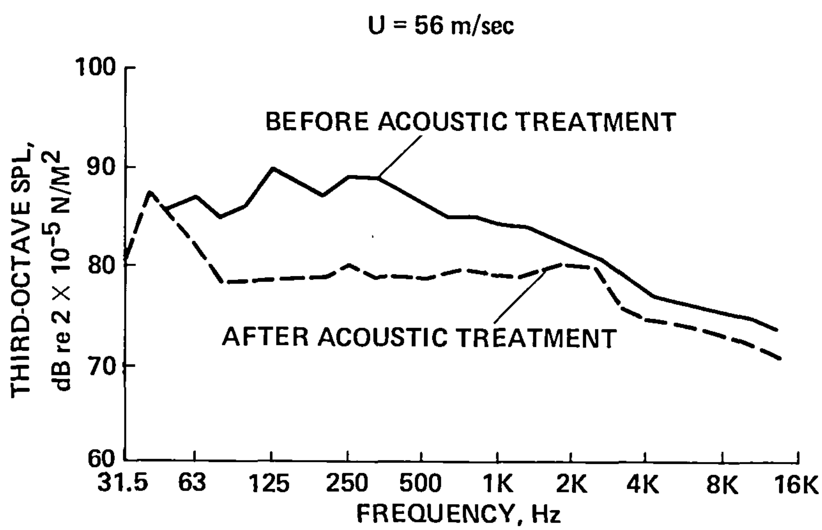


Figure 10.– Effect of 7- by 10-Foot Wind Tunnel modifications on background noise: closed test section with hard walls, in-stream measurement.

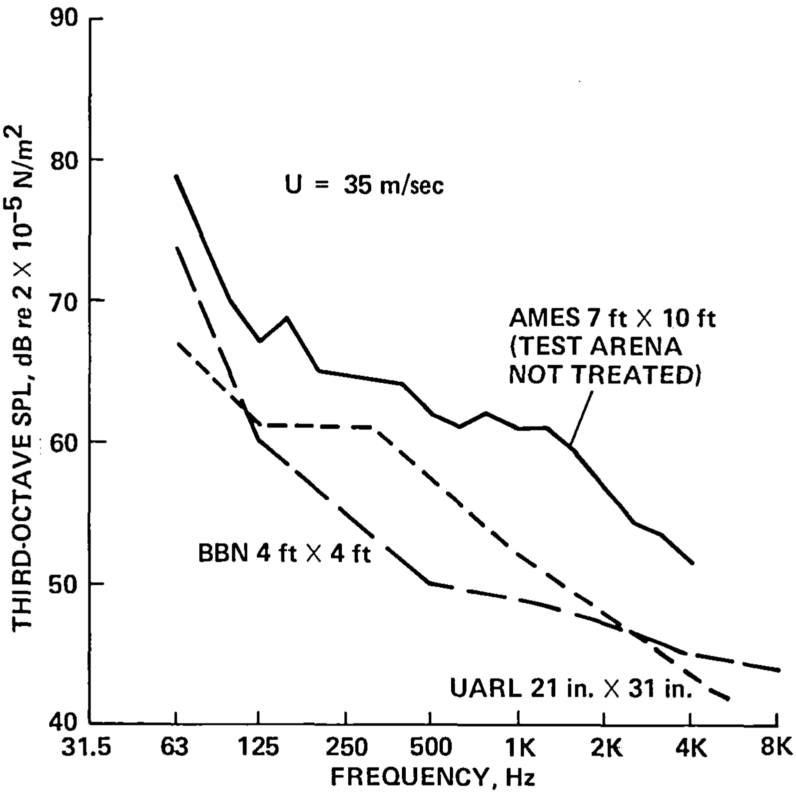


Figure 11.– Background noise of several open-throat wind tunnels measured approximately 2 m from the flow.

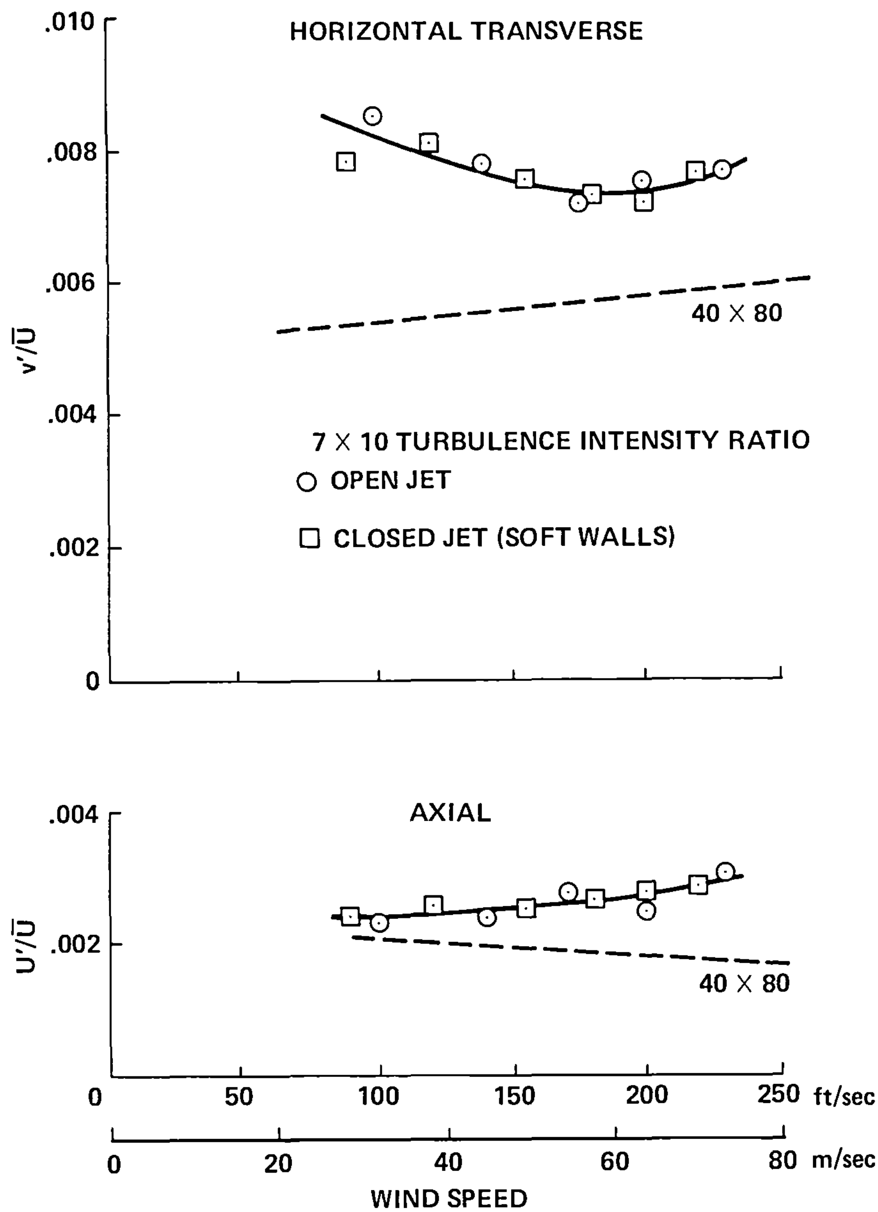


Figure 12.– Turbulence level of modified 7- by 10-Foot Wind Tunnel.

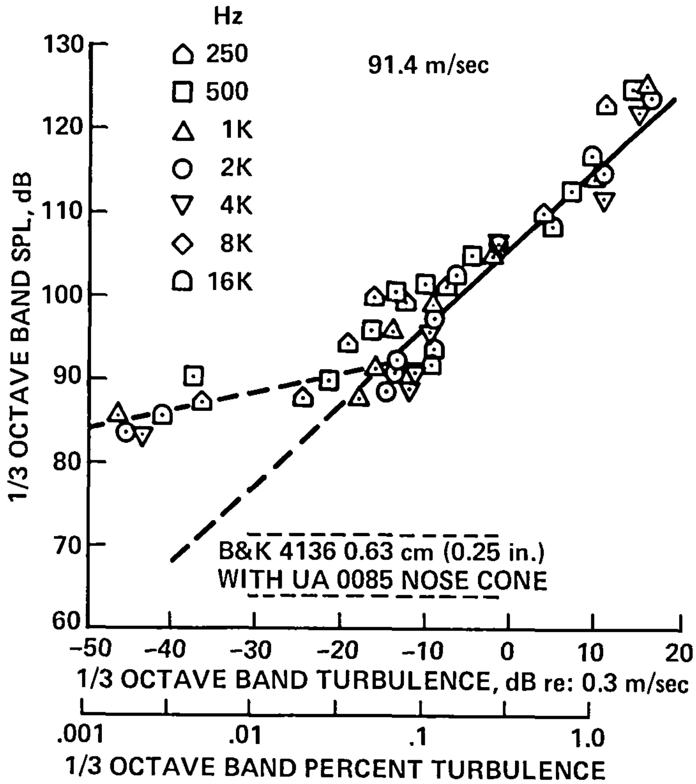


Figure 13.– Relationship between noise measured by a microphone and the turbulence of the surrounding airstream.

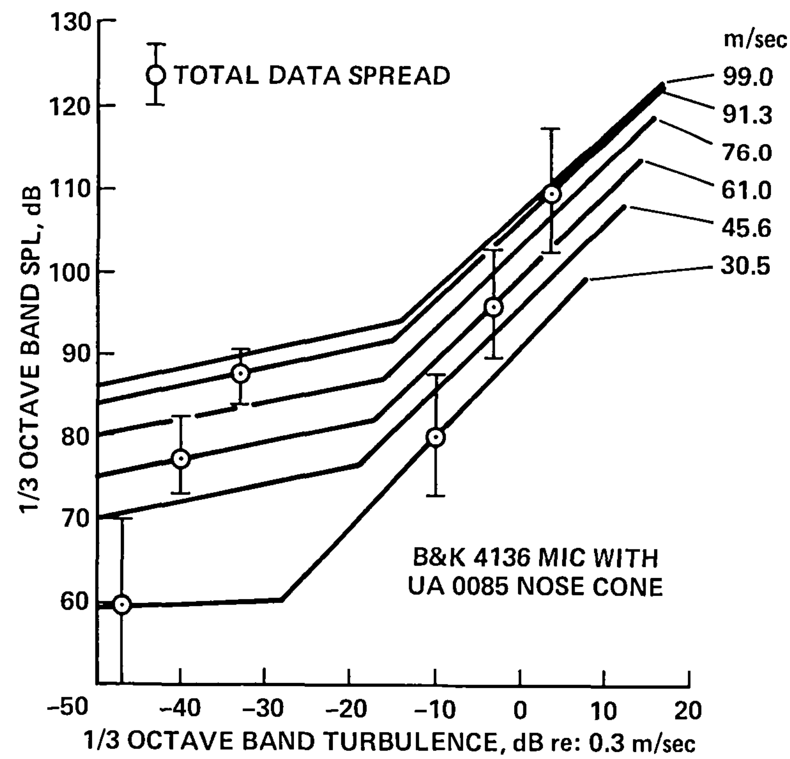


Figure 14.– Relationship between turbulence of an airstream and the noise measured by an immersed microphone for several airspeeds.

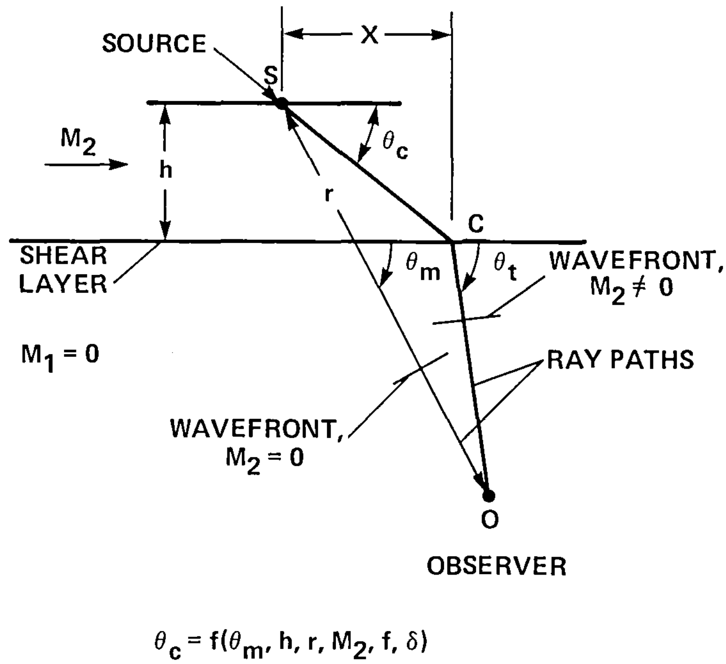


Figure 15.– Refraction of a sound wave by a shear layer.

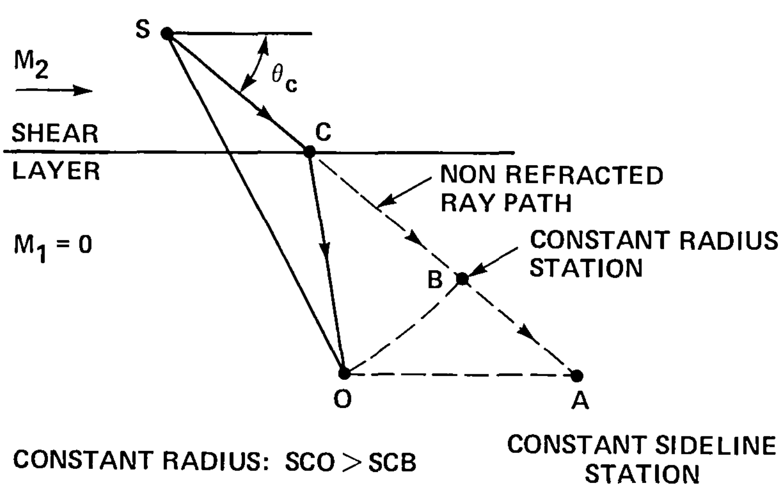


Figure 16.– Effect of shear layer on the amplitude of a sound wave.

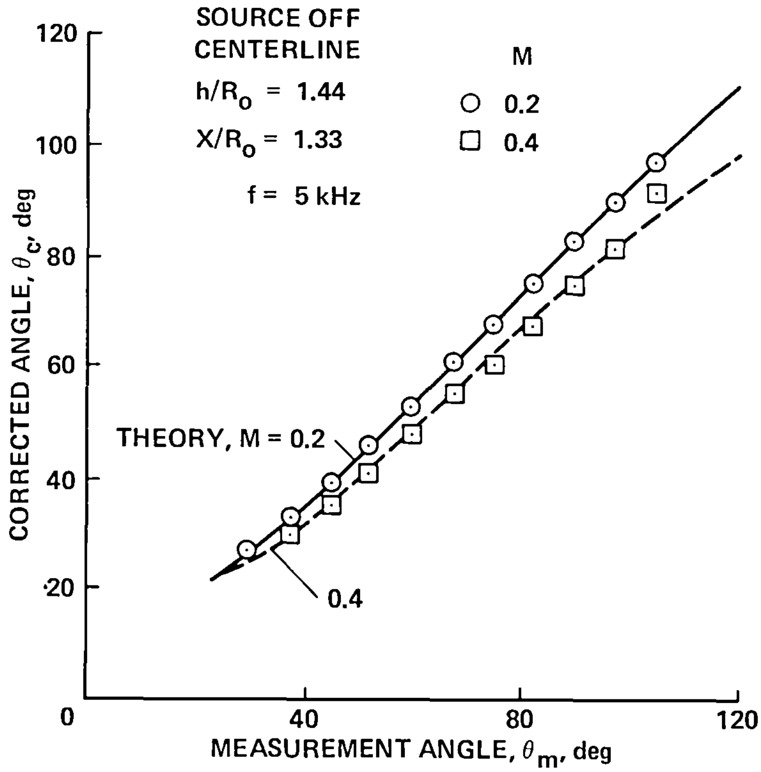


Figure 17.– An example of the angle corrections for the transmission of a sound wave through a shear layer.

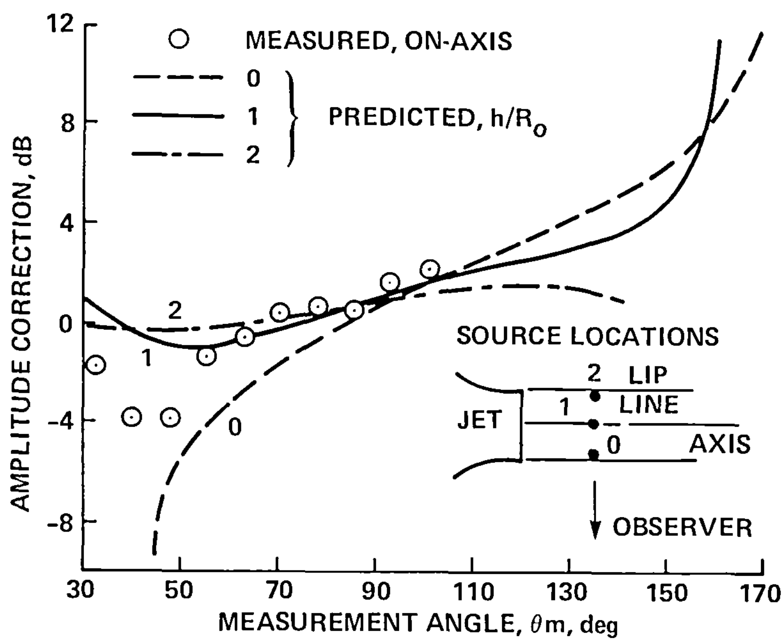


Figure 18.– An example of the amplitude correction for the transmission of sound through a shear layer.

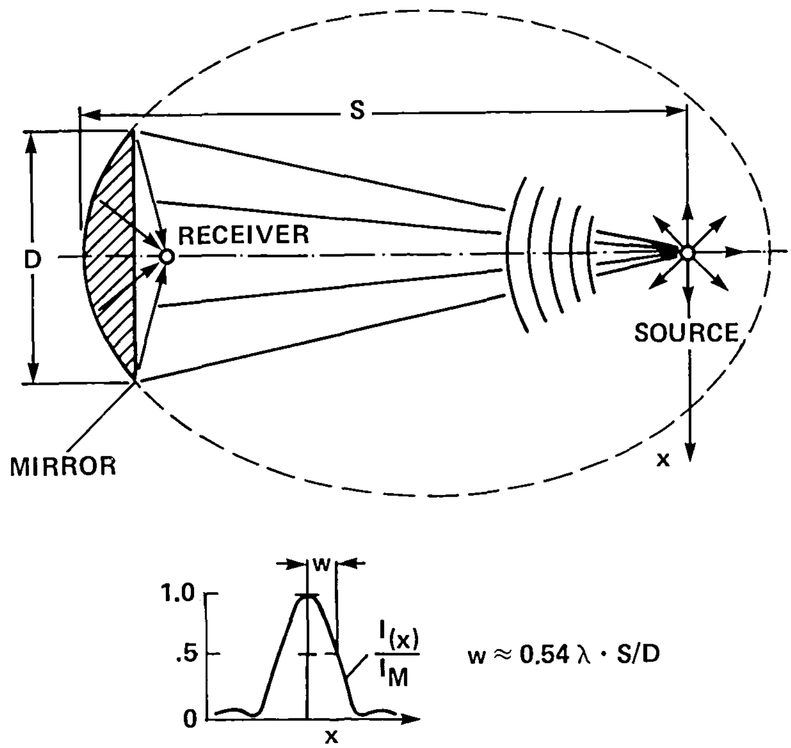


Figure 19.– Elliptical acoustic mirror for sound-source location.

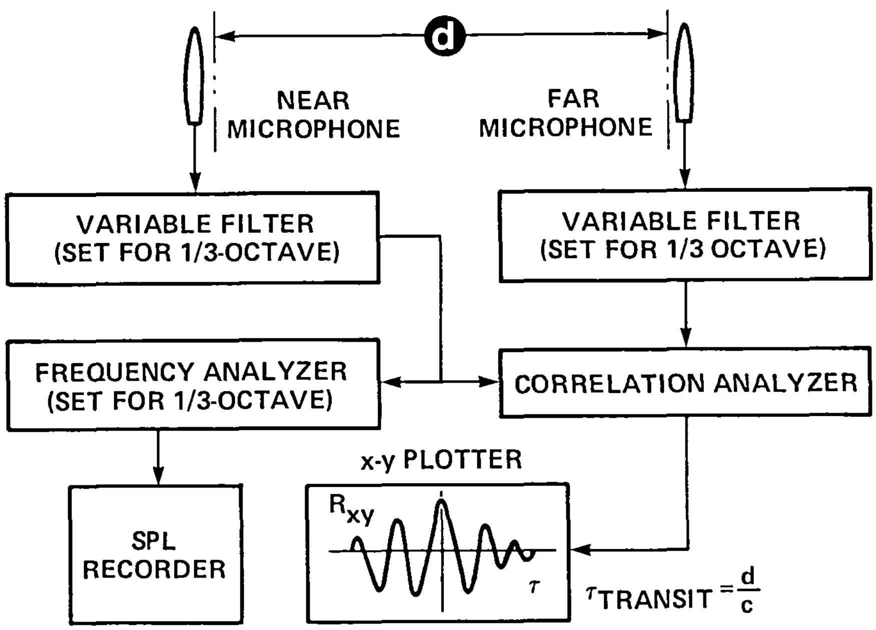


Figure 20.– Schematic of correlation microphone for source location and discrimination against background and reverberant noise.

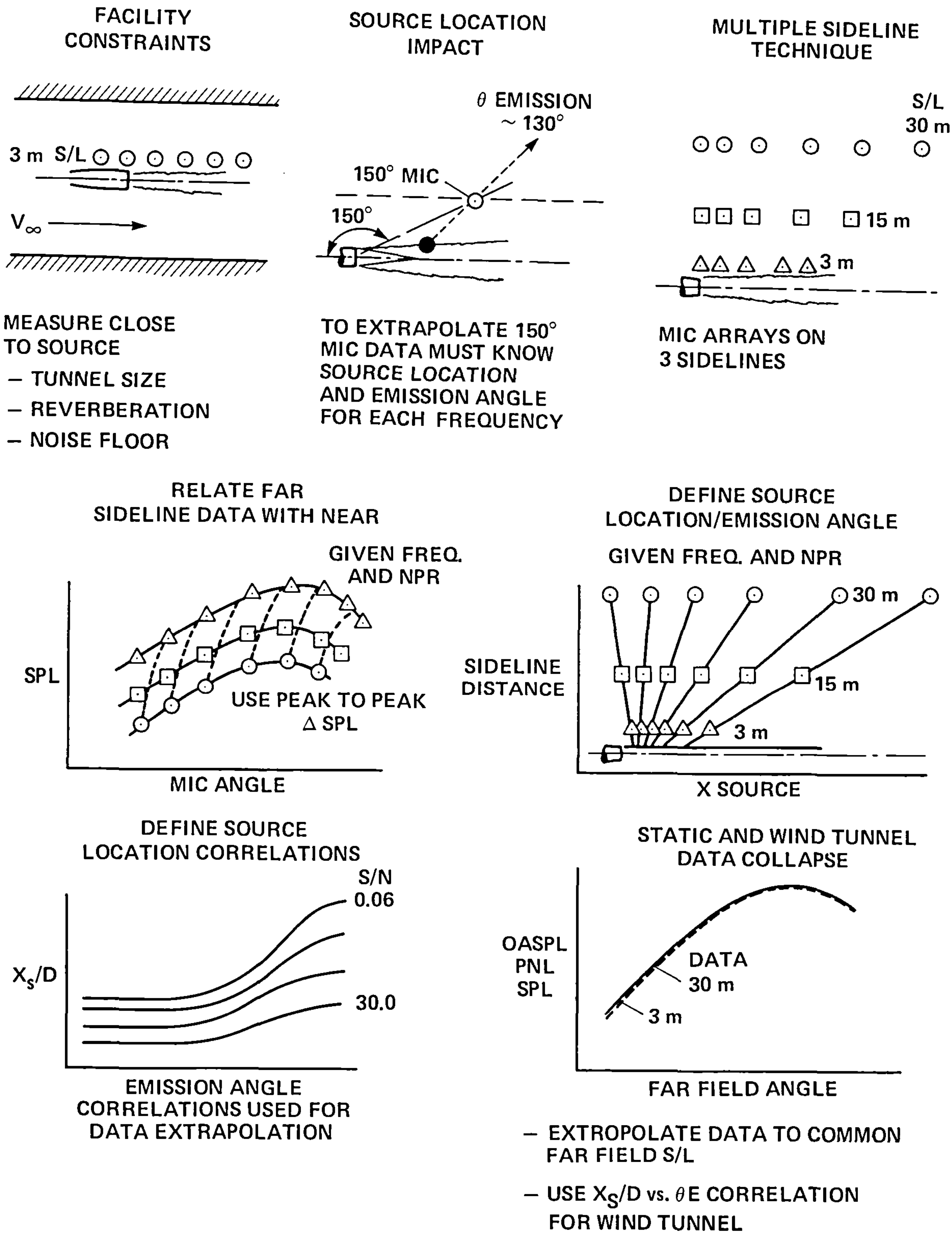


Figure 21.– Multiple sideline technique for source locations and extrapolation of near-field data to the far field.

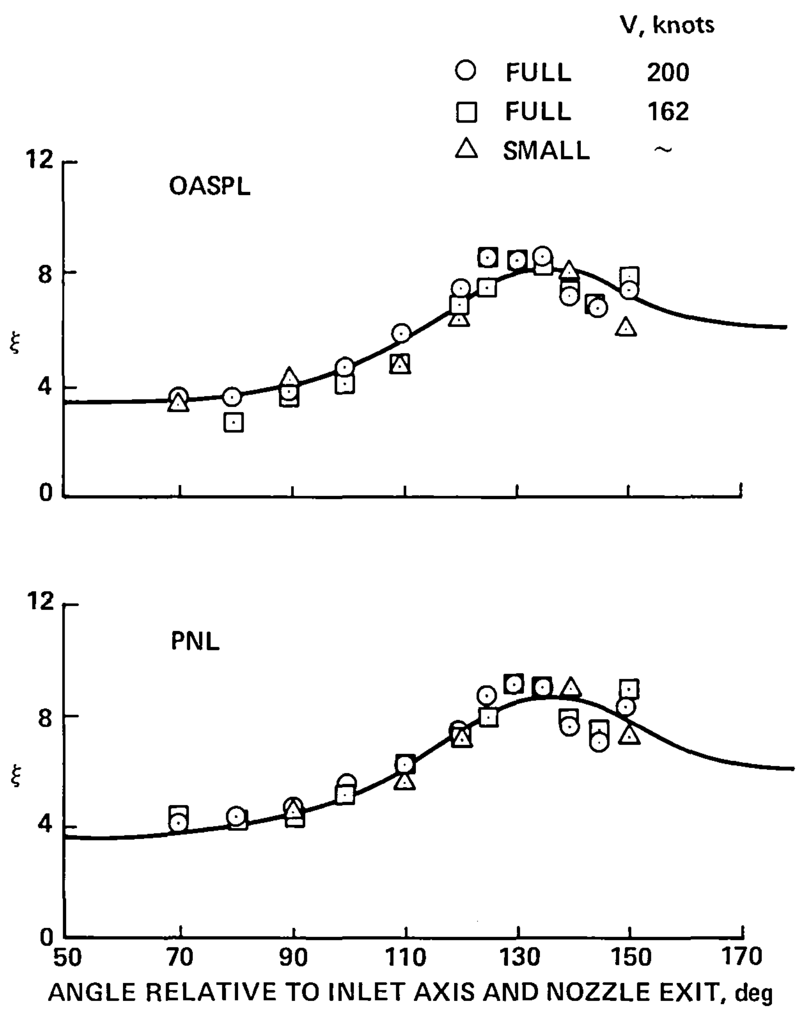


Figure 22.– Comparison of relative velocity exponent for full- and small-scale results simulating the JT8D engine.

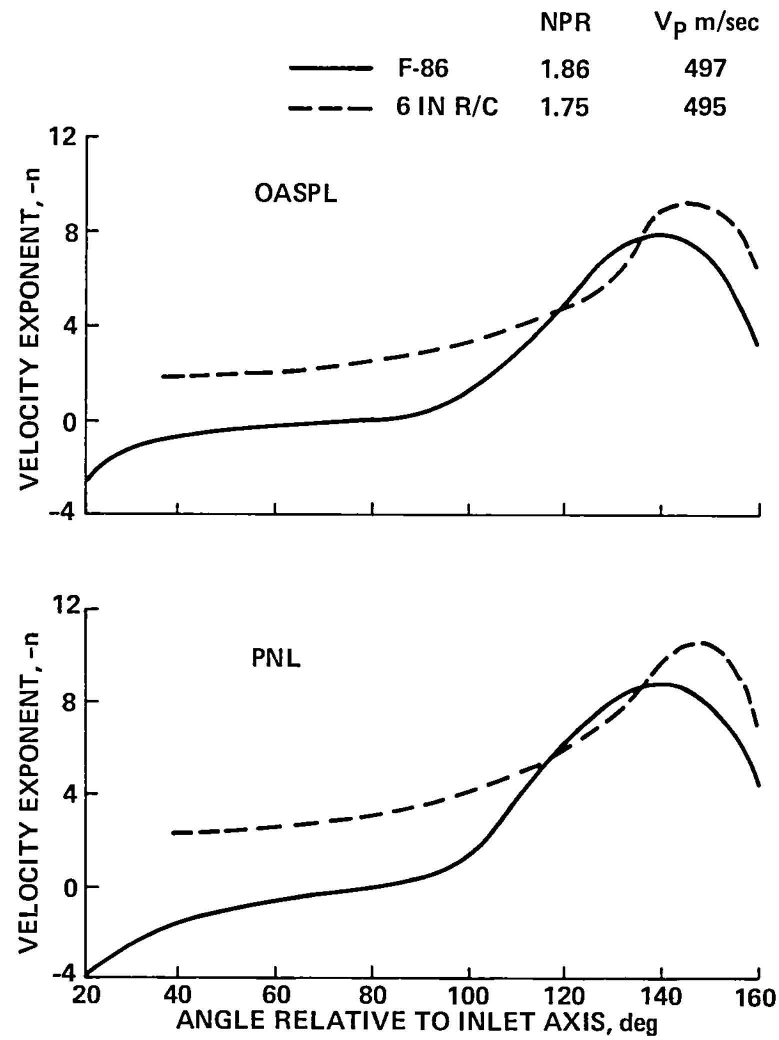


Figure 23.– Relative velocity exponents for an F-86 and a small-scale nozzle.

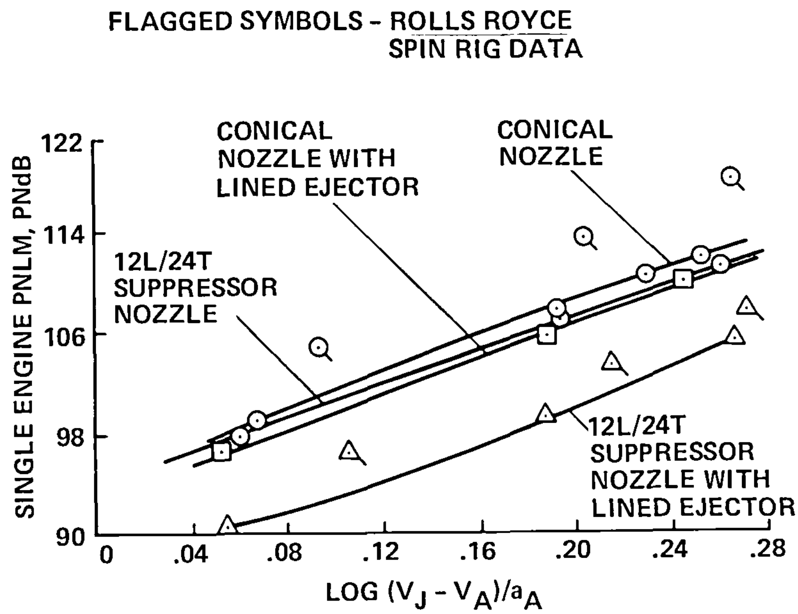


Figure 24.– Comparison of Rolls Royce Spin Rig small-scale data with Ames 40- by 80-Foot Wind Tunnel small-scale data.

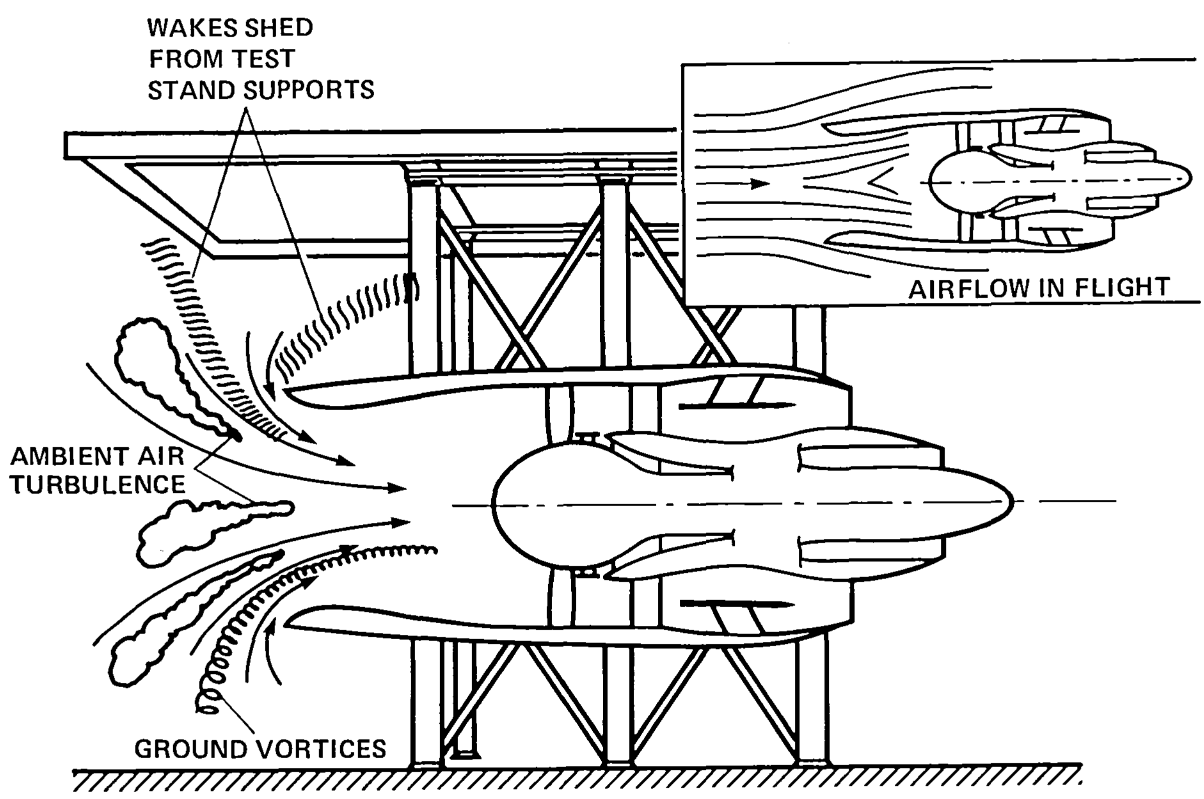


Figure 25.– Inlet flow disturbances which occur during ground static tests.

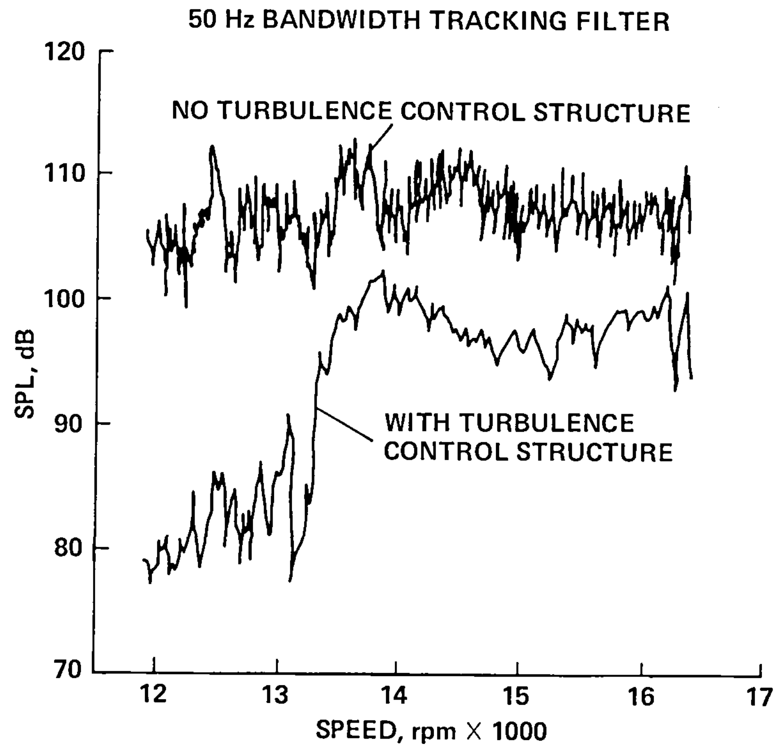


Figure 26.– Effect of static test stand and atmospheric turbulence on blade passing frequency.

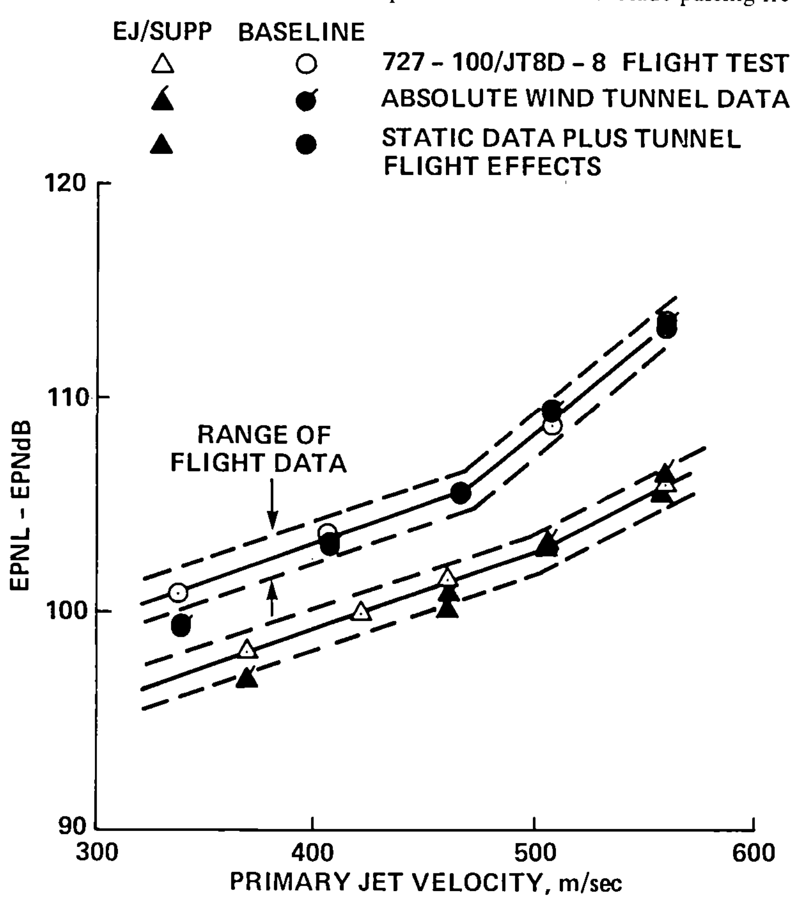


Figure 27.- Comparison of wind-tunnel and flight-test noise results.

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16. Abstract

This paper summarizes the technical content of the NASA Ames Research Center "Workshop on Aeroacoustics Tunnel Testing Techniques" held in March of 1979. In reviewing the progress made in acoustic measurements in wind tunnels over the 5-yr span of the workshops, it is evident that a great deal of progress has been made. New, specialized facilities have been brought on line, special measurement techniques have been developed, and corrections have been devised and proven. This new capability is in the process of creating a new and more correct data bank on acoustic phenomena, and represents a major step forward in acoustics technology.

Additional work is still required, but now, rather than concentrating on facilities and techniques, researchers may more profitably concentrate on noise-source modeling, with the simulation of propulsor noise source (in flight) and of propulsor/airframe airflow characteristics. Recent promising developments in directional acoustic receivers and other discrimination/correlation techniques should now be regularly exploited, in part for model noise-source diagnosis, but also to expedite extraction of the lone source signal from any residual background noise and reverberation in the working chamber and from parasitic noise due to essential rigs or instrumentation inside the airstream.

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