Workshop Report for the 4th AIAA Aeroacoustics Conference

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THE AIAA is ever striving to keep its membership informed of the latest developments and status of its several disciplines. The Aeroacoustic Technical Committee, at its 3rd Specialists Conference,[1] established a concept of technical workshops to review the respective subject areas. These workshops are intended to create open discussion on the state of the various subtechnology problems, recent accomplishments, the major problem areas, to air legitimate differences, and to propose future needs and courses of action – all from a technological point of view.

These workshops are now a regular part of Aeroacoustic Conferences. This article is a summary of the workshops conducted at the 4th AIAA Aeroacoustic Conference in October of 1977. The chairmen of these workshops prepared written summaries. These have been edited and give an overview of the status of noise technology. Specifically addressed are Jet Exhaust Noise, Turbomachinery Noise, Duct Acoustics, Aircraft Engine Core Noise, Airframe Noise, Sonic Boom and Atmospheric Wave Propagation, and V/STOL Noise Technology.

Aeroacoustics is a maturing technology. Significant advances have been made to reduce aircraft noise; witness the current widebody aircraft and the future aircraft whose designs are now under serious consideration. Substantial work will be required to produce additional significant reductions. The trend of diminishing support for technology research and development is counter to future large-increment reductions in aircraft noise. Noise is a difficult and complicated technology; new sources often appear as current sources are suppressed or reduced. "How quiet is quiet enough?" is always a valid question. However, proposed and projected noise legislation certainly will necessitate a relatively major national commitment (a reversal of trends). Much work, from basic mechanism understanding to applied demonstrations, remains to be done.

Brief Review of Significant Points of Papers Presented and Status of Technology

Contributed by
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Gordon Banerian presented a paper on the Status of Jet Noise (Paper 77-1262), indicating the ability to make jet noise predictions, outlining problem areas, summarizing suppression techniques, and discussing flight effects. The general conclusion was that although an extensive data base exists on jet noise, the ability to accurately predict inflight jet noise is not yet satisfactory. Also, more research is required to obtain a better understanding of the fundamentals involved in jet noise generation, suppression and inflight effects.

J.K.C. Low (Paper 77-1330) showed extensive data obtained by flight testing large aircraft. Jet noise and core noise were separated and it was found that these two components were modified differently by the effect of flight. An interpretation of the flight test data obtained by J.R. Brooks (Paper 77-1325) indicated a core noise content which is higher than predicted by current methods. There was reluctance to accept large-magnitude core noise as the cause of discrepancies between flight data and model testing. Installation of an engine in the aircraft indicated a difference in jet noise results as compared with results obtained from the same engine isolated on a test stand.

Several visualization studies were presented to show the presence of large-scale turbulent structures in high Reynolds number jet flows. A group of investigators from France used signal enhancement by superposing many pictures as discussed in Paper 77-1349. This work at ONERA, using correlation techniques between flowfield and far-field signals, demonstrated that at least 50% of the noise radiated at the peak noise angle was related to coherent motions within the turbulent flow. These experiments were conducted at a ratio of jet exit velocity to ambient speed of sound of 1.2 and the efficiency of radiation of the large-scale structure is likely to increase at higher velocity ratios. The authors indicated that their estimate of 50% might change with an improvement in their data analysis technique. A method of calculating the radiation characteristics of the large-scale structure which agreed with the ONERA measurement was presented by P.J. Morris and C.K.W. Tam in Paper 77-1351. It was indicated that full-scale engines also contain a coherent turbulent structure. However, it was noted that jet noise prediction methods exist which do not account for the large-scale structure. During the presentation of Paper 77-1350 by V. Sarohia and P. Massier, Schlieren motion pictures taken at high speed were shown frame by frame to indicate the formation, growth, and amalgamation of these structures. Also, simultaneous pressure measurements made in the near field indicated that the convection of these eddies did not appear to generate noise, whereas amalgamation of two adjacent structures produced oscillation in the pressure signals of the near-field microphones.

In Paper 77-1328, presented by V. Sarohia, it was shown by a sequence of shadowgraphs that a large wavy (and possibly spinning) motion present in underexpanded jet flows is enhanced by an outer flow which simulates forward motion. The outer flow caused intensification of strong sound waves which travelled upstream, as was shown in high-speed Schlieren motion pictures. These strong random sound waves (or weak shock waves) may be related to jet crackle. Enhanced mixing of the boundary layer flow with the primary jet mixing layer suppressed the large unstable motion of the jet and the associated intense sound waves.

A.M. Cargill, in Paper 77-1263, presented the noise characteristic of inverted velocity profile coannular jets and showed that a peak noise reduction of 4 PNdB can be obtained when compared with a mixed flow of the same thrust. In flight, this benefit is expected to be 2 EPNdB. In Paper 77-1264, R.S. Larson showed experimental data on duct-burning turbofans, as well as a prediction based on a flow model which compared well with the experimental results. The benefit of noise reduction is not expressed in EPNdB terms, but the predicted spectra shown seem to indicate a considerably larger reduction than 4 PNdB. There appears to be

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agreement between the data from the two different sources mentioned, but the conclusions of the authors differed with respect to application to a real engine. Additional work must be done to quantify the benefits that can be obtained from duct-burning turbofans.

The possibility of suppression or redirection of jet noise from a high-velocity jet by a neighboring jet of lower velocity prompted several investigators to study this technique. The phenomenon is essentially one of total reflection of sound which is emitted by the far jet and incident on the near jet at an angle greater than the critical angle.

Recent experiments at SNECMA (Paper 77-1368) have shown that amplification of broadband jet noise by upstream disturbances occurs in both model and engine scale situations. The broadband jet noise may be amplified by either broadband or discrete tone excitation. Though no analytical explanation of the phenomenon was presented it was felt to be related to the excitation of the large-scale components of the turbulent jet flow.

Discussion

For coannular nozzles, the results of Rolls Royce and those of SNECMA agree for a nozzle at the same specific thrust; that is, one can expect a noise reduction of 4 to 6 dB. In the U.S., the reduction is believed to be closer to 8 to 10 dB by some people; others believe that the U.S. Pratt & Whitney data agrees with the Rolls Royce data. It was pointed out that assumptions must be made when model data is applied to engines. When comparisons are made of data obtained by different investigators, it is important to take into account the configuration of the types of nozzles used as well as other factors. For coannular nozzles, noise reductions are not the same even for the same configuration if there are differences in the velocity ratio or pressure ratio of the two jets. A reference condition should be established.

All techniques of jet noise suppression have problems and a new concept is needed. We are presently working on old concepts and are running out of new ideas. Industry needs to have university personnel explore the unexplored. The legislators are essentially putting aircraft out of business.

There was controversy about the importance of absorption in predictions and the applicability of prediction methods. Some people believed that absorption must be taken into account; others believed it made only about 1 to 1½ dB difference. Still others had skepticism regarding the relevance of such prediction methods to real engines. Comments were made that there are many kinds of turbulence which cannot be defined and that there are boundary-layer effects which originate on the airframe and influence the jet, particularly in the vicinity of the nozzle exit.

An attempt to limit the noise amplification by insertion of a thin coannular cylinder in the cone at the jet exit was discussed. The cylinder reduces the radial velocity fluctuation at the jet lip and modifies the mean velocity profile. It was not clear as to which of these two effects reduces the broadband noise amplification. As a result of the discussion, it was decided that full-scale engine data need to be examined for the presence of noise amplification. Also the experimental techniques for determining the coherent noise field of jets should be used in full-scale engine experiments.

Problems that Should be Investigated

1) Methods of reducing shock noise in supersonic jets.
2) Methods of jet noise suppression. Any future SST must meet the noise regulations.
3) Influence of large-scale turbulent structures on jet noise production.
4) Definitive study of the effect of flight on core noise.
5) Influence of the installation of the engine on an aircraft on jet noise in flight.

Turbomachinery Noise Workshops

Contributed by
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It has now been some time since it was first recognized that static aircraft engine fan noise tests are easily contaminated by inlet flow distortions. Much of the research conducted during the last few years has consequently been devoted to developing static (i.e., fixed frame) test facilities that are relatively free of these contaminations. One such facility that has received considerable attention is the acoustic wind tunnel, which was described in detail at the last workshop.[1] Another approach to eliminating inflow distortions, which has primarily been developed during the past year and a half since the last workshop, consists of inserting the fan or compressor inlet into an opening in a large spherical screen-covered honeycomb structure. The sides of the honeycomb are aligned with the radial direction. Such installations have been able to achieve large reductions in the blade passing frequency tone (over ordinary static tests) for cutoff fans, which would presumably produce no such tone when operating in clean inlet flows. However, they have not been able to reduce these tones to the levels observed in acoustic wind tunnels, which often eliminate them entirely. It is not yet clear whether this is due to the screens' inability to completely clean up the inlet flow distortions or to some additional tone reduction that occurs in the acoustic wind tunnel from, say, the alteration of the casing boundary layer by the mean flow. If such additional mean flow effects do, in fact, occur there is probably little point in trying to improve the inlet screen facilities. But if, on the other hand, the screens, as they are now constructed, leave some residual distortion in the flow, there is a great deal to be gained from trying to improve them by eliminating this distortion.

Since the screens seem to cause a marked reduction in the "flutteryness" of the tone, any residual inlet flow distortion is probably quite steady. However, it is not entirely clear whether this is due to the screens' ability to stabilize the portion of the external flow distortions that they cannot eliminate or whether the screens are themselves responsible for introducing additional distortions into the flow – though it is hard to see how the latter can occur in some of the cleaner rigs that have been built. There may even be an amplification of small convection currents that occur behind the screens.

In fact, a major disadvantage of the screens is that they are placed in a very-low-velocity region of the flow. This causes a strong damping (due to contraction of the flow) of any radial velocity distortions that persist behind the screens but, due to the stretching of radial vorticity, distortions in the transverse velocity components can be greatly amplified. It therefore seems worthwhile to carefully investigate the flowfield just downstream of the screens.

It will almost certainly be necessary to rely on facilities that impose some sort of mean flow if it turns out that, for the reasons alluded to above, testing with screens is not acceptable. Such facilities have the additional advantage of producing the same (hard to calculate) convective amplification of the sound that occurs in forward flight provided, of course, that the mean flow is sufficiently large. On the other hand, acoustic wind tunnels are expensive and may never be suitable for testing full-scale engines. But since it has been found that most of the inlet flow distortion can be eliminated by imposing only very small mean flows, it may be possible to develop cheaper and larger facilities by using a shroud and relying on the ejector action of the fan to produce the mean flow.

It is worth noting that even though flyover noise is controlled by the aft radiated sound, most static facility testing has concentrated on the forward arc noise. However, the measurements show that the mean flow into the fan can have a definite effect on the aft radiated sound. In fact, the imposition of a mean flow not only reduces the level of the aft radiated fundamental blade passing frequency tone – which is presumably caused by inlet flow distortions in cutoff fans – but also causes the second harmonic of this tone to be much less fluttery. Since there is no change in the level of this harmonic, it is probably produced by the rotor-wake/stator interaction and is affected by changes in the mean inlet flow only because the inlet distortions are able to produce significant modulations of the rotor wakes.

It is possible to develop a facility for measuring aft radiated noise which uses screens but has none of the disadvantages resulting from placing them in a low-velocity region of the flow. This can be accomplished simply by inserting the screens in the duct just upstream of the fan face.

In some tests, the imposition of an incident mean flow has not entirely eliminated the forward arc fundamental blade passing frequency tones produced by cutoff fans and, in the one case where it was measured, has not entirely eliminated the aft radiated fundamental tone. This residual tone may not be caused by inlet flow distortions but rather by a rotor-wake/stator interaction that can occur because the irregular spacing of its vanes causes the stator to behave as if it had a different number of vanes than its actual number. In this way the apparent vane/blade ratio could differ from the cutoff valve for which the fan was designed.

There is increasing evidence that the highly irregular flow near the rotor tip is responsible for producing a significant fraction of the rotor wake/stator noise. For example, changes in rotor tip clearance have been observed to change tone levels by as much as 3 dB in the presence of an inlet flow control structure, which presumably eliminates most of the inlet flow distortion noise generated by the rotor. If the tip flow does play a dominant role, schemes for reducing rotor wake/stator noise by adjusting the radial loading on the rotor to produce more cutoff radial modes will certainly become less attractive.

There is also increasing evidence that the tip region plays an important role in the inlet flow distortion noise generated by the rotor. Some of the evidence comes from observations that changes in inlet contour – which presumably alter the casing boundary layer – can significantly affect the noise produced by a rotor. Even more impressive evidence comes from the large increases in rotor tone levels that are produced by inserting probes through the casing wall even when they extend only short distance into the fan duct. Experiments are underway to further assess the importance of the tip region.

Our understanding of broadband noise (which accounts for more of the radiated energy than the tones at lower speeds) has not substantially improved over the past few years. However, it has been found to be uninfluenced by inlet flow control screens and unaffected by forward velocity in both flight and acoustic wind tunnel tests. This tends to indicate that its dominant source is not the inlet turbulence outside of the casing boundary layer.

On the other hand, the broadband noise does exhibit a strong dependence on rotor loading. This would occur if it were generated either by the rotor-wake/stator interaction or by the turbulence in the rotor blade boundary layers interacting with the trailing edges of these blades. The experimental evidence which might serve to identify the actual source is at best contradictory. In some experiments, the broadband noise was significantly altered by increasing the stator chord – indicating that it was caused by the rotor-wake/stator interaction. In other experiments, removing the stator altogether was found to have relatively little effect on the broadband noise. In fact, it had much less effect than changes in blade loading – indicating that it was the rotor blade boundary-layer turbulence that produced the sound.

One might conclude from this that the noise was produced by different mechanisms in the different engine tests. But the broadband spectral shapes seem to be very similar for all engines tested. In fact, they all tend to peak at about 2½ times the blade passing frequency. This does not necessarily imply that the broadband noise and the tones are both caused by the same source (as would be the case if they were due to large-scale turbulence entering the fan) since the blade passing frequency divided by μ rel/(blade chord) (where μ rel denotes the mean flow velocity relative to the fan blades) does not change appreciably either with operating conditions or fan design. Consequently, the fixed relation between peak frequency could also be interpreted as the fixed relation between peak frequency and μ rel/(blade chord) that one would expect to find if the sound were generated by the turbulence in the blade boundary layers.

Except for possible entropy sources, the mechanisms responsible for producing turbine tones are not essentially different from those that produce fan noise tones. However, the turbine tone sound field has a much simpler structure since the rotor/stator blade numbers are usually such that only a single propagating mode can exist at the fundamental tone frequency. On the other hand, it may be more difficult to calculate this sound since it is produced by the complicated distortion field that arises from the several turbine stages that precede the last few stages which actually produce the sound.

An additional complicating factor results from the propagation of the tones through the turbulent shear layer of the exhaust flow. This tends to produce a "haystacking" in their spectra which disappears in flight.

Turbines can be designed so that their fundamental blade passing frequency tones will be completely cut off, but it is usually necessary to pay an unacceptable weight penalty to accomplish this.

The status report paper (Paper 77-1319) presented at the conference on turbomachinery noise by C.E. Feiler was entitled "Summary of Forward Velocity Effects on Fan Noise."

Duct Acoustics

Contributed by

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There were four sessions at the Conference on Duct Acoustics: Duct Acoustics I was mostly on theoretical developments; Duct Acoustics II was on computational techniques; Duct Acoustics III was on measurements; and Duct Acoustics IV dealt mostly with applications. There was some overlap since the boundaries were not sharply defined.

The workshop session began by a brief review of these sessions by the respective session chairmen. Duct Acoustics I included the state-of-the-art talk by P.D Dean and P.G. Vaidya (Paper 77-1279). From a practical point of view, the most apparently significant paper in that session was by E.J. Rice (Paper 77-1281). He had shown earlier that the cutoff ratio was a very useful concept a far as the design of liners and the prediction of their performance was concerned. In this paper he showed that the radiation problem scaled reasonably well according to the cutoff ratio. There were two papers on nonlinear effects. The first of these by A.H. Nayfeh (Paper 77-1282) postulated some fascinating generalizations of the cutoff phenomenon which could occur in the presence of weak undulations in hard walls. M.S. Tsai discussed propagation of a wave packet in a lined duct. W. Mohring's paper on Acoustic Energy Flux (Paper 77-1284) was concerned with an extension of S.S. Davis' work on sound power transmission across a variable-area duct. A.N. Abdelhamid's paper (Paper 77-1283) showed how asymmetry could be exploited to achieve a higher value of optimum attenuation in rectangular ducts.

D.L. Lansing reviewed Duct Acoustics II. Commenting on the Vaidya paper, he said that although Green's functions are very elegant, he has some concerns about their utility, based on past experience. There were two papers on finite elements in that session – W.R. Watson (Paper 77-1300) and A. Abramson (Paper 77-1301). It appeared to Lansing that now there seems to be some light at the end of the tunnel, as far as the interior duct problem was concerned (at least at low speeds of mean flow). However, there was no clear solution for the exterior problem in sight. Perhaps Vaidya's method might work. There were two papers on nearly choked flows – A.J. Callegari and M.K. Myers (Paper 77-1296) and A.H. Nayfeh, J.E. Kaiser, and B.S. Shaker (Paper 77-1297). Lansing stressed that the problem was important from both practical and fundamental points of view. The problem is one of essential nonlinearity, and straightforward linear approximations just will not work!

A.H. Nayfeh reported that in session III there were two papers dealing with in-duct and far-field measurements – B.W. Lowrie and B.J. Tester (Paper 77-1331), and M. Perulli and J.M. Ville (Paper 77-1332). There were two experimental papers from NASA Lewis – H.E. Bloomer, J.W. Schaefer, and C.E. Feiler (Paper 77-1333), and M.F. Heidman and D.A. Dietrich (Paper 77-1334). In the case of Multiple Pure Tones, the agreement was good at lower tones but not so good at the higher ones. A.S. Hersch and B. Walker presented two papers on the effect of grazing flow on the acoustic impedance. One dealt with porous materials (Paper 77-1335) and the other dealt with perforated plates (Paper 77-1336).

E.J. Rice's section IV had papers dealing with inlet shapes – J.M. Abbott (Paper 77-1354) and D. Sloan, C. Rayl, and B.W. Farquhar (Paper 77-1355). The effect of the shapes does seem to be significant. S.L. Sarin and D.A. Corelisse (Paper 77-1356) unexpectedly discovered that the intake noise can be significantly reduced by injecting hot air over the duct surface. The rest of the papers contained some discussion on the difficulty in carrying out experiments. D.T. Sawdy and R.J. Beckemeyer (Paper 77-1358) showed that the behavior of folded cavity liners can be explained by means of an extended reaction analysis. These liners give better low-frequency attenuation without the use of excessive backing depths. A.N. Abdelhamid (Paper 77-1357) showed the results of using lined radial baffles. A.I. El-Sharkaway and A.H. Nayfeh (Paper 77-1359) gave theoretical and experimental results for an expansion chamber. Rice commented that those results are bound to change when the presence of flow is considered.

The discussion that followed these summaries could be outlined by considering the Duct Acoustics field as subdivided into three subfields: 1) generation, 2) transmission, and 3) radiation.

In the case of generation, we still have insufficient knowledge of the back reaction. P. Baade has made a beginning on experimentally distinguishing pressure and velocity sources. However, more work is needed. We also have a serious problem in measuring all the modes which are generated. Some participants suggested that we ought to abandon the modal concept. It could be replaced by the cutoff ratio (Rice) or by the axial phase velocity. In any case, it is the axial phase velocity which could be readily measured in a nondestructive way. There was no clear consensus reached on this issue.

In the case of transmission, there was a question raised about the validity of the assumption of local reaction. It was also suggested that we should look into the desirability of encouraging extended reaction, where it might be beneficial.

The problem of nearly choked inlets still appears to be controversial. We don't seem to understand the physics of the reflected wave, and its relationship to the shock at the throat. It was suggested that there was some room for flow visualization type experimentation. There was an agreement that the problem was nonlinear and that there is a strong interaction of the mean flow with the acoustic field.

In the case of the radiation problem, its dependence on the inlet shape has been shown. However, good analysis is lacking.

Good experimental facilities were thought to be in short supply. There is a need to validate all those theoretical results. Perhaps, the onset of an activity to build spinning mode synthesizers was a good thing. There were still a lot of problems to be solved, however, before an accurate identification of modes was possible.

To sum up, the workshop led to a healthy discussion of various problems of Duct Acoustics and it left the participants with a farily good notion of what the future directions ought to be.

Aircraft Engine Core Noise

Contributed by
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The term "core noise" is used to designate the contribution to the overall exhaust noise of an aircraft engine, generated by sources within the engine. Candidate noise sources generally considered in this category include combustion noise, turbine noise, obstruction noise, and noise generated at the nozzle exit plane due to unsteady flow interacting with the nozzle surfaces.

While noise generated by the turbine dominates the high-frequency portion of the core noise spectra, research over the last several years has led to a general consensus that core noise at low frequencies (i.e., below 2000 Hz) is controlled by combustion-related sources. Discussions in the Core Noise session and in the workshop were restricted primarily to noise in this low-frequency regime. The remainder of this workshop report concentrates on the recent work conducted in the area of low-frequency core noise generation and transmission. Areas where further research is required were discussed in the workshop and are identified in each of these categories.

Core Noise Generation

Very little work has been conducted in the past year that could lead to definitive analytical models for predicting combustion noise from real aircraft engine combustors. Researchers at Princeton University, however, have continued their effort to determine the relative strengths of the various direct combustion noise source terms. Results of recent studies indicate that for open flames, the dominant term controlling noise levels is the volume integral of the time derivative of the heat release rate. This result is consistent with the less exact engineering approaches currently being used by various investigators for predicting combustion noise.

In 1976, following the 3rd AIAA Aeroacoustics Specialists Conference, it was generally agreed that direct combustion noise, rather than indirect combustion noise (or entropy noise), was the dominant core noise source. During the current Core Noise session and workshop however, several authors (i.e., W.C. Strahle, A.M. Karchmer, B.N. Shivashankara) raised anew the possibility of combustion-related sources other than direct combustion noise being important. Comments to this effect were based on experimental evidence from burner rigs and engines. Investigators at NASA and Boeing reported results from use of coherence techniques (on YF-102 and Garrett turboshaft engines, respectively) to determine the contribution of the combustor to the far-field noise levels.

During the Core Noise workshop the following areas were identified as those where more work is required:

1) Well planned and controlled experiments, as well as advanced signal processing techniques, are required to separate the contributions of the various combustion-related noise sources (i.e., direct, indirect, etc.).

2) For direct combustion noise, a need exists to determine the importance of source region correlation size on the observed noise levels. Specifically, what geometric parameters govern source size? Hole pattern distribution? Number of fuel nozzles? Turbulent length scales?

3) In the prediction of direct combustion noise, much more work is required to relate the unsteady heat release rate Q to geometry and steady performance parameters. It was believed that the lack of this information may be responsible for the current inability to develop a single prediction procedure that applies to all aircraft engine burners.

4) Although use of coherence techniques for relating internal combustor and far-field signals can be useful for

qualitative diagnostics and for defining *minimum* levels of far-field combustion noise, the utilization of these methods for quantitative definition requires uncontaminated signals in the burner. Before these techniques can be used as a suitable substitute to conventional methods for defining far-field combustion noise, more work is required to develop methods of separating propagational noise in a burner from the nonpropagating hydrodynamic noise contaminants.

Core Noise Transmission

Although various methods differ significantly in their approach to predicting the core noise "insertion loss" due to a turbine downstream of a combustor, there was general agreement at the workshop that the magnitude of this loss is in the range of 5 to 15 dB for most engine configurations. These methods range in complexity from those that use a constant loss per stage, to those that predict attenuations as a function of turbine work extraction, source correlation size, ratios of characteristic impedance across the turbine, etc. Future experimental and theoretical studies should consider in more detail the modal distribution of the noise at the combustor/turbine interface, realizing that for typical engine sizes, the plane wave and first circumferential mode are the only ones propagating in the frequency range of interest. All higher-order modes are below cutoff and therefore do not carry acoustic energy to the farfield.

Some very interesting results on the transmission of core noise at the jet exhaust plane were presented by D. Bechert of DFVLR in Berlin, where experimental evidence was shown to indicate that at low frequencies (typically about 100 to 200 Hz in an engine), the internally generated noise may be absorbed in the radiation process by transfer of acoustic energy to the jet turbulence. Earlier work by these same investigators has indicated additional evidence of a coupling of core and jet noise, where it was claimed that jet noise levels may indeed be amplified by the internal noise. Several investigators emphasized that in the future it may be counterproductive to treat core and jet noise as separate disciplines, and that a need exists to look at these two as a coupled system.

The status report paper (Paper 77-1273) presented at the conference on engine core noise by R.S. Zuckerman was entitled "Core Engine Noise Reduction: Definition and Trends."

Airframe Noise Workshop Report

Contributed by
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There were two sessions devoted to airframe noise at the 4th Aeroacoustics Conference. The results presented in the papers and the discussions at the workshop at the end of the Conference showed that progress is continuing to be made in prediction, measurement, and understanding of airframe noise.

All of the present methods of predicting airframe noise rely to a large extent on empiricism. Whether or not that will always be the case was a matter of debate during the workshop discussions. Some participants felt that it is now time to look at airframe noise problems from a more fundamental point of view in order to improve our understanding of the physical processes involved in airframe noise generation. They felt that computational fluid dynamicists and aeroacousticians should join to come to grips with the problem of solving for the turbulence flowfield, and the resulting noise caused by flow over solid surfaces, by an attack on the Navier-Stokes equations.

Other participants felt that it would be a millennium before such an approach would yield useful results for engineering applications. There has been little success so far with calculating turbulent flowfields from first principles. There was general agreement, however, that basic research was needed.

Research aimed at improving our understanding of airframe noise generating mechanisms is being carried out through improved experimental techniques as well as by the development of new theoretical methods. Work described in the papers and during the workshop discussions dealt with the application of acoustic-mirror techniques and cross-correlation methods for determining sound source locations, use of gliders to study landing gear and flap noise, and model and full-scale airplane tests of complete airplane configurations. Recent tests results have already led to a fuller understanding of airframe noise generation mechanisms.

It is now fairly certain that airplane wheel wells are not, by themselves, an important source of airframe noise, and that they do not generate the strong discrete tones that would be predicted from tests on isolated simple cavities. Wings and flaps are important noise sources which deserve a great deal more study. For example, we still are uncertain about the relative importance of the following sources of noise from trailing edge flaps: 1) vorticity in the turbulent boundary layer in the region of the trailing edges, 2) turbulent flow impinging on and convecting past the flap segments, and 3) vorticity at the inboard and outboard ends of individual flap segments.

Model-scale testing is being used more and more to study airframe noise, but there was general agreement among the workshop participants that scaling is a major difficulty. Reynolds number effects are important and there is now no known way to account for different Reynolds numbers. Further comparison of model and full-scale test results and improved understanding of airframe noise mechanisms should lead to a clearer understanding of what the scaling problems are and to better methods of scaling the noise produced by particular components.

Airframe noise still appears to be a topic worthy of a great deal of further research. Predictions, based on the latest methods, show that airframe noise of future large airplanes with new quieter engines will be a serious practical problem. Furthermore, the fundamental knowledge to be gained from airframe noise research will be applicable to a wide variety of other noise problems such as: turbomachinery noise, helicopter rotor noise, automobile and truck cooling-fan noise, and wake noise from submarines and torpedoes.

The status report paper (Paper 77-1268) presented at the conference on airframe noise was by R.L. Chapkis and A.H. March.

V/STOL Noise Workshop

Contributed by
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A significant increase in the number of papers attests to the growing conern with V/STOL noise. At the present time two configurations, the helicopter (Paper 77-1337, A.R. George) and the externally blown flap (EBF) configurations (Paper 77-1313, J.S. Gibson), appear to be of primary concern. Since the primary external noise source of the helicopter is due to rotating lifting airfoils while the EBF signature is dominated by the engine exhaust and its interaction with the various surfaces and slots associated with multiflap wings, V/STOL noise encompasses a wide variety of aeroacoustic disciplines.

EBF Noise

Much diversity of opinion remains regarding the relative strength of the several potential noise sources occurring on or near the wing. These include scrubbing, or jet impingement noise, the dipole noise produced by large eddies passing over the sharp trailing edge, turbulent noise over the upper and lower surfaces, and possible tones due to slot openings between flaps.

Refractions of the noise field by the shear flow further impede source identification.

One researcher reported that the secondary mixing region, behind the trailing edge, was found to be a stronger acoustic source than the primary mixing region and that the turbulence dynamics in the two zones are drastically different.

A problem has been noted regarding the use of zero-speed data as a basis for predicting forward flight effects. If, for example, one considers the forward velocity effects on turbulence, one would expect the noise to go up with velocity, while experimental data has indicated exactly the opposite trend.

Rotary Wing Noise

Recent activity by the FAA and ICAO toward development of noise certification rules for helicopters has given an impetus to the development of improved rotor noise prediction and reduction techniques. As with the EBF configuration, prediction of forward flight effects proves especially difficult. For example, four different theories for impulsive noise at high forward speed were discussed: thickness noise, quadripole noise due to momentum flux changes on the flow over the airfoil, aeroelastic effects, and time-varying drag divergence are all under study as possible important contributors.

Interest in blade tip development for noise reduction continues high with a report on a new shape which is apparently effective in restructuring the vortex core, thereby having a beneficial effect on the reduction of impulsive noise due to rotors cutting their own wake during descent. It was also pointed out that some previous experimental tips may have been too short and that swept tips, for example, should be a significant portion of the wavelengths to be affected.

Internal Noise

A paper which was presented on interior noise of a EBF STOL revealed a general interest in this important subject. Although the levels in the STOL are approximately the same as those of a large helicopter, the sources are quite different. The STOL noise is primarily due to engine noise, while the helicopter noise is a combination of aerodynamic excitation of the fuselage due to the rotor at low frequencies, and tones due to transmission gear noise at higher frequencies. Another source of high interior noise peculiar to V/STOL occurs on tilt-rotor configurations in the rotor down, or cruise, condition where the clearance between fuselage and rotor tip is considerably less than that normally encountered with airplanes. This results in high levels of fuselage excitation and, hence interior noise. The diversity of configuration-dependent sources indicates an interesting potential for a separate session at a future symposium.

Workshop on Sonic Boom and Atmospheric Wave Propagation

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The analytical modeling of focusing effects generated by supersonic transports and other supersonic aircraft under certain flight conditions remains a research area that present a challenge. This problem appears to be solvable with state of-the-art analytical and numerical techniques. Additiona experimental modeling of focusing effects in shock tubes ballistic tunnels, and novel wind tunnel configurations woul be helpful both as a guide to and as a referenece for comparison of anticipated analytical results. The recent experimental work by Sanai and Toong at the Massachusett Institute of Technology is considered to be definitive in establishing conditions of focusing and defocusing due to acceleration superbooms. The infrasound profiles of th Concorde as measured by the Lamont-Doherty Geologica Observatory team and the report by N.K. Balachandran a this conference constitute reliable and accurate data However, the value of the data may be more substantial thar reported, and further explanation in terms of width of profile amplitude, and frequency dependence is suggested. Possibl upper atmospheric reflection of the Concorde boom ma account for some of the reported profile characteristics.

The utility of the parabolic approximation (Paper 77-1310 should be exploited in predicting aeroacoustic fields ir stratified moving media. The parabolic approximation, which is used quite extensively in ocean acoustics, represents ar established technique with considerable documentation. Ar area where future work is needed is that of extending the parabolic approximation to include randomness in the media through which the acoustic wave propagates. A perturbation approach in which randomness of order of the inverse of the acoustic wavelength ($1/\lambda$) should be fruitful.

In the area of shockwave propagation in real gases, recent investigations (Paper 77-1312) suggest that proper modeling should include nonlinear and relaxation effects simultaneously. The need for improved rise time calculations of shockwaves in real gases is recognized and represents an area in which research is needed. Appropriate scaling of physical effects coupled with the technique of matched asymptotic expansions is recommended as an approach with high potential.

The recent investigations of the effects of turbulence on acoustic wave propagation (Paper 77-1308) indicate that the requirement for conservation of energy is not satisfied by some of the more recent models. This area of research is one which is characterized as greatly in need of experimental confirmation of analytical models. The concern for including time variation as well as spatial variation in modeling random inhomogeneities may not be as important as previously thought, in that time variation has been shown to have little effect in several calculations performed by Albert George and his associates at Cornell University. Greater use of classical results (i.e., Tatarski) is recommended in appropriate cases.

References

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