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Workshop Report for the AIAA 6th Aeroacoustics Conference

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THE AIAA 6th Aeroacoustics Conference was held in Hartford, Conn. on June 4-6, 1980. The meeting was well attended with papers contributed by researchers from nine different countries. Since the previous aeroacoustics conference a good deal of progress on the understanding of certain noise generation mechanisms as well as on the development of noise prediction procedures and suppression devices has been made. These results were reported and discussed in this conference. However, frequently it was found that as one source of noise was reduced, other previously less dominant noise sources were exposed. This continued to present frustrations and challenges to the investigators. In certain areas of aeroacoustics the problem remained not so well understood. Fresh ideas and new approaches are definitely needed.

Some of the high points of the conference were the workshops of the different areas of aeroacoustics. The primary purpose of these workshops was to provide a forum where new ideas and concepts could be openly discussed and controversies freely debated. In addition they also served as a convenient occasion for experts involved to assess past progress and to identify major problem areas. The workshops were initiated at the AIAA 3rd Aeroacoustics Specialists Conference. They were highly successful and have since become an important part of all subsequent conferences. Summaries were published in the *Journal of Aircraft*.[1-3] This article is a collection of the summaries of the workshops conducted at the AIAA 6th Aeroacoustics Conference. The summaries were prepared by the workshop chairmen. After some editing, they are gathered below.

Jet Noise

Contributed by

Dennis K. McLanghlin, Oklahoma State University

In the jet noise workshop the five chairmen of the jet noise sessions initiated discussion by summarizing and highlighting the papers which were presented in their respective sessions. Despite the fact that the study of noise produced by high speed jets is completing its third decade many new and innovative studies were reported on.

Several papers focused on the flowfield mechanisms present in the jet, with additional discussion on interaction and noise producing processes. An interesting computer movie was shown by Bayliss and Maestrello (Paper 80-0960) demonstrating the prediction of a sound pulse with the jet shear layer. The vortex pairing, or coalescence phenomenon, continues to receive the attention of experimenters as it is undoubtedly an important if not the controlling mechanism in subsonic jets in particular. Laufer and Monkewitz (Paper 80-0962) and Kibens (Paper 80-0963) reported on experiments which explored the basic vortex interaction phenomenon. The first presented some new ideas on a possible feedback mechanism controlling the pairing process in the subsonic round jet. The second reported on a study of the interaction of jet flow instabilities with upstream delivery pipe resonances. There was general agreement that studies of this nature should help improve our understanding of the role of large-scale flow processes in the production of aerodynamic noise.

We are now beginning to see jet noise analyses utilizing the experimental evidence collected over the past several years on coherent structure in jet turbulence. Papers were presented utilizing discrete vortex modeling [Kitaplioglu and Kibens (Paper 80-1003)] as well as wave analysis of the large-scale structure [McLaughlin et al. (Paper 80-0964) and Morris (Paper 80-1004)]. The last of these papers specifically addressed the issue of broadband jet noise amplification due to upstream discrete tone disturbances. This phenomenon is becoming accepted as one of the major causes of "excess" noise defined several years ago to be the extra jet noise full-scale engines experience in comparison with model jets. Of course we continue to see development of jet noise prediction methods which depend more heavily upon empirical evidence than the previously mentioned theories. These latter methods are directed toward more complicated engine configurations, or toward interpretation of the differences between engines in flight and those in static tests.

Engine and airframe manufacturers continue to expend significant effort in attempting to understand installation and flight effects. There was excellent participation from industries in the United States, and several European countries at the Aeroacoustics Meeting in general and the Jet Noise workshop in particular. As expected the majority of papers from these participants was in the area of installation and flight effects.

The most lively debate of the workshop was initiated by the discussion of the paper by Sarohia et al. (Paper 80-1032). In a study of flight effects they used a Schlieren apparatus to visualize a very clear large-scale jet flapping of a supersonic jet in the presence of a large coannular outer stream. Sarohia et al. hypothesized that the phenomenon observed is similar to jet "crackle" identified previously by Ffowcs Williams et al.[4] Many in the workshop audience expressed their doubt of such an explanation. Most noteworthy, Kibens, McDonnell Douglas Research Laboratories, reported that a similar instability of the jet was suppressed in their facility by the introduction of forced jet entrainment. An unanswered question on this subject remains: Is this large-scale jet instability, so evident under some specific experimental conditions, nevertheless an integral part, in a more random manner, of the large scale turbulence of a jet?

From the tone of the workshop and the individual jet noise sessions we have an idea of major future activity in jet noise research. Several new large facilities have been constructed recently for the purpose of studying flight effects on jets (and their noise production). We should look for new experimental evidence from these laboratories that should help sort out the confusing picture we now have. Shock associated noise produced by supersonic jets has evidenced a recent increase in research activity. Several papers were presented at the past meeting and more will undoubtedly be written in the near future. There seemed to be general agreement that the analysis of Harper-Bourne and Fisher,[5] which works quite well for converging nozzle jets, is inadequate in the case of con-

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vergent/divergent nozzles. Experiments such as those reported by Seiner and Norum (Paper 80-0965), in which a hot-film probe was used to survey the flowfield near a shock/mixing layer intersection, are beginning to help provide understanding of the complicated physical phenomena in shock associated noise.

Finally, papers in other sessions on nonlinear propagation effects drew the attention of jet noise analysts. Concern was expressed that the analysis of jet noise may become even more complicated if effects of nonlinear propagation distortion are to be included.

Duct Acoustics

Contributed by

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The workshop discussion ranged over a broad variety of topics including some aspects of turbomachinery noise. This summary is a brief report of a few of the highlights of the workshop.

Theoretical Developments

Finite element and finite difference methods for solving duct propagation and radiation problems are encountering computer storage limitations when applied to complex geometries or high-frequency sound. Condensation methods for reducing the order of the system matrices need to be explored more extensively. Integral equation methods do not appear to be readily adapted to include airflow. Two approaches which may circumvent the problems of these methods are being investigated. These include time-dependent methods and ray theory solutions. The time-dependent finite difference analysis which solves the hyperbolic form of the wave equation has been found to be superior to the steady-state techniques because of shorter solution times and the elimination of large matrices but has difficulties handling cutoff modes. A ray theory formulation, based upon the ideas of geometrical acoustics, is a fully legitimate approach to the problem within the assumptions of high frequency. This method appears to be attractive for propagation problems in ducts with variable geometry, variable impedance liners and flow, and also has the potential for dealing with radiation from ducts including the effect of inlet or exhaust flows. Some theoretical development appears needed in order to use ray theory for realistic source distributions. A parabolic formulation of the equations may make it possible to extend the ray theory solution to lower frequencies.

In-Duct Source Definition

It was agreed that the design of advanced "optimized" duct liners requires detailed knowledge of the turbomachinery noise source. However, practical methods for the measurement and characterization of the acoustic wave structure within a real engine continue to be elusive. The direct measurement of duct modes using in-duct microphones has been found to be very sensitive to engine rpm changes and requires an impractical number of microphones if many modes are propagating. The concept of grouping modes according to cutoff ratio is gaining wider acceptance as a tool for making predictions of liner performance and for conceptually simplifying the problem. It is not clear, however, how a direct measurement of the cutoff ratios or incidence angles of the important families of propagating modes is to be made in situ in an engine. Some innovative thinking in data acquisition and analysis appears necessary if these ideas are to become useful diagnostic tools for the liner designer.

Sound Propagation through Transonic Flows

Research on this topic is motivated by the need to obtain a clearer understanding of the sound reduction which has been observed in tests of high subsonic Mach number inlets. Theoretical studies of nonlinear interaction of sound propagating through near sonic flows have predicted that acoustic shocks may occur at mean-flow Mach numbers as low as about 0.8. According to the theory, the dissipation of energy associated with the shocks is the major mechanism responsible for the sound reduction. There is a need now for some fundamental experiments to verify the existence of the acoustic shocks and confirm their role in sound attenuation. Such experiments are currently underway at NASA Langley utilizing two-dimensional and axisymmetric ducts with constricted high subsonic Mach number sections.

Noise Suppression

Our ability to model the acoustic behavior of bulk liners and predict the impedance and propagation constants of such liners in terms of easily measured structural properties is steadily improving. However, engine tests of bulk liners have produced rather ambiguous results regarding the superiority of these liners over resonator-type absorbers. More careful documentation of the test conditions, liner construction, and engine acoustic and flow environment are recommended as a means for sorting out the discrepancies. There is still the hope that bulk absorbers will have broader bandwidth of absorption than resonator liners, which tend to be narrowly tuned. Very broad bandwidth of absorption will be desired in the future when attention is directed towards reduction of the broadband noise generated by turbomachinery.

There is considerable current interest among liner designers in "linear" liners which, unlike resonator-type liners with perforated plate facesheets, behave linearly with SPL and in the presence of flow. Such liners can be realized by using porous or woven fiber facing sheets in place of the currently used perforated plate. The prediction of the impedance and attenuation characteristics of such liners is much more reliable than for liners with perforated plate facesheets and, hence, the designer can proceed with considerably more confidence in his design task. The suitability of woven fibers for use in aircraft engine ducts remains to be demonstrated.

Source Impedance

The acoustic power radiated by noise sources in ducts is in general a function of the acoustic impedance of the source and the acoustic load of the environment into which the radiation takes place. The duct, together with its surface treatments, is traditionally looked upon as part of the acoustic load coupling the main free-field impedance to the source. Owing to the difficulty of defining the turbomachinery acoustic source impedance, it has been customary to assume that the amplitude of the incident field in the duct excited by the source is not a function of the duct liner impedance nor the duct exit radiation impedance. This is equivalent to assuming the source impedance to be high. It was mentioned that based on some recent calculations at General Electric, the amplitude of the incident sound field excited by fluctuating aerodynamic forces has been found to be very much a function of the acoustic environment. This means that in the design of acoustic liners for maximum transmission loss, the impact of the liner impedance on the source acoustic output must also be evaluated.

Brief Notes

1) A boundary layer over a perforated plate is an important determinate of orifice impedance and, hence, the boundary layer properties must be known in order to predict the attenuation of conventional duct liners made of perforated plate backed by honeycomb. Measurements of the characteristics of boundary layers in engines in the presence of high intensity sound are not available and are considered to be an important missing element in engine liner design.

2) It was pointed out that the prediction of fan inlet and exhaust radiation are usually treated as separate problems,

whereas, in fact, these sound fields may be highly correlated because they originate from a common source within the engine. The far-field radiation pattern can then contain strong diffraction patterns resulting from the cancellations and reinforcements of the coherent radiation from these two sources.

Turbomachinery Noise

Contributed by

E. B. Smith, General Electric Company

The Turbomachinery Workshop followed two turbomachinery noise sessions with a total of 12 papers presented. One session was devoted entirely to rotor-turbulence noise generation and reduction with emphasis on ground-test techniques which simulate the flight inlet-flow environment. The second session dealt primarily with noise source mechanisms and some special techniques of measurement. Because of the interest of the participants, the workshop discussions centered around these two subjects. The general state of fan noise predictions and some special problems dealing with interstage resonances were also discussed briefly.

John F. Groneweg, NASA Lewis Research Center, led a discussion of analytical fan noise models and has provided the following summary of this area.

Analytical modeling has concentrated mainly on describing individual fan noise generation mechanisms such as rotor-turbulence, rotor-inflow distortion, and rotor-wake-stator interactions. Experimental confirmation using practical fan stages has been primarily for rotor-turbulence and rotor-inflow distortion cases, reflecting the recent emphasis on controlling fan inflow for flight simulation purposes. The technique of introducing controlled inflow distortions in the form of cylindrical rod wakes is a promising experimental approach to model validation. Such experiments have the benefit of building confidence in the modeling of the blade response to flow disturbances, which is the heart of any generation model. New mechanisms such as those associated with rotor tip and hub flow regions which interact with the stator deserve analytical effort.

Models which combine several mechanisms into a composite fan prediction are needed to allow parametric investigations of relative mechanism strengths. Such a multisource model requires careful attention to the consistency of blade response assumptions. One viewpoint is that a consistent "first-order" blade source model is a dipole source distribution on a flat plate cascade in compressible flow including noncompact source effects. A model consistent to second order would include quadrupole source terms and blade geometry details such as blade camber, thickness, and angle of attack. Predicted mode content in an annular geometry is the desired output to serve as an initial condition for propagation and suppression analyses. In view of the difficulty of mode measurement in practical fan environments, a source mode prediction model, validated in laboratory experiments, would be an operational alternative to model measurements to obtain source initial conditions.

Most of the modeling effort has concentrated on tone prediction at subsonic tip speeds. The multiple pure tone (MPT) analyses that have been done have mainly emphasized the relation of blade-to-blade geometric nonuniformities to the qualitative MPT spectral characteristics. Much less attention has been given to overall MPT sound power dependence on blade relative Mach number. The peaking and decrease in MPT power with increasing fan tip speed may be a nonlinear shock propagation effect which has received some attention, but it seems that work linking transonic fan aerodynamic and geometric design parameters to shock strength and propagation behavior deserves additional investigation. The question was raised as to the level of current practical concern for MPT levels as a contributor to flyover EPNL. An answer offered was that blade passing tone and its harmonics and broadband are of greater current practical concern, but perhaps inlet treatment designed for MPT's might be profitably reduced or the space devoted to suppressing other spectral components.

The broadband component remains an unknown in terms of dominant practical mechanism; and therefore a definitive analytical treatment which describes engine broadband levels is lacking. Theoretical broadband levels generated by inflow turbulence-rotor interaction have been calculated and compared to measurements in sufficient detail to conclude that the broadband mechanism in practical fans is due to flow disturbances other than those affected by the passive inflow control devices currently used to simulate flight. Broadband levels have been empirically correlated with rotor incidence angle; but some contrasting experimental evidence indicates that the stator influences broadband levels. The question was raised as to whether a wake pulse position (PPM) and pulse amplitude modulation (PAM) formulation had received further investigation as a model for broadband generation due to rotor-stator interaction. No affirmative response was given and the difficulty of linking the PPM and PAM parameters to rotor blade geometry and aero-operating condition was offered as a reason.

A blade row interaction analysis which allows for acoustic resonance between rotor and stator blade rows was mentioned as an analytical effort currently underway. One of the goals is to determine if such a model can at least qualitatively account for repeatable maxima and minima observed in far field, narrowband tone power as fan speed is varied.

D.C. Matthews and D. F. Rogers, Pratt and Whitney, led a discussion on the degree of flight-noise level simulation achievable during static engine testing by the reduction of fan noise generated by rotor-inflow distortion interaction. Conducting static tests with an inflow control structure installed or in a large wind tunnel, are two methods for obtaining the desired reduction in inflow distortion, and the effectiveness of each was reviewed in the discussion.

The need for inflow control is illustrated by the significant difference that exists between acoustic data obtained during static engine testing without inflow control and measurements made during aircraft flyovers. It has become clear that data from typical static tests are not adequate for accurate flight-fan-noise predictions or for evaluation of source noise reduction concepts. Since it is advantageous to perform as much noise reduction concept evaluation as possible during static engine testing (flight testing is time consuming and expensive), it is essential that proper inflow control methods be used.

Studies in the development and use of inflow control structures during static engine testing have been conducted by several investigators. Until recently, all published work had shown the effectiveness of inflow control structures based on fan rig or small-scale engine (JF15D) test results. The general conclusion reached was that use of an inflow control device will result in reduced fan tone noise levels if 1) flow velocities across the structure covering are kept to a relatively low level, 2) distortion due to support structure is minimized, and 3) the device is shaped to minimize changes in acoustic radiation patterns. Most of the impact of an inflow control structure is observed at blade passage frequency, although small changes are observed at times for other noise components.

Although the various inflow control devices have been shown to be effective in reducing fan noise levels during static testing, a true assessment of the effectiveness of the devices required comparable flight test data. The first full-scale direct comparison between flight data and data obtained statically with an inflow control structure installed was presented at this meeting by Pratt and Whitney Aircraft and the Boeing Commercial Airplane Co. Results from this program showed that inflow control structures were effective in achieving noise levels statically for the JT9D engine that closely approximated levels measured in flight. The fact that two different control structure designs resulted in equally good comparisons with flight noise data indicates that adequate simulation is not restricted to one particular design for this application. Various test results show that the inlet boundary layer thickness measured during static engine operation is about twice the boundary layer thickness measured in flight. The good agreement observed between the JT9D static and flight noise levels indicates that efforts to obtain complete boundary simulation may provide only a small acoustic benefit for engines of that type, and that the designs of inflow control structures currently used are satisfactory. However, for other engines or fan rigs where the dominant noise sources are influenced by flow characteristics in the boundary layer region, an improved screen device/boundary layer control system may be required for adequate flight noise level simulation. An additional benefit can be attributed to the use of an inflow control structure; that is, the stability of engine and rig operating characteristics is considerably improved and more accurate acoustic and engine-rig performance data result.

The importance of inflow control structures in simulating flight noise levels has been verified by the studies noted above. Various investigators have evaluated several structure shapes, sizes, and coverings to ensure effective operation of the device while minimizing acoustic transmission loss and changes in acoustic radiation patterns. Although all of these designs have shown a degree of effectiveness, further effort is required in the refinement of design parameters for structure use in specific applications. In addition, other static-to-flight noise level comparisons, where an inflow control structure had been used for the static test, would be advantageous for corroborating available results.

An alternative method for reducing the impact of rotor-inflow distortion interaction noise is the use of wind tunnels. Wind tunnels are attractive because the flow distortion can be reduced to low levels without the need for an inflow control structure, and forward velocity effects can be examined. Studies by General Electric and others have shown that large-scale facilities such as the 40- × 80-ft tunnel at the Ames Research Center can result in inflow distortion levels and measured noise levels that are comparable to the respective levels obtained with an inflow control structure installed. A comparison of the wind tunnel results with flight test results is still required. A significant drawback to the wind tunnel method, however, is the lack of tunnels of sufficient size to be able to install high bypass ratio engines and obtain accurate acoustic data.

Parma Mungur, General Electric Co., led a discussion of some facets of acoustic propagation in the interstage area and flow ducts of fan engines. The effect of reflection at the blade and vane rows produces both backward and forward travelling waves, resulting in an appreciable effect on the primary source radiation characteristics. This phenomenon has been given less attention than it deserves and needs further effort and clarification.

Aircraft Interior Noise

Contributed by

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This workshop consisted of short presentations by researchers doing work related to aircraft interior noise control and discussion of the presentations by workshop attendees. The information presented at the workshop indicates that progress is being made in developing noise-reduction prediction procedures for aircraft, spacecraft, and automobiles. Much of the current work has been inspired by the renewed interest in fuel-efficient turboprop transports. The control of interior noise of Prop-Fan transports is one of the objectives of the current work. These transports are expected to cruise at 0.7-0.8 Mach number and are driven by advanced transonic tip-speed propellers. Interior noise control of general aviation and the emerging larger commuter aircraft is also receiving attention. Also, the downsizing of automobiles resulting from interest in greater fuel efficiency has created a need for research to maintain the same interior comfort as that of the existing larger vehicles. The techniques being used for automobile interior noise may be applicable to aircraft noise control. While the turbofan transports are receiving attention to reduce transmission of noise into the cabin, the technology appears to be evolutionary and considered proprietary by the airframe companies. Therefore there was little discussion of turbofan interior noise control in the workshop.

In the study of Prop-Fan transport noise control, the work has been primarily analytical. The analysis work reported in the workshop indicated that there would be weight penalties for the added fuselage wall treatment needed to reach acceptable interior levels, but these penalties did not significantly affect the fuel conservation potential of the Prop-Fan concept.

Several researchers took the position that the analytical procedures now available should be capable of accurately predicting the noise reduction of aircraft fuselage walls. If it is found that predicted noise reductions do not match measurements, these researchers believe that improving the details of the analysis will eliminate these discrepancies. Other attendees at the workshop suggested the need for practical demonstrations of the methodologies used in the Prop-Fan studies for two reasons: first, it is possible that they could be optimistic in that they do not consider the effect of practical installation constraints such as gaps between panels, low transmission loss through windows, or grounding out of isolators between multilayer wall panels; and, second, they could be pessimistic in that the complexity of the propeller as an acoustic source may not be represented with sufficient detail to allow accurate fuselage noise-reduction calculations.

Comments were made about the low level of low-frequency noise reduction measured for turbofan and turbojet transports in contrast to the high level of low-frequency noise reduction which apparently exists in propeller aircraft. The need for experiments to resolve this difference was noted.

The beneficial effects of adding stiffness to the sidewall of an aircraft was discussed. Benefits in the 100-300 Hz frequency range were found in application of honeycomb to a general aviation aircraft. Panel tests of an integrally stiffened aluminum panel (Isogrid) showed benefits in the 200-2000 Hz range.

Results of recent testing were discussed which showed the noise-reduction potential of a device to hold a predetermined phase relationship between the propellers on an aircraft. By careful selection of the phase relationship and by holding the phase very accurately, it is expected that significant reductions in peak noise in the cabin may be achieved.

Structure-borne noise is also being addressed in testing of single-engine general aviation aircraft where it has been found that propeller and engine induced vibration, which is transmitted through the aircraft structure and then radiated as noise, is as important as the airborne noise which passes through the fuselage walls and is then radiated as noise. The importance of structure-borne noise in multiengine aircraft of all sizes has not yet been addressed but was considered by the workshop attendees as a fruitful area of research.

The attendees found the approach used in reducing automobile interior noise to be of interest in that it relies on a combination of analysis and experiment. The basic premise of the automotive approach is that a new automobile prototype is built which bears some relationship to existing designs. The vehicle is driven and the existence of noise problems is established. Experimental model analysis is then conducted, and the natural modes of the vehicle established. The relationship of the noise problem, the natural modes, and the structural motions of the various parts of the vehicle are used to establish structural changes to minimize or eliminate the problem. This appears to be a well-established procedure in the automotive field that might be applied to aircraft.

In summary, it appears that progress is being made in interior noise control of propeller driven aircraft. However, there is a critical need for experimental work on actual aircraft to 1) define the noise-reduction problem in detail, 2) establish the accuracy of available analytical models, and 3) evaluate new noise-reduction concepts. The two technical sessions on interior noise and the attendance at these sessions and at the workshop indicate that there continues to be considerable interest in this subject and offers the hope that substantial progress will be made in the near future.

Airframe and Propulsive Lift Noise

Contributed by

Roy K. Amiet, United Technologies Research Center

Airframe noise has been an important topic of research over the past few years. For an ideal aircraft configuration the airframe noise represents a noise floor which is difficult to reduce. As the aircraft becomes less clean, the airframe noise becomes an increasingly important noise contributor. When propulsive lift configurations are used, the noise can become comparable to or greater than that of the propulsive jet, if due to nothing more than reflection of jet noise by the airfoil for the case of lower surface blowing. Airframe noise can be especially significant during landing, when the aircraft is in its least clean condition.

Because of the scale involved, there is a strong economic incentive to use model testing rather than full scale when possible. It was generally agreed that this produced satisfactory results for most situations where scaling could be applied. However, it was felt that there was certain situations where scaling either did not apply or the appropriate scaling laws were not understood. Included among these were multiple flap situations and cases where vibration affected the noise generation process. Generally, scaling can be applied to the noise produced by individual components, but difficulties may arise when attempting to scale the noise produced by component interactions where more than one mechanism may be important. For these it may be necessary to test on a larger scale.

A noise source location receiving significant attention in this workshop was the flap side edges, in contrast to the leading and trailing edges, which have received more attention in the past. It was felt in many situations the side edges could be more important than the leading or trailing edges. For a stalled aircraft and for a blown flap the trailing edge would be expected to be dominant. For an airfoil in a turbulent flow, the leading edge would be expected to dominate the noise generation. However, for an unstalled wing or a deflected trailing-edge flap in the smooth flow, the side edges could be the dominant source as turbulent air from the pressure surface moves around the tip to reach the suction surface. This was the subject of a theoretical paper by Hardin (Paper 80-0978). Also, methods of reducing this side-edge noise were discussed in a paper by Fink (Paper 80-0979).

Several experimental papers were presented during the conference. The consensus of the workshop was that while the available methods were able to satisfactorily predict airframe noise under certain regimes, under other conditions the predictions deviated significantly from measurements. Prediction of directivity appeared to be the weakest link. Also, the method of predicting multiple flap noise was discussed. If the flaps are independent, the noise from each flap can be added logarithmically. In general, however, because of the interaction between flaps it is not sufficient to use such a simple treatment and an analysis must be made of the entire flap system.

Methods of decreasing edge noise were tested with results presented in two of the experimental papers. These edge treatments included sawtooth attachments of various sizes for upper surface blown flaps and porous or perforated edges. Two other possibilities mentioned during the workshop were to round the side edges and to place some type of flexible membrane between the slots of a multiple flap. The purpose is to eliminate to some extent the sharp airfoil edges, which are generally acknowledged to be the source of much of the noise. The consensus of the workshop was that all of these methods have the potential for reducing noise, as has been demonstrated experimentally for several of them. It was felt that further work needs to be done on the performance penalties that each of them would produce, whether owing to a decrease in the airfoil lift, or an increase in the drag.

Propeller and Helicopter Noise

Contributed by

Harry E. Plumblee Jr., Lockheed-Georgia Company

Two sessions were held on propeller and rotor noise. The topics covered were familiar. They ranged from installation effects on propellers to tip vortex noise on rotors.

Two papers were presented concerning comparisons of full-scale propeller noise measurements with noise prediction for aircraft in flight. Another covered the influence of installation on the noise of a propeller in front of a wing-flap combination and of propeller angle of attack. Other subjects reported were the influence of propeller vibration on noise, formulae for calculating propeller noise, the noise from three model propfans, and an overview of NASA's propeller and rotor noise research.

The topics presented concerning rotor noise included papers on rotor thickness noise, transonic effects on rotor noise, broadband rotor noise, noise of the rotor tip vortex, and nonlinear propagation of rotor noise.

The propeller noise discussions could loosely be divided into two categories, i.e., experiment and prediction. The following paragraphs will touch each of these, based on the workshop comments.

Propeller noise experiments discussed fell into two categories, i.e., model and full scale. Model-scale experiments that contained new results were those on installation effects. These experiments showed that the presence of a wing about ¾ of a diameter behind the propeller could increase the noise by as much as 5 dB. In addition, it was shown that an angle of attack relative to the freestream of 10 deg also resulted in as much as a 7-dB increase in both tone and broadband noise. The two effects can be considered independent, Tanna et al. (Paper 80-0993).

Full-scale results discussed included experiments using general aviation-type aircraft. The tests highlighted significant differences between both model-scale experiments and prediction methods. The most serious discrepancy is in broadband noise, Succi (Paper 80-0994) and Dahan et al. (Paper 80-0997).

Recommendations from the floor included a call for more tests on installation effects, both model- and full-scale; much more comprehensive broadband noise tests; and, a more realistic simulation of the flight geometry and environment in future model-scale experiments.

Comments on propeller noise prediction established that a reliable broadband noise prediction method is required. Existing methods are in error by as much as 10 dB. A call was also made for a simplified propeller noise prediction covering the tip Mach number range ($0.9 \leq M_N \leq 1.2$). However, it was finally stated that a unified theory will be needed to include all the effects that significantly influence propeller noise. This unified theory could be based on Farrasat's recent work (Paper 80-0996) but requires more precise definition of the flowfield, the unsteady blade loads and transonic effects, Yu and Schmitz (Paper 80-1009). It was also commented that a 3-D nonlinear theory may be required.

Helicopter noise experimental data and problems discussed were related to broadband noise and tip vortex noise, George et al. (Paper 80-1010). It was commented that the tip vortex disappears in model-scale wind tunnel experiments, whereas it remains a noise source in full-scale rotors. More experiments to study Reynolds number effects were called for. It was also pointed out that a concerted effort needs to be made to establish a national data base on aerodynamic and acoustic effects on rotor noise. The data should be on a consistent basis rather than the ad hoc character of the existing data. Better test facilities, like the new acoustic wind tunnel at NLR in Holland, were called for.

Several of the participants made a plea for big computer programs that include realistic aerodynamic effects such as blade twist, unsteady loading, blade interactions, and transonic aerodynamics. It was once again suggested that the Farrasat method could be used as the basis for the big computer programs.

A final general plea was made for more cooperation between industry and universities. The comment was made that universities should continue the detailed research on individual sources, whereas industry (and perhaps government) should be primarily concerned with developing the big computer programs. It was felt that industry would gain by sponsoring more university research, rather than leave it all to government and private support.

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