tion of the NASA tracking ship "Vanguard" using range measurements through the two satellites ATS-3 and ATS-5. Analysis of the results of these tests is not yet complete.

Both an analog and a digital implementation of the correlation technique were used. The ATS-3 satellite caused pulse modulation of the transmitted tone set due to its axial spin. An analog correlator was used on the ship as the phase detector in phase locked loops which generated continuous replicas of the range tones, in phase with the intermittently received samples. Accuracies of 0.3° were achieved.

The position of the moving ship was determined in real time by the ground control station at Rosman, N.C., using the phases of the returned ranging tones. The digital phase measuring method with four samples per cycle was employed, using a PDP-11 computer for the division and arctangent routines. Initial data show that phase measurement accuracies of 0.5° are being achieved.

References

[1] Laughlin, C. R., Hilton, G., and Lauigne, R., "OPLE Experiment," GSFC X-733-67-266, June 1967, NASA.

SEPTEMBER 1973 J. AIRCRAFT VOL. 10, NO. 9

Aircraft Environmental Problems

V. L. Blumenthal,* J. M. Streckenbach,† and R. B. Tate‡
The Boeing Company, Commercial Airplane Group, Seattle, Wash.

The problems facing industry, the airlines, and local communities in a continuing reduction of noise and atmospheric pollution are discussed. Some of the major obstructions currently hindering progress in these areas are defined. Recent research, including ground and flight tests aimed at solving noise problems, is briefly covered. Illustrations are given to demonstrate the importance of accelerating advances in technology and research facilities development, along with suggestions for research that will promote valid and meaningful problem solutions.

Introduction

THE need for relief from irritating aircraft exhaust emission and noise is clearly recognized and progress is being made on a broad front. For example, all the new high bypass ratio engine exhausts are virtually invisible as a result of advances in engine burner technology. In addition, almost the entire fleet of JT8D-powered aircraft, the 727, 737, and DC-9, has been retrofitted with new burner cans in the last two years, such that visible aircraft smoke from commercial airplanes is rapidly becoming insignificant.

Research into means of reducing the impact of aircraft noise is beginning to pay off. All new high bypass engine aircraft are noticeably quieter than the airplanes of a few years back. In addition, we are pleased to be able to say that quiet nacelles for both the 727 and 737 have been developed and are in production. In fact, in the last year and a half, the airlines have purchased 117 of these JT8D-powered aircraft that meet FAR 36 Appendix C noise levels. Sixteen are scheduled for delivery by the end of 1972.

The FAA, NASA, and the airlines have been actively pursuing noise abatement operating procedures that have greatly improved community noise situations in many localities. Avoidance of noise-sensitive areas where possible, high-altitude overflights, steep approaches and takeoffs, reduced or delayed landing flap settings, and power cutbacks are some of the procedures currently being practiced on a routine basis.

Current Commercial Fleet

In the world today there are over 2840 JT3D and JT8D powered commercial aircraft. Comments are frequently made that these are old aircraft and engines, and should be retired. This is not only completely unrealistic, it is also far from the truth. Both the engines and aircraft have been continuously improved such that those now coming from production lines are generally considered modern in every respect, except for noise and exhaust emissions. Fortunately for the traveling public and those benefiting from shipment by air, the continuous upgrading of these airplanes has resulted in reductions in the costs of air travel and shipping during an extended period of inflation. This ability to keep down costs has been and is of benefit to almost all U.S. citizens, not just to the so-called "jet set."

In addition, the fleet is not really old in terms of accumulated years, even though a few of the airplanes may be approaching retirement age. As seen in Fig. 1, 45% of the JT3D and two-thirds of the JT8D fleets are less than 5 years old. Furthermore, as indicated in Fig. 2, these airplanes are fulfilling an essential role in the air industry. Currently, over three-quarters of the commercial airlines seats are on airplanes powered by JT8D or JT3D engines. There is no way open for these airplanes to be replaced with new aircraft or be retrofitted with new engines in the near future, even if funds were available. The current wide-body jets with new high bypass engines are too large for thin routes that will always be present. No high bypass

Presented as Paper 73-5 at the AIAA 9th Annual Meeting and Technical Display, Washington, D.C., January 8–10, 1973; submitted March 19, 1973; revision received July 9, 1973.

Index categories: Aircraft Noise, Aerodynamics (Including Sonic Boom); Aircraft Noise, Powerplant.

*Director, Noise and Emissions Abatement Programs. Associate Fellow AIAA.

†Senior Group Supervisor, Noise and Emissions Abatement Programs. Associate Fellow AIAA.

‡Senior Group Supervisor, Propulsion/Noise Staff. Member AIAA.

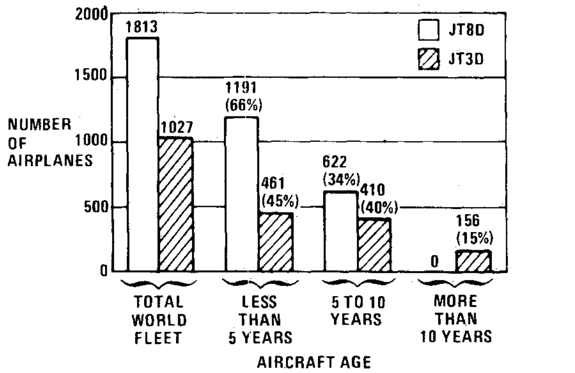

Fig. 1 World airline fanjet fleet (JT3D and JT8D engines) as of September 1972.

replacement engines in the 20,000- to 30,000-lb thrust class are in production or likely to be in production in the near future. This has been and still is a major problem for needed follow-on production of the current family of jets, and is a roadblock in the planning of new-generation aircraft.

Historically, with few exceptions propulsion systems for the commercial fleet have been derived from military engines, where the initial development was funded by the government. Figure 3 shows the genealogies of the JT3D and JT8D engines powering the current low bypass ratio fanjet fleet of commercial airliners. Each has been continually improved and uprated, such that today they are well-proven engines that incorporate significant technical advances over their ancestors. Although these engines are noisier, and probably have higher exhaust emissions than desired, their well-established reputation for reliability deserves careful consideration of means by which they can be quieted. The airplanes they power are not old, yet retrofitting of existing airplanes with a new quiet engine is not economically feasible, even if such an engine were available. Engine replacement costs for the world fleet are estimated to be in excess of $30 billion.

But a new engine for incorporation into production of future aircraft in this fleet category, as well as for a new generation of aircraft, is urgently needed. Such an engine could logically fall into the thrust range shown in Fig. 3. Even with an immediate development go-ahead, it would be some time in the late 1970s before one could be certified for airline use.

Only one engine powering the current U.S.-built fleet, the JT9D, has been developed without a military predecessor or strong government support, and this program has involved serious financial strain. Although a major problem exists because there is no quiet high bypass engine available in the 20,000- to 30,000-lb thrust class, and a very obvious need exists, it appears highly unlikely that industry can be induced to proceed on such a development without government help. It would be unfortunate if we were to permit a foreign country to preempt this market.

Noise Technology

The technical tools used to produce today's efficient, safe, and reliable air transportation system were not developed over night. If this were possible we need not have passed through those stages of slow flight in unpressurized cabins, exposed to illnesses from turbulent air, often grounded unreliable service, and the many other trials that confronted the air traveler and the operator not many years ago. Throughout the last 50 years, such concentrated attention has been applied to the technologies of aerodynamics, structures, propulsion, and flight controls, to name a few, that some universities and colleges have become famous through their expertise in these technical areas. Endowments, such as those made by the Guggenheims, have resulted in major private and state facilities devoted entirely to the study and advancement of flight. The U.S. Government established a National Advisory Committee for Aeronautics with substantial budgets to further those technologies, to train those specialists, and to develop those laboratories associated with flight as a means of transportation, and to a greater or lesser extent, this knowledge-producing process has been paralleled throughout the world. The point is that a very broad library of information and problem-solving capacity has been accumulated over the years in those technologies pertaining to the building and operating of aircraft through the widespread efforts and expenditures of money by a great many people, organizations, industries, and governments. Unfortunately, very little has been put into the library on how to make aircraft quiet. We would cite as a major problem, the lack of a national resolve, purpose, or conscience to move forward rapidly in developing a firm technical basis for making noise-oriented decisions. The current void in acoustics technology cannot be filled over night any more than the other aircraft-related technologies could have been. However, the present rate of advancement is too slow to meet the needs of today.

Design and Test Techniques

In the area of design and test techniques one of the most frustrating aspects of current aircraft noise reduction efforts is the recurring need to prove out solutions through full-scale tests. These are not only costly but consume valuable time and limit the scope of investigations necessary to develop appropriate solutions. Boeing alone has spent company funds totaling more than $60 million over the past 15 years, in developing noise reduction improvements for commercial airliners. This has been supplemented with over $30 million in government funding. Yet the progress made to date, though considerable by some standards, is recognized as having been accomplished in

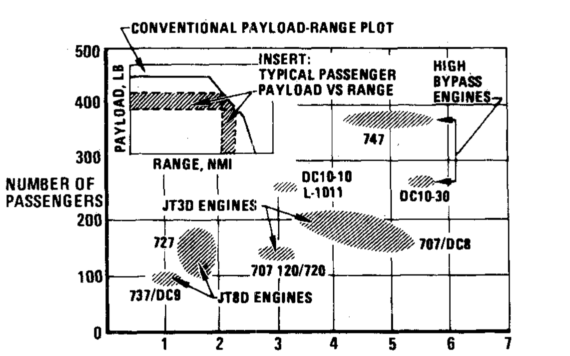

Fig. 2 Payload-range comparison of the current world fleet.

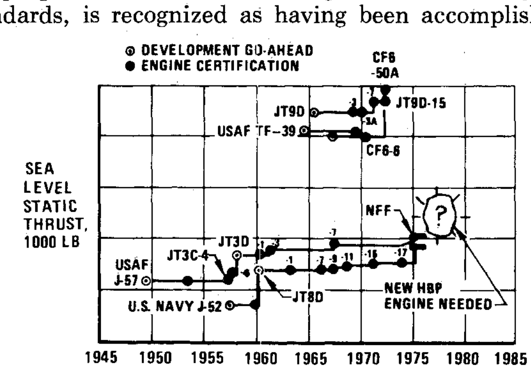

Fig. 3 Engine development genealogy.

an environment of technical uncertainties and has generally resulted in less than optimum solutions.

Much of the research and results from the above expenditures and activities is summarized in earlier papers presented before U.S. Senate and House committees and the Environmental Protection Agency.[1] An urgent need was emphasized for advancing the state of the art in acoustic technology, and it was clearly demonstrated that current progress has been the result of cut-and-try research with many more failures than successes.

During development and improvement of the early 707 and DC-8 turbojet-powered airplanes, jet roar was the predominating noise to which people objected. Although we didn't at that time, and still don't, fully understand the mechanisms of jet noise, an empirical approach resulted in multitube nozzles that offered moderate quieting of those airplanes.

Turbofan engines that followed the pure jets reduced jet roar somewhat, but contained other noise sources, mainly rotating machinery noise produced by the fan.

Tests on the 727 airplane showed that noise reduction was dependent on lowering both jet noise roar and the higher frequency rotating machinery noise. A program was started to find more effective means of noise suppression. The first immediate step was to reduce both the 727 and 737 rotating machinery noise levels as far as possible with sound-absorbent linings without waiting for a solution to the jet noise problem. As soon as configurations were developed that could meet Federal Air Regulation Part 36, Appendix C noise levels, airlines insisted on new purchases having this capability. As a result, virtually all 727s delivered beyond the end of this year will comply with government noise regulations that were originally established for the later high bypass fleet, and 737s are rapidly following.

Because of the lack of knowledge of jet noise mechanisms, many experimental model-scale and full-scale jet noise suppressors were designed, built, and tested. In general, the configurations investigated proved less than satisfactory although some offered enough potential to carry into flight test in addition to ground test. Some problems were identified by these early 727 programs:

Most concepts offered minimal jet noise reduction, and caused unacceptable airplane and engine performance losses.

Some configurations, although effecting some reduction of jet noise, could not be physically installed on the airplane.

It was found that the total range of engine power settings had to be considered, with simultaneous, but different, treatment of several noise sources required.

Extrapolation of results from one test configuration to another concept could not be done with any degree of confidence.

The need for further development of acoustic lining concepts to effectively reduce jet and fan noise was recognized.

The costly, time-consuming effort experienced in the full-scale testing was supplemented with small-scale models for initial screening of suppression concepts. However, these techniques uncovered more problems:

The validity of the scaling principles was limited by the lack of knowledge concerning jet noise theory.

Model sizes were limited by lack of suitable compressed air facilities. In available facilities, it was difficult to scale actual velocity and temperature gradients and boundary layer conditions.

It was difficult, if not impossible, to simultaneously scale turbomachinery and jet noise sources in the models. In fact, we still do not fully understand how to duplicate full-scale turbomachinery noise in small-scale models.

Scaling of sound absorption characteristics of acoustic lining materials is crude in the present state of the art. Final tuning can only be done full scale.

In some cases it was learned that the test facility generated noise sources of its own that masked the true simulated noise sources.

Finally, weather and local reflections associated with the test facility had to be understood before meaningful test results could be interpreted.

During the early model- and full-scale testing of jet noise suppressors[1] a 48-lobe nozzle surrounded by an acoustically lined ejector shroud was found to offer promise of jet noise reduction without excessive degradation of performance. Investigations to fit this concept to the specific requirements of the JT8D engine resulted in development and fabrication of a 36-lobe suppressor nozzle and a lined ejector shroud. Because the dominant noise sources of the 727 installation included both fan and jet components, the ejector-suppressor was supplemented with an acoustically treated, ringed inlet to suppress the forward-radiated fan noise. The objective was a balanced design that would work equally well in reducing jet-dominated takeoff noise and fan-dominated approach noise. Full-scale ground tests of this configuration were encouraging and indicated 727 noise reductions of 5, 10, and 8 EPNdB in the cutback, approach, and sideline conditions were attainable. Although these initial "boilerplate" ground tests indicated undesirable range losses for the airplane, it was believed that the weight and drag penalties and engine losses associated with the range loss could be minimized with further development.

On July 1, 1971 the FAA entered into a contract with Boeing to refine the ejector suppressor concept. The primary objective was to provide significant noise reduction along with reasonable performance capabilities.

Because of the time and cost involved in full-scale investigations, small-scale models were again developed for parametric screening of variables that would point toward an optimized configuration, even though it was recognized that it would be difficult to extrapolate scale model data to full-scale values.

The first scale models built and tested in support of this program were 60° half-scale segments of suppressor nozzle and shroud assemblies. The objective was to improve on the suppression/propulsion performance by detailed study of lobe geometry effects, and to develop lining technology. The logic behind this model concept involved considerations of cost, scaling laws, and facility airflow capacity. Because we do not have adequate knowledge of scaling acoustic lining characteristics, it was desirable to keep the model size as near full scale as possible. But even with half-scale models, the airflow capacity of the test facility would permit only a 60° segment of each configuration. The data acquired in these tests failed to correlate to an acceptable degree with full-scale testing of similar configurations.

Concurrently, a series of ⅕-scale test models of complete nozzles and ejectors was built to evaluate various ejector shroud configurations, secondary air inlet designs, internal plug designs, and nozzle geometries to optimize both 36-lobe and 20-lobe nozzle configurations, the size again being dictated by facility airflow capacity. Models of 20-lobe and 36-lobe designs with various ejector geometries were tested after analytical studies had indicated that a 20-lobe system should provide comparable noise reduction, as compared with the earlier 36-lobe concept (although there were conflicting theories about this), and with lower airplane performance penalties. Figures 4 and 5 are photographs of a one-fifth-scale model of a 20-lobe nozzle with and without the lined ejector shroud.

Initial testing revealed the presence of facility noise sources that clouded the comparison of the 20- vs 36-lobe designs, making a design decision infeasible. Facility

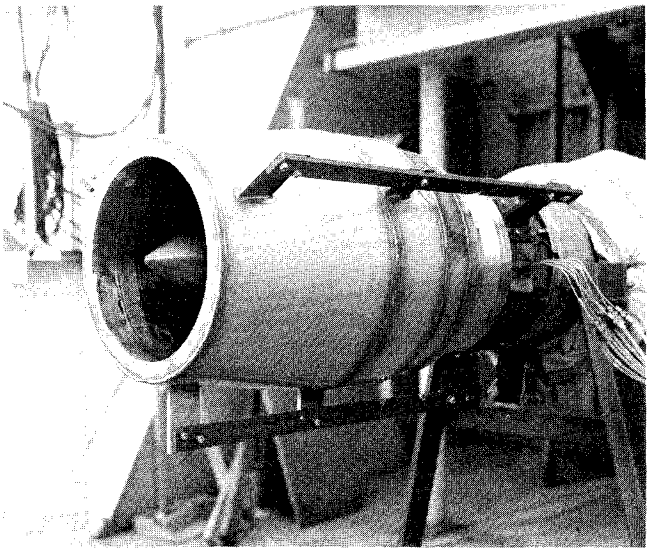

Fig. 4 ⅕ scale model 20-lobe nozzle with lined ejector.

modifications to reduce the noise contributions of such sources as burner, pressure reduction values, line connections, and facility walls, were incorporated. Figure 6 is a typical illustration of data taken before and after these modifications. Figures 7 and 8 are typical data plots of the 20- and 36-lobe model tests (at takeoff and cutback power) that followed the initial corrective action on the facility. Both plots indicate superior noise suppression performance for the 20-lobe design. Although these tests provided the basis for a decision to use a 20-lobe design in the subsequent full-scale ground test hardware, the model test data still contained facility noise that would preclude accurate projection to full-scale estimates over the complete range of power settings. The 20-lobe configuration was selected because the model jet noise suppression was superior to the 36-lobe concept, and the performance penalties were lower. When the 20-lobe design showed improved jet noise suppression over the 36-lobe, the question arose about the merits of a 16-lobe nozzle. However, because of the lack of suppression theory, we could not be assured that fewer lobes would be better.

The program proceeded with design and fabrication of a full-scale ground test configuration of a 20-lobe suppressor enclosed in an acoustically lined ejector shroud to determine the combined effectiveness of the ejector-suppressor and inlet treatment on jet, fan, and core noise, and verify the lining design. Ground testing on a JT8D engine was completed at our Boardman, Oregon facility in August

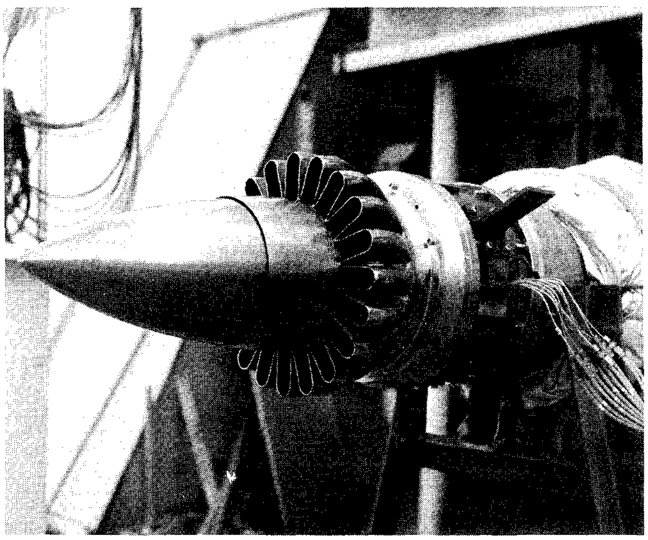

Fig. 5 ⅕ scale model 20-lobe nozzle without ejector.

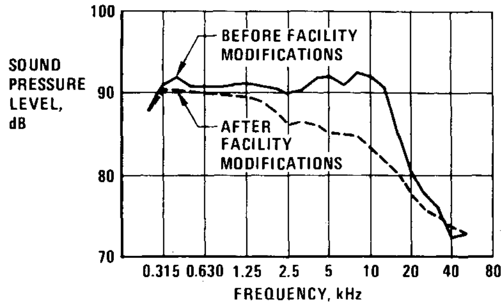

Fig. 6 Influence of facility modifications on ⅕ scale conical nozzle test results.

1972. Figures 9 and 10 are views of the test installation with and without the ejector shroud installed. As summarized in Fig. 11, the full-scale test results confirmed the model-scale tests in that the 20-lobe unit provided greater noise suppression than the earlier 36-lobe unit.

Jet suppression model test techniques do not account for engine fan or core noise generated upstream of the nozzle. These internal engine noises are dominant at lower power settings on actual engines. Figures 12 and 13, showing takeoff and approach power data, identify turbomachinery noise in the full-scale data at frequencies above about 3000 Hz. Also, at both power levels, test facility burner noise still existed at frequencies below about 200 Hz even after modification of the facility discussed earlier. Finally, in the midfrequency range from about 200 to 1500 Hz, the noise level for the full-scale ejector-suppressor at approach power was considerably higher than the model-scale data predicted. This again illustrates that we are not yet able to accurately predict full-scale results using small models.

Another problem exists in predicting flight test results on the basis of full-scale ground test data. Early analysis showed that actual flight noise reductions associated with the ejector-suppressor concept might be different from the static test results. Some of the reasons follow.

Different noise sources (e.g., fan noise and jet noise) will change levels relative to one another when going from a static test condition to flight conditions. Simultaneous simulation of in-flight relative jet velocity and fan speed is not possible with a static test rig.

The effects of airplane forward speed on the levels and directivities of engine noises and the strength and location of various jet noise sources need to be better understood. Current techniques for evaluating the jet noise suppression effectiveness of a suppressor nozzle employ "relative

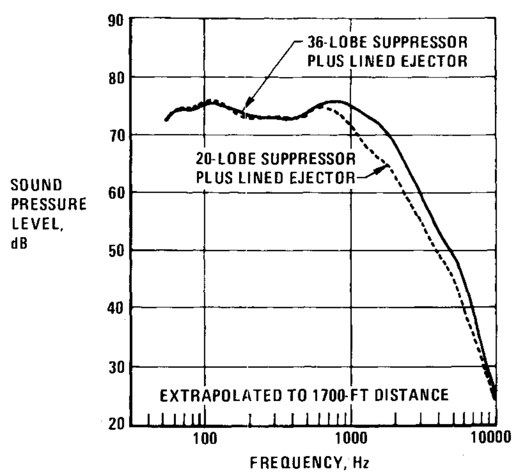

Fig. 7 Spectral comparison, 36-lobe and 20-lobe ejector-suppressor models (⅕ scale), takeoff power.

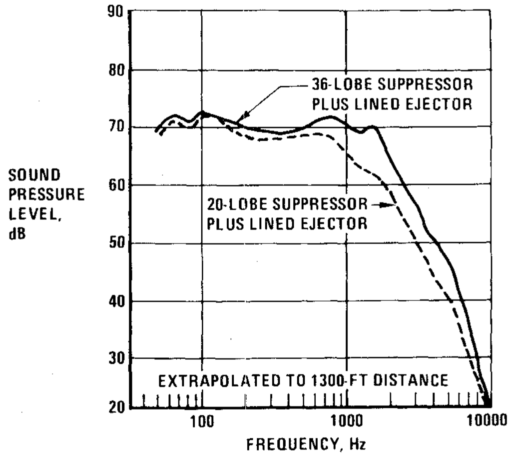

Fig. 8 Spectral comparison, 36-lobe and 20-lobe ejector-suppressor models (1/5 scale), cutback power.

velocity" as the primary ground-to-flight correlating parameter. During static ground test, jet suppression characteristics are determined by operating the conical and suppressor nozzles at essentially equal ideal jet relative velocities. This technique presumes that the jet noise of the conical and suppressor nozzles is reduced due to airplane velocity in the same basic manner. Available ground-to-flight data correlations for *conical* nozzles indicate that relative velocity is a reasonably valid parameter for in-flight jet noise prediction. However, analysis and limited experimental data indicated that the jet noise of the ejector-suppressor concept might respond to airplane velocity in a different manner than the conical, and that peak jet noise might be reduced only slightly. If this were true, then ejector-suppressors, operating in the jet velocity regime of the JT8D, would be hard-pressed to provide the hoped-for in-flight suppression, as illustrated in Fig. 14.

An attempt was made to include the relative shifts of different noise source levels when going from ground to flight estimates. It was assumed that the statically generated fan noise was the same as the in-flight fan noise if fan rpm was the same. Jet noise was assumed to be jet velocity minus airplane velocity for noise generated aft of an ejector shroud or conical nozzle, and suppressor lobe exit velocity minus shroud secondary air velocity for noise generated within an ejector shroud.

Estimates using the above procedures resulted in projected flight attenuation values 1 to 3 EPNdB (effective

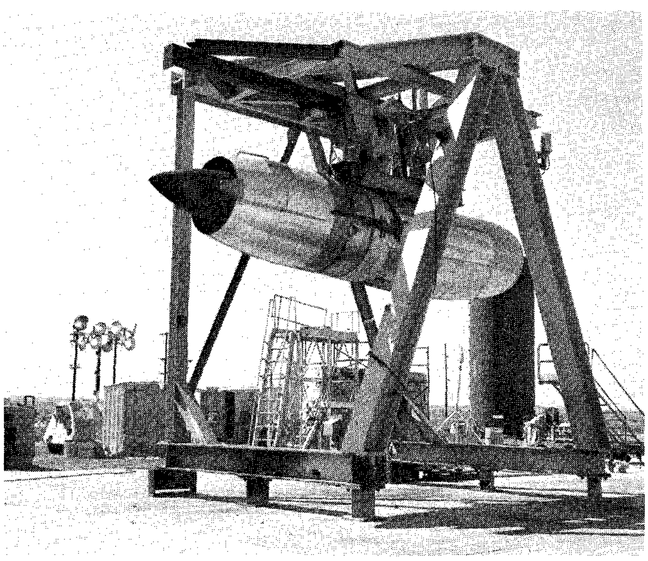

Fig. 9 Full-scale 20-lobe ejector-suppressor ground test setup.

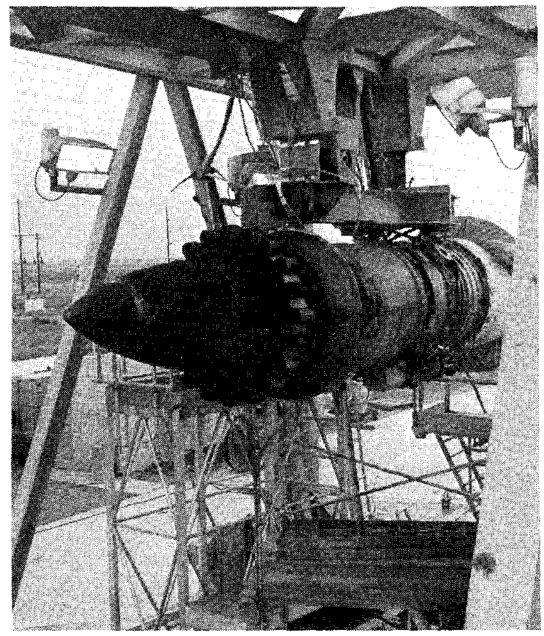

Fig. 10 Full-scale 20-lobe suppressor ground test setup without ejector shroud installed.

perceived noise decibels) below direct static test evaluations. These estimates indicated possible differences between static test and flight test measurements, but did not include all factors contributing to such differences. The technique used was unproven. The impact of the treated nacelle thrust loss on airplane noise suppression could only be estimated. The effects of the physical presence of the airplane itself, i.e., wing wake and shielding, were not fully understood. Finally, deficiencies in acoustic ground reflection interference characteristics can influence EPNL. It was not possible to account for all these effects, so that even with a static test data base, a flight test was required to determine the noise suppression potential of the configuration.

Flight testing of the 20-lobe ejector-suppressor was completed in October 1972. The data from these tests will be in the FAA summary report.[2] Figures 15 and 16 are photographs of the flight test installation on a 727 airplane. Preliminary test results show that a significant noise reduction was measured, as indicated in Fig. 17 for takeoff power. Data scatter between test runs was attributed to weather and ground reflection anomalies and small variations in thrust setting and altitude. Repeat runs were necessary to provide sufficient data for statistical analysis. Comparisons of flight test measurements with predictions based on static test data indicated that considerable progress was made in prediction capability. However, it was

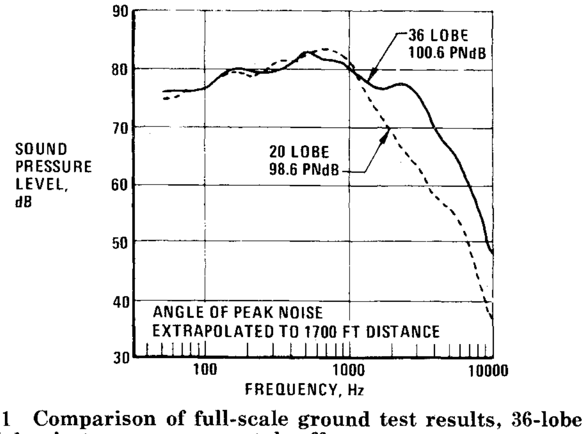

Fig. 11 Comparison of full-scale ground test results, 36-lobe vs 20-lobe ejector-suppressors, takeoff power.

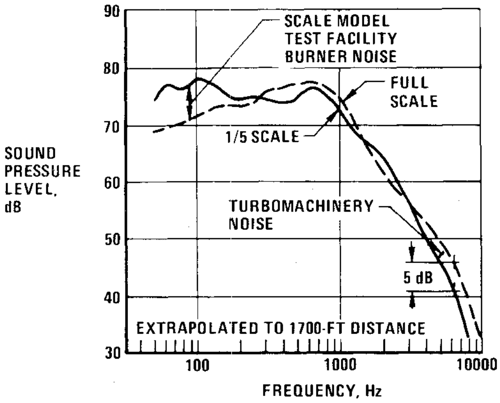

Fig. 12 Model vs full-scale comparison, 20-lobe ejector-suppressor ground test, takeoff power.

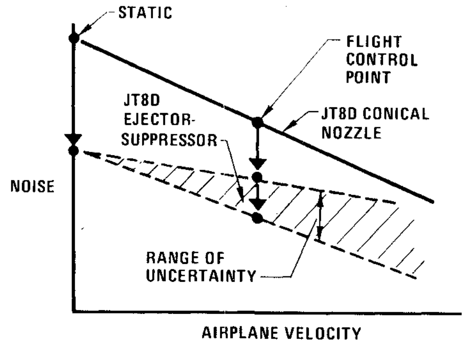

Fig. 14 Airplane velocity effect on jet noise suppression.

also clear that further refinement of static-test-to-flight prediction procedures is needed, and that in the meantime, it is still necessary to build full-scale hardware, and in most cases to resort to flight testing when it comes to making major decisions. Furthermore, we have been able to accomplish only about one full-scale cycle per year in our R&D activities (Table 1). This is time and dollar consuming.

Aerodynamic Noise

Advances have been made in the technologies of quieter engine design and the acoustic treatment of engine installations to attenuate engine-generated noise. Considerable payoff is expected on future aircraft/engine combinations designed from the beginning for very low noise. This has encouraged predictions that noise at the standard FAR 36 noise measuring points can be reduced 10 dB, or more, per decade starting immediately.[3] However, recent studies and flight tests of large commercial airplanes strongly indicate that we now face an airframe noise constraint for at least the approach condition, below which additional noise reduction would be difficult even if the airplane had no engines.

Thus, a new consideration or problem appears to be emerging for future aircraft designers, with little information currently available that points toward a solution. The complexities of the task can be appreciated by realizing that many of the advanced technology high lift devices, and other configuration innovations that have done so much to improve airplane performance, may also be noise-generating devices that contribute to aerodynamic or aerophysical noise. Very recent 747 and 727 flight tests identify airframe noise levels for these aircraft approximately 8 EPNdB below the current FAR 36 standards. Data are shown on Fig. 18. Airplane noise level asymptotically approaches a limit as engine noise is reduced, as shown in Fig. 19. The asymptote itself represents the airplane noise level without engines. These same tests indicated that flaps and landing gear can contribute as much as 10 to 12 EPNdB to total approach noise. They also showed EPNdB varying as approximately the fourth power of velocity, whereas Lockheed[4] showed a sixth power of velocity relationship for PNdB. Certainly many questions need to be answered. How much noise would various aircraft make if their engines could be shut down? How far are these levels below attainable levels with engines operating? Can noise be reduced through speed reduction without, at the same time, increasing flap noise? Should landing gear be enclosed in pants? How effective are aspect ratio or wing loading changes? These and many other questions need evaluation to determine what ultimate noise levels can be attained. One message is clear. We must avoid writing rules, generating laws, or making promises that may be technically unattainable.

Annoyance

The aircraft industry seriously needs a reliable measure of noise acceptability to use in the initial planning and design of aircraft and engines. How quiet must future aircraft be to satisfy community demands several years after the design is frozen? We can determine what range, payload, and other mission characteristics an airplane must have by accepted analytical techniques and by discussions with potential customers. But how can an airplane be practically designed to ensure that it will have acceptable noise characteristics? The broad variation of the effects of noise on people and the insufficient psychoacoustic research to define human responses to noise have prevented

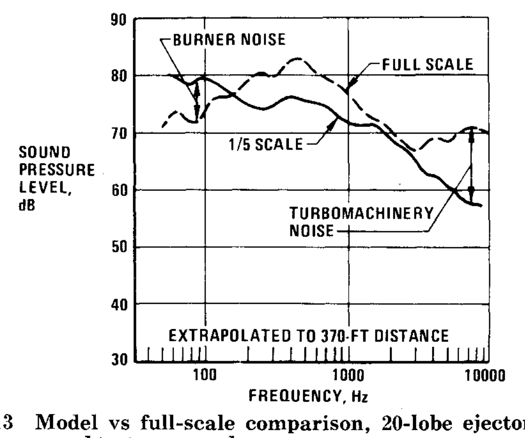

Fig. 13 Model vs full-scale comparison, 20-lobe ejector-suppressor ground test, approach power.

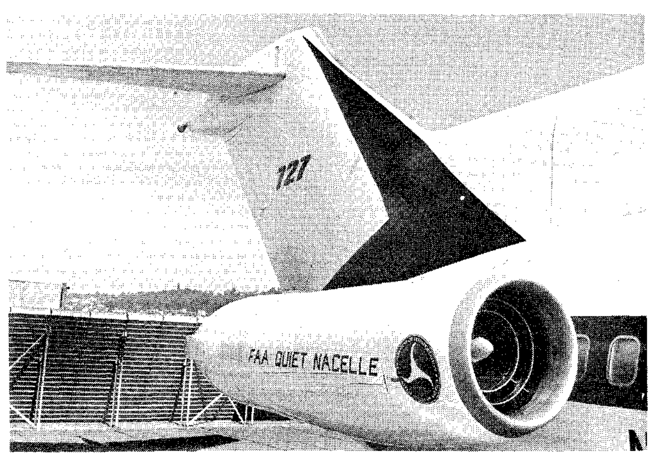

Fig. 15 Flight test installation, 20-lobe ejector-suppressor, front view.

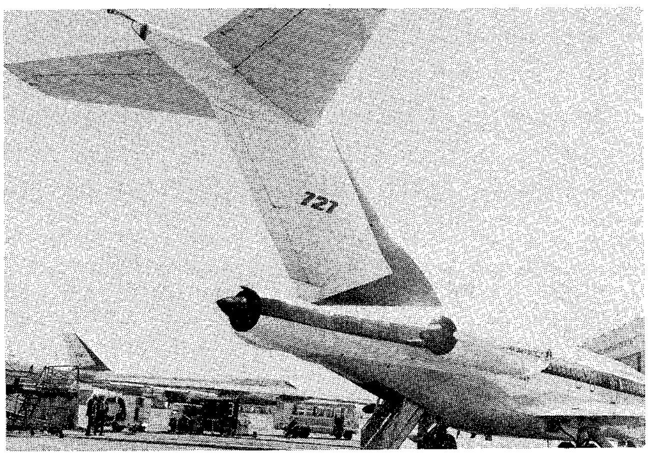

Fig. 16 Flight test installation, 20-lobe ejector-suppressor, rear view.

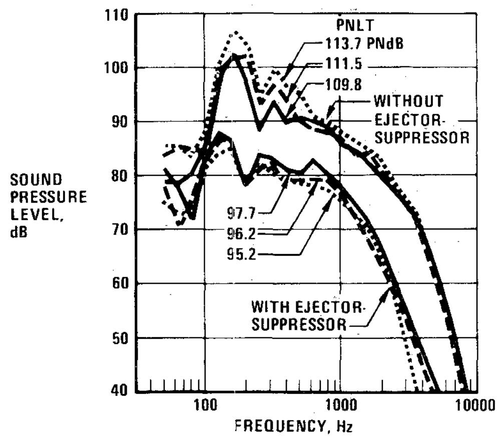

Fig. 17 Comparison of 727 flight test data with and without 20-lobe ejector-suppressor, three typical flights each at takeoff power.

the production of analytical techniques that can be used with confidence. Noise acceptability information should be on hand at the outset as a prime design parameter for airplanes of the future.

Operating Procedures

The FAA, NASA, the airlines, and the manufacturers have been implementing noise abatement operating procedures that have contributed to measurably improved community noise situations in many localities. Current FAA/ATA procedures being adopted by the airlines, although not necessarily fully exploiting the possibilities available, can be performed with few, if any, changes in on-board equipment or instrumentation. By the addition of certain automated control features, flight director modification, path computations, and ground equipment, further noise reductions can be attained. Toward this end, NASA Ames is pursuing the functional implementation of the two-segment approach concept for noise abatement.

In developing a noise abatement concept, a major need is to establish the criteria for performance and safety standards. This effort is difficult and costly. Considerable analysis and design-proving must be accomplished before end-product practicality is proven. Statistical examinations must be made of: winds—cross, shear, turbulence, equipment tolerances, failure modes, crew action, recovery, monitoring, flight margins to overspeed, stalls, path deviations, and redundancy levels, isolation.

Systems limitations as well as system performance must be demonstrated by flight test. Unless such a course is followed in evaluating noise concepts, it could be misleading to arrive at conclusions regarding system cost, complexity, noise benefits, or other pertinent factors required to judge acceptability in an airline environment. Unfortunately, there is no known short cut. In general, it can be stated that the systems and operations shall: maintain current safety standards, cause no significant increase in pilot workload, be compatible with IFR and VFR operations, and be economically acceptable.

In future procedures development, improved communications between manufacturers, airline managements, government agencies, and line pilots, is an important factor. In addition, current and future noise control legislation must formally recognize noise abatement procedures and encourage their use.

As in other areas of noise reduction, funding must be made available to supplement limited industry resources in order to permit full potential benefits of operational noise reduction procedures.

Table 1 JT8D Engine exhaust noise suppression development, expenditures in millions of dollars

Year	Program	Boeing funded	Government funded
1969	48-lobe ejector-suppressor, model and full-scale testing	0.500	...
1970–71	36-lobe ejector-suppressor, model and full-scale testing	2.590	...
1971	20-lobe ejector-suppressor, model and full-scale design	0.220	0.880
1972	20-lobe ejector-suppressor, full-scale ground and flight test	0.750	3.000

Exhaust Emissions

At the time of this writing, the Federal Government is considering the publication of regulations limiting aircraft engine exhaust emission of certain pollutants. The effect of such emissions on the entire atmosphere and global climate is being studied within the Department of Transportation's Climatic Impact Assessment Program (CIAP) whose objective is to make an over-all assessment by the end of 1974. Although we have studied this subject extensively and can find no present cause for alarm, we are following the progress of the CIAP with interest. We do not believe we should attempt at this time to prejudge its final assessment, and therefore will confine our remarks to the more real and immediate effect of aircraft engine

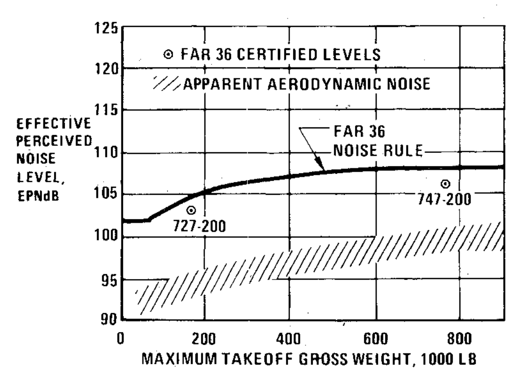

Fig. 18 Preliminary flight test results, aerodynamic noise (approach, 1.0 naut mile).

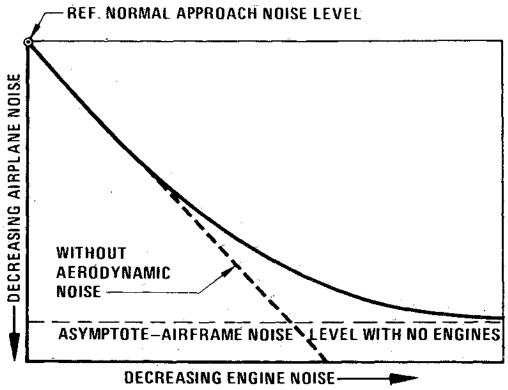

Fig. 19 Airplane approach noise vs engine noise.

emissions on local airport and surrounding community air pollution.

In April 1971, the Environmental Protection Agency (EPA) published the National Ambient Air Quality Standards (NAAQS). These standards cover six common air pollutants: oxides of sulphur, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen dioxide. They specify the levels of these pollutants below which the public health and welfare would not be endangered.

Examination of the sources and concentrations of air pollution has shown that in the urban environment the aircraft engine contributes generally less than 1% of the total man-made levels. However, in the immediate vicinity of the airport the percentage contribution of aircraft engines increases. Furthermore, as the contribution of the automobile decreases, the aircraft percentage will go up. The question is, is there a problem and must something be done?

First, the magnitude of any potential problem must be determined, both as it exists today and as it will exist in the future. The magnitude, of course, is defined by the extent to which the established ambient air standards are or will be exceeded. This extent can be determined only through actual measurements and validated airport modeling.

In concluding this subject, we express the hope that aircraft engine emission standards will be related realistically to the attainment of the ambient air quality standards through actual airport measurements and validated airport modeling, and that requirements, whether operational or technological, will be evaluated on the basis of the relationship between the over-all cost of the improvement and the degree of improvement relative to the standard—in other words, cost effectiveness.

Federal, International, and Local Legislation

In operating a worldwide commercial airline system, the airlines and aircraft industry currently face problems of legislative proliferation in noise and pollution control at all levels of government. While federal governments are pushing through laws in the several countries served by international carriers, pressure from the public is forcing action at local government levels. Many U.S. and overseas cities are enacting curfew laws, while state, county, and city governments are drafting laws governing noise and pollution limits of aircraft operating in their individual jurisdictions. When it is realized that these many autonomous jurisdictions are establishing rules that vary from each other, and from federal rule-making action, it can be appreciated that the aircraft industry and the world's airlines are faced with a momentous problem in planning future products and in operating these products on the world's airways of the future. Considering that it takes several years from inception to certification of a new commercial airliner, some means must be found to change random legislative action to unified, feasible, and coordinated worldwide noise control legislation. Current uncertainties as to the ultimate criteria for noise and pollution reductions make long-range planning of future products difficult and risky.

Airlines operating across local and national jurisdictions are currently provided with reasonably standard operating procedures governing such areas as air traffic control, airplane performance, and safety, all of which have been cooperatively established at national and international government levels. It is inconceivable that noise and pollution legislation should be any less well organized on an international and uniform basis. One of the keys to such unified agreements between governments is a well-established measure of goodness, acceptable to all authorities. Much progress must be made to arrive at this necessary state of affairs.

Land Usage

A large part of the potential solution to the aircraft community noise and pollution problems is in the area of land usage around many of the world's airports. This is also an area in which little organized action is being accomplished at this time. Several roadblocks stand in the way of improving this situation. First, in the case of existing airports, little control has been exercised in granting nearby building permits. The conflicting interests of land developers and local governments have too often resulted in decisions in favor of the developer. Many major airports, as a consequence, are now surrounded by noise-sensitive installations such as dwellings, schools, and businesses. Lawsuits for damages are rampant, in some cities totaling billions of dollars in suits pending action by the courts. The only immediate relief for these situations appears to be in acquisition of noise-sensitive properties, and replanning of the purchased land for non-noise-sensitive use. One of the problems that immediately arises in such acquisition is, of course, money. From a long-term viewpoint the cost of acquisition might be expected to be balanced by income from the property from the new users. But how to handle the financial problems is complicated by the inability of local governments to raise the initial capital to get the ball rolling. A further complication arises in the form of conflict between the multiple and varying responsibilities and ordinances of state, county, and city jurisdictions. Such variations preclude unilateral action by any one agency, especially in cases where the airport community crosses jurisdictions. Something needs to be done to ease the process of unified, single-purpose action in solving land-use problems around existing airports. Continual resort to the law courts is simply not the answer.

Summary

The aircraft industry, the airlines, and federal and local governmental agencies face many problems in continuing to minimize the effect of aircraft noise and exhaust emissions on the environment. The present costly and time-consuming procedures for making progress demands the early development of significant advances in technology, and in the associated design and operation of quieter, cleaner engines and aircraft.

To highlight the technical side of the story, we would like to re-emphasize some key thoughts relative to the more serious problems that need urgent attention.

Trained personnel are in very short supply to support the increasing attention being given to all areas of noise reduction, aircraft noise being but a small portion of the whole. It is necessary to recognize applied acoustic engineering as a major technical discipline, and to establish adequate educational curricula and associated research facilities to produce qualified personnel in this field.

Acoustics research laboratory facilities are few and far between. The past development of sophisticated aerodynamic facilities by government, industry, and educational institutions is an example of the road we must follow promptly if we are to develop the broad information bank necessary for effective and efficient design of noise reduction concepts.

The field of acoustics research is wide open to improving understanding of the mechanics of noise, and to determining means of defining full-scale flight hardware from scale-model testing. The specific examples covered in this paper demonstrate quite clearly that we have a long way to go in attaining this capability.

There is a critical need for a new high bypass turbofan engine in the 20,000- to 30,000-lb thrust class, for use both in the continued production of current aircraft, and for designing advanced technology aircraft of the future. The noise reduction benefits and performance improvements of such an engine are well recognized. But it is unlikely that industry can proceed on development of such a commercial engine without government help such as existed in past derivation of commercial engines from military predecessors.

The existence of airframe noise in the absence of engine noise must be given increased attention in establishing attainable noise levels for current and future aircraft. It has become apparent that a limit exists, beyond which quieting the engine installation will be ineffective unless progress is made toward cleaner aerodynamic design and/or cleaner operation of the aircraft.

The aircraft industry needs a reliable measure of noise acceptability for use in the initial planning and design of aircraft and engines. The very subjective nature of noise precludes basing design on the pure physics of noise alone. Yet introducing a new airplane into airline service requires major financial commitments by the manufacturer several years before airplane certification. One of the most important design parameters in future aircraft is its community noise acceptability when it enters service. The high economic penalties resulting from "overkill" in designing to unknown requirements are not tolerable.

The already-demonstrated community noise benefits associated with noise abatement operating procedures must be exploited further, through development of ground and airborne equipment that will provide even greater benefits, within the limits of safety and economic constraints. Such techniques must be included as an important segment of the over-all problem, and used in conjunction with other noise reduction efforts.

Effort must be directed toward establishing aircraft engine emission standards that will form a basis for realistic and cost-effective design of future propulsion systems. It is important that such standards be derived through actual airport measurements and modeling, rather than the arbitrary legislation of unrealistic standards that are technically and economically out of balance with the total environmental picture.

In conclusion, we hope that this paper will serve its intended objective of defining important areas of research that need urgent attention and adequate funding to ensure a continued improvement in the environment within reasonable economic constraints.

References

[1]Blumenthal, V. L., Russell, R. E., Streckenbach, J. M., "Summary, Noise Reduction Research and Development," *Hearings Before the Subcommittee on Aeronautics and Space Technology of the Committee on Science and Astronautics*, No. 17, U.S. House of Representatives, Ninety-Second Congress, Second Session, Jan. 18–20, 1972.

[2]"727 Noise Retrofit Feasibility—Volume III, Upper Goal Flight Testing and General Summary," Rept. FAA-RD-72-40, III, Dec. 1972, Federal Aviation Administration, Washington, D.C.

[3]*Civil Aviation Research and Development Policy Study Report*, CARD Study, DOT TSP-10-4, NASA SP-265, March 1971.

[4]Gibson, J. S., "The Ultimate Noise Barrier—Far Field Radiated Aerodynamic Noise," *Proceedings of the International Conference on Noise Control Engineering*, Institute of Noise Control Engineering and the Acoustical Society of America, Washington, D.C., Oct. 4–6, 1972, pp. 332–337.