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PROJECT REPORT

NOISE STANDARDS
FOR
CIVIL SUBSONIC TURBOJET ENGINE-POWERED AIRPLANES
(RETROFIT/FLEET NOISE LEVEL)

14 November 1974

SUMMARY

The FAA has been concerned with the noise levels of turbojet (axial flow jet and axial flow fan) powered airplanes that do not comply with FAR 36 since its promulgation in 1969. Two ANPRMs and one NPRM related to retrofitting operational airplanes to meet the noise levels specified in FAR 36 have been published for public comment. This report examines these three proposed actions in detail and recommends two regulations based upon their best features.

The first regulation would be a straight retrofit rule which would be effective in fully exploiting current and available noise control technology. The second regulation would be a Fleet Noise Level (FNL) rule which would supplement the first rule and which would be an effective medium for exploiting near and far future technology.

The Analysis Section discusses technology options for source noise control including Quiet Nacelles, Refan, and miscellaneous other methods applicable now and in the future to all civil subsonic turbojet engine-powered airplanes. Included in the Analysis are estimates of the noise levels and the unit and investment costs for the various retrofit options available to the large transport airplanes and to the smaller business jet airplanes as well. Also included in the Analysis, are discussions of the concepts of Fleet Noise Level (FNL), Day-Night Level (Ldn), and Noise Exposure Forecast (NEF) with numerical examples, which illustrate the pertinent relationships.

The Health, Welfare and Economic Considerations Section discusses the costs of achieving various cumulative noise levels beginning with

the investment costs developed previously. Six retrofit options are chosen for study and their cost-effectiveness determined, including the costs of protecting people within specified Day-Night Level (Ldn) noise exposure areas. Compatible land use costs are determined including the costs for sound insulation of buildings, relocation of people, and land development. Cost allocation and financing methods are discussed and a number of retrofit financing alternatives are presented.

The Appendixes contain sample regulations and detailed discussions of the methodologies for FNL and Ldn/NEF.

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1. INTRODUCTION AND REQUIREMENTS

Public Law 90-411 amended the Federal Aviation Act of 1958 to require that, in order to afford present and future relief and protection to the public from unnecessary aircraft noise and sonic boom, the Federal Aviation Administration (FAA) shall prescribe and amend such regulations as the FAA may find necessary to provide for the control and abatement of aircraft noise and sonic boom. In addition, PL 90-411 provided detailed specifications that must be considered by the FAA in prescribing and amending aircraft noise and sonic boom regulations.

The Noise Control Act of 1972 (Public Law 92-574) supersedes Public Law 90-411 and amends the Federal Aviation Act of 1958 to include the concept of "health and welfare" and to define the responsibilities of and interrelationships between the FAA and the Environmental Protection Agency (EPA) in the control and abatement of aircraft noise and sonic boom. Specifically, the Noise Control Act requires that, in order to afford present and future relief and protection to the public health and welfare from aircraft noise and sonic boom, the FAA, after consultation with EPA, shall prescribe and amend such regulations as the FAA may find necessary to provide for the control and abatement of aircraft noise and sonic boom.

The Noise Control Act also requires that EPA shall submit to the FAA proposed regulations to provide such control and abatement of aircraft noise and sonic boom (including control and abatement through the exercise of any of the FAA's regulatory authority over air commerce or transportation or over aircraft or airport operations) as EPA determines is necessary to protect the public health and welfare. The regulations proposed by EPA shall be based upon, but not submitted before completion of, a comprehensive study to be undertaken by the EPA and reported to Congress.

The Aircraft/Airport Noise Study, which has been completed, was required to investigate the:

(1) adequacy of Federal Aviation Administration flight and operational noise controls;

(2) adequacy of noise emission standards on new and existing aircraft, together with recommendations on the retrofitting and phaseout of existing aircraft;

(3) implications of identifying and achieving levels of cumulative noise exposure around airports; and

(4) additional measures available to airport operators and local governments to control aircraft noise.

The study was implemented by a task force composed of six task groups whose product consisted of a report to Congress and six volumes of supporting data (one volume for each task group). The reports are identified as References 1 through 7.

Concurrent with the Aircraft/Airport Noise Study, the EPA prepared a general document of criteria, Reference 8, in conformance with Section 5(a)(1) of the Noise Control Act. This "Criteria Document" reflects the scientific knowledge most useful in indicating the kind and extent of all identifiable effects on the public health and welfare which may be expected from differing quantities of noise.

In addition, as required by Section 5(a)(2) of the Noise Control Act, the EPA has prepared a document on the levels of environmental noise, the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety. This "Levels Document" is identified as Reference 9.

As a result of the Aircraft/Airport Noise Study, EPA determined that an effective program to protect the public health and welfare with respect to aircraft noise would require the development and proposal to the FAA of three complementary types of regulations:

(1) Noise abatement flight procedures,

(2) Noise source emission regulations (type certification) affecting the design of new aircraft and requiring the modification or phaseout of certain portions of the existing fleet, and

(3) An airport noise regulation, which would limit the cumulative exposure received by noise-sensitive land areas in communities surrounding airports. Such a regulation, by acting as a performance standard for the airport as a complex source, would require achievement of mutually compatible airport operational and land use patterns.

The following eight areas have been identified for aircraft noise regulations to be proposed by the EPA for promulgation by the FAA under Section 611 of the Federal Aviation Act as amended.

(a) Flight Procedures

(1) Takeoff

Individual airports, or runways of the airports, can be placed into the following three main categories regarding community noise exposure: sideline noise sensitive; near downrange noise sensitive; and far downrange noise sensitive. A set of three standard takeoff procedures suitable for safe operation of each type of civil turbojet airplanes are being considered for use, as appropriate, to minimize the noise exposure of the noise sensitive communities.

(2) Approach and Landing

The following two standardized approach procedures, suitable for safe operation of each type of civil turbojet airplanes, shall be proposed for use as appropriate to minimize community noise exposure: reduced flap settings; and two segment approach (approximately 6 /3).

(3) Minimum Altitudes

Minimum safe altitudes, higher than are presently specified in the Federal Aviation Regulations, shall be proposed for the purpose of noise abatement, applicable to civil turbojet powered airplanes regardless of category.

(b) Type Certification

(4) Retrofit/Fleet Noise Level

Nearly 1,800 existing large turbojet airplanes, having at least 4,000,000 operations per year in the United States are not covered by any noise rule but are the major source of noise impact in the vicinity of most commercial airports. Regulations shall be proposed to insure that both the existing and future civil aircraft fleet are controlled to noise levels as low as possible by available technology.

(5) Supersonic Civil Aircraft

Regulations shall be proposed which would limit the noise generated by future types of civil supersonic aircraft to levels commensurate with the subsonic civil fleet.

(6) Modifications to Federal Aviation Regulations (FAR 36)

Modifications to FAR 36 shall be proposed for lowering the noise criteria levels for all new airplane types that must comply. In addition, various amendments shall be proposed that would: require altitude and temperature accountability; strengthen test conditions for acoustical change approvals; and, in general, make the rule clearer and more effective.

(7) Propeller Driven Small Airplanes

Noise standards shall be proposed for propeller driven small airplanes applicable to new type designs, newly produced airplanes of older type designs, and to the prohibition of "acoustical changes" in the type design of those airplanes.

(8) Short Haul Aircraft

Noise standards shall be proposed for all aircraft capable of vertical, short, or reduced takeoff or landing operations. The required lengths of runways for these operations are being considered as: 1,000 ft. for VTOL; 2,000 ft. for STOL; and 4,000 ft. for RTOL.

In prescribing and amending standards and regulations, Section 611 of the Federal Aviation Act as amended requires that the FAA shall consider whether any proposed standard or regulation is:

(1) consistent with the highest degree of safety in air commerce or air transportation in the public interest;

(2) economically reasonable;

(3) technologically practicable; and

(4) appropriate for the particular type of aircraft, aircraft engine, appliance, or certificate to which it will apply.

The above considerations of safety, economics, and technology are constraints on the noise regulatory actions that may conflict with full achievement of the stringent requirement of protection to the public health and welfare. To achieve compatibility, the regulations must be carefully constructed, comprehensive, and sophisticated instruments for exploiting the most effective and feasible technology, flight procedures, and operating controls available.

The regulations proposed by the EPA for promulgation by the FAA must be practically as complete and comprehensive as the FAA would propose on their own initiative. Otherwise, conflicts between the regulatory constraints of safety, economics, and technology and the requirement of protection to the public health and welfare could delay constructive action indefinitely.

The development of an aircraft noise regulation starts with the preparation of a project report, which is primarily a technical document providing as much definitive information as possible on such matters as background, objectives, available technology, cost-effectiveness, and recommended criteria for levels, measurements, and analyses. The project report will provide the basic input necessary for the preparation of a notice of proposed rulemaking (NPRM), which will be the format of each regulation to be proposed by the EPA to the FAA.

The procedure is to solicit comments on each project report from an EPA Working Group and a broad segment of interested organizations and the public. Numerous representatives of Government, the aviation community, environmental groups, and private citizens are participating in the review process and are making valuable contributions. The project reports, while in the draft stage, do not reflect official EPA policy or position. They are, however, an effective medium for informing the interested parties of contemplated actions, furnishing them with pertinent data, and providing a vehicle or conduit for receiving information.

The comments are carefully analyzed and used to prepare a second draft reflecting constructive suggestions and including valuable supplementary information. It is anticipated that three drafts at most are needed to surface all of the controversial issues and to identify and gain access to all data necessary for the development of the regulations.

The EPA has issued a Notice of Public Comment (Federal Register, Vol. 39, No. 34, 19 February 1974) (Reference 10) concerning aircraft and airport noise regulations. This Notice can be considered as an ANPRM identifying nine aircraft and one airport noise regulatory actions that could be effective in controlling aircraft noise. The first seven actions proposed in the Notice are identical to the first seven items presented here. Actions 8 and 9 of the Notice, R/STOL and VSTOL aircraft, respectively, are included in Item 8, Short Haul Aircraft, presented here. Action 10 of the Notice refers to the airport noise regulation.

The purpose of the Notice is to invite interested persons to participate in EPA's development of the regulations to be proposed, by submitting such written data, views, or arguments as they may desire.

The Notice is not definitive in regard to any particular proposed regulation but refers to them in a general way. Information is solicited relating to the basic requirement that the regulations contribute to the promotion of an environment for all Americans free from noise that jeopardizes their health or welfare, or to the four statutory constraints pertaining to safety, economics, and technology.

Requests for information concerning the Notice should not be confused with similar requests concerning a project report on any one of the proposed regulatory actions. The project reports are specialized detailed documents containing recommended procedures and much supporting data and are circulated for comment and critique.

2. SYSTEMS CONTROL OF AIRCRAFT NOISE

Protection to the public health and welfare from aircraft noise is accomplished most effectively by exercising four noise control options taken together as a system:

(a) source control consisting of the application of basic design principles or special hardware to the engine/airframe combination which will minimize the generation and radiation of noise;

(b) path control consisting of the application of flight procedures which will minimize the generation and propagation of noise;

(c) receiver control consisting of the application of restrictions on the type and use of aircraft at the airport which will minimize community noise exposure; and

(d) land use control consisting of developing or modifying airport surroundings for maximum noise compatible usage.

In general, the primary approach for noise abatement is to attempt to control the noise at the source to the extent that the aircraft would be acceptable for operations at all airports and enroute. And in principle, aircraft noise can be controlled extensively at the source by massive implementation of available technology. In practice, however, technology capability for complete control without exorbitant penalties is not yet available and may never be. A regulation requiring full protection to the public health and welfare by source control, therefore, would have the effect of preventing the development of most new aircraft and grounding the existing civil fleet.

Path control, for most cases, can be an effective option for substantial reduction of aircraft noise. Furthermore, it has the advantage that the results are additive to those obtained by source control. However, specialized flight procedures are limited because of the need to maintain the highest degree of safety. Therefore, a regulation requiring full protection to the public health and welfare by flight procedures is not feasible at this time and probably never will be. Nevertheless, all aircraft can be flown safely in various modes that produce a wide range of noise exposure. And, at the least, those safe modes, which will minimize the generation and propagation of noise, should be identified and standardized.

The major problem with aircraft noise in terms of numbers of people exposed, occurs in the vicinity of airports. This problem could be relieved by the application of various operating restrictions at the airport. Extensive use of restrictions, however, is practical only if all feasible source and path control options have been implemented. Unless this has been done, the airport restrictions may result in unnecessary damage to the local and national economy.

A concept under consideration at this time is that the airport authorities in some cases, and the FAA in other cases, would impose restrictions on the aircraft operators as needed (curfews, quotas, weight, and type limitations, preferential runway use, noise abatement takeoff and approach procedures, landing fees, etc.) to ensure that the airport neighborhood communities are noise-compatible consistent with the requirements of health and welfare. It must be clearly understood that the restrictions available to the airport operator will be those approved by the FAA, CAB, and EPA. The highest degree of safety must be maintained and interstate and foreign commerce requirements must be considered. Restrictions involving flight safety and air traffic control would be the sole responsibility of the FAA.

As an example of this concept, determination of runway usage to minimize community noise impact would be made by the airport operator after consultations with the municipal authorities of the airport neighborhood communities. High priority would be given to maximum implementation of long range land use planning for noise compatibility. If the FAA agrees with the operator's runway designations, the FAA would decide which takeoff and approach procedures must be implemented by aircraft using the designated runways. In all cases, pilots would be given discretionary authority over operating procedures for safety and air traffic reasons.

After all feasible noise control measures have been applied to the aircraft by design, treatment, or modification of the source, by flight and air traffic control procedures, and by proper design, location and use of airports, the noise may still be a problem at some locations. In this event, compatible land use is probably the only remaining solution. The land use control option is more easily exercised in the development of new airports than as a remedial measure for existing noise impacted communities. For the latter case, the costs of land use control are so high that maximum effort must be devoted to implementing the source, path, and receiver control options taken together as a system.

The extent to which the control options must be regulated is dependent upon the meaning and quantification of public health and welfare. Three important considerations must be emphasized. First, the FAA noise regulations have the requirement of protection to the public health and welfare. Second, the regulations are constrained by safety, economics, and technology. Third, the requirement and the constraints may appear to be in opposition to each other and the conflict can be resolved only by implementation of the noise control options taken togehter as a system.

The point is that aviation is a national asset and that ill-conceived regulations, purportedly designed to protect the public health and welfare, might actually have the opposite effect if they would result in destroying, seriously crippling, or severely limiting the viability of the national aviation system. On the other hand, well-conceived regulations, while protecting the public health and welfare directly, might actually accelerate the development of aviation by minimizing public hostility.

This is a broader interpretation of the meaning of public health and welfare than was indicated by the legislative history of the Noise Control Act of 1972. For example, Senator Tunney, the floor manager for the Senate bill, emphasized that air commerce was not an overriding element (Congressional Record, Vol. 118, page S18644, 18 Oct. 1974):

> "The key element in this proposal is the protection of the public health and welfare. The key element is not, as some may believe, protection of commerce."

The intent of this discussion, however, is to emphasize that the broad and narrow interpretations are not necessarily in conflict. Properly constructed regulations, as components of a system of noise control options, collectively can provide the protection required by the act without damage to the national aviation system. However, insistence that one component alone must provide all of the necessary protection, may delay constructive action indefinitely.

If ever the requirements for protection to the public health and welfare from aircraft noise can be identified conclusively and satisfied only by a particular method of noise control, then that method should be used. Health and welfare requirements should override such detrimental effects as delaying the development of a new aircraft type, grounding some existing aircraft, or reducing operations at an airport. Until such identification can be made, however, a systems implementation of all the noise control options should be considered as the most feasible method for equitably sharing the costs of noise control among all segments of the aviation community and the public.

The noise control regulations prescribed by the FAA for the aircraft manufacturers and operators shall be expected to provide protection to the public health and welfare to the highest degree possible in conformance with the systems implementation of the source and path control options. The regulations shall be expected to reflect the latest state of the art of safe technology without prohibitive impairment of aircraft performance (range, payload, field length, etc.). If, however, it is evident that source and/or path control are the only or least costly levels, then aircraft performance loss to any reasonable extent must be accepted.

Noise regulations that pertain to source emissions or flight procedures of specific types of aircraft cannot be expected to take into consideration such unknowns as the quantity of these aircraft that eventually will be produced, from what airports they will be operated, or what noise-compatible land use will be implemented in the vicinity of these airports. Consequently, source emissions or flight procedures regulations should be developed with due consideration given to the total system concept. The regulations should be of the "umbrella" type in the sense that those aircraft regulated can all comply by use of available technology although some may be capable of achieving lower noise levels than others. Various models of aircraft within specific type classification may not have the same capability for generating or controlling noise because of such differences as size, weight, powerplant, etc. The regulations should be flexible enough to consider the effect of these factors on noise and attempt to control the levels to the maximum practical extent. "Umbrella" type regulations do not mean that the worst offenders would be permitted to comply without penalty. On the contrary, a properly constructed set of regulations, representing components of a system of noise control options, probably would require the greatest sacrifice from the worst offender. The various aircraft/engine types have different weights, thrust, engine characteristics, and flight performance characteristics, all of which influence their noise generation and reduction capabilities. Consequently, it is not reasonable to expect that a particular source or flight procedures regulation should require equal noise level compliance from all types, weights, thrust, etc., of aircraft.

As an example, FAR 36 has several features that discriminate, in the "umbrella" sense, among the various classes of airplanes. Greater weight airplanes are permitted higher compliance levels; four engine airplanes are permitted greater sideline distances; and four engine airplanes are not permitted as much percent thrust reduction at takeoff. The above discriminating features contained in the same source control regulation permit some airplanes to make more noise than others. In the end, however, the airplanes producing the most noise will be the primary candidates for operating restrictions at the airports as necessary to protect the public health and welfare. The implementation of these restrictions is likely to impose the greatest burden on the noisiest airplanes.

The airport restrictions would provide incentive for the aircraft operators to conduct thorough investigations and consider maximum utilization of the available noise control options. The fact that an aircraft manufacturer or operator has barely complied with an FAA "umbrella" type regulation would not ensure the acceptance of a particular airplane at all airports. The airport restrictions would, therefore, encourage the aircraft operators and manufacturers to satisfy the FAA regulations by maximum utilization of the source emissions and flight operations noise control technology within their capability and not merely to comply with specified limits.

3. OBJECTIVE

The objective of this project is to promulgate a rule which will control the noise of civil subsonic turbojet engine-powered airplanes, regardless of category, to levels as low as is consistent with safe technological capability, and which:

(a) will be fully responsive to the requirements of Reference 9 for protection of the public health and welfare,

(b) will not impose unreasonable economic burdens on the national aviation system,

(c) will not degrade the environment in any manner, and

(d) will not cause a significant increase in fuel consumption.

The intent of this project report is to provide as much definitive information as possible on such matters as background, available technology, cost effectiveness, and recommended criteria for levels, measurements, and analyses. This project report will provide the basic input for the preparation of a notice of proposed rule making (NPRM) which will be the format of the regulation to be proposed by the EPA for promulgation by the FAA in conformance with the Noise Control Act of 1972.

The noise rule should have the earliest practical effective date, should be a requirement for the operation of United States registered civil subsonic turbojet engine-powered airplanes and thereby:

(a) insure that future community noise due to the operation of these aircraft has been reduced to the lowest feasible levels and smallest practical areas commensurate with the current state of the art;

(b) provide a regulatory maximum noise limit on civil subsonic turbojet engine-powered airplanes to form a basis for meaningful long-range land use planning in the vicinity of airports;

(c) provide economic incentives for the development of quieter airplanes by limiting operations of noisy ones;

(d) permit the fullest practical range of airplane design and retrofit options so that cost-effective noise reduction can be achieved.

4. BACKGROUND

Three regulations to date have been prescribed which have a significant influence on aircraft noise and sonic boom. These rules, identified as References 11, 12, and 13, accomplish the following:

(a) Reference 11 (FAR 36) prescribes noise standards for the issue of type certificates, and changes to those certificates, for subsonic transport category airplanes, and for subsonic turbojet powered airplanes regardless of category. This rule initiated the noise abatement regulatory program of the FAA under the statutory authority of Public Law 90-411.

(b) Reference 12 is an operating rule prohibiting supersonic flights of civil aircraft except under terms of a special authorization to exceed the speed of sound (Mach 1.0). Authorization to operate at a true Mach number greater than unity over a designated test area may be obtained for special test purposes. Authorization for a flight outside of a designated test area at supersonic speeds may be made if the applicant can show conservatively that the flight will not cause a measurable sonic boom overpressure to reach the surface.

(c) Reference 13 requires new production turbojet and transport category subsonic airplanes to comply with FAR 36, irrespective of type certification date. This rule established the following dates by which new production airplanes of older type designs must comply with FAR 36.

- o 1 December 1973 for airplanes with maximum weights greater than 75,000 pounds, except for airplanes that are powered by Pratt and Whitney JT3D series engines.
- o 31 December 1974 for airplanes with maximum weights greater than 75,000 pounds which are powered by Pratt and Whitney JT3D series engines.
- o 31 December 1974 for airplanes with maximum weights of 75,000 pounds and less.

By promulgating (a) and (c), above, the FAA has made the ruling, with no serious objections from the aviation community, that all new types and new production of older types of civil subsonic turbojet propelled airplanes will meet the noise requirements of FAR 36 or be excluded from operations within the national airways system. As these new, quieter airplanes enter the system, some of the older, noisier airplanes will retire naturally. But most, having considerable economically useful lives, will remain in the system and be the dominant source of noise impacting communities in the vicinity of the nation's jetports. A significant portion of these older noisier airplanes may be reasonably expected to be used to service routes and airports which have not previously been exposed to the high level of noise generated by turbojet propelled airplanes. In recognition of these factors, the Federal government, and the aviation industry, have sought safe, technologically practicable, and economically reasonable methods of noise retrofitting these airplanes. Concurrently, since 1970, the FAA has explored various regulatory means of making the noise retrofit and compliance with FAR 36 mandatory. A discussion of each of the three FAA proposed rules related to the retrofit of old designs of turbojet powered airplanes is provided in the following paragraphs.

A. Straight Retrofit, ANPRM 70-44

This advance notice, issued by the FAA in November, 1970 (Reference 14), stated that the FAA was considering rule making to establish noise reduction requirements that would involve modification (retrofit) of currently type certificated subsonic turbofan engine powered airplanes, regardless of category, as a condition for further operation of these airplanes. Two reasons were given for the need for noise reduction retrofit:

> "The first reason is the obvious public need for relief. It was the noise of the current fleet of aircraft that, in large part, led to the enactment of Public Law 90-411 and with respect to which the public need for protection is clearly the most urgent. The near-total noise saturation of hundreds of airport neighborhoods has been well documented and needs no further elaboration other than to restate the FAA's commitments to using every legal regulatory technique at its disposal to reduce the noise impact of aircraft through source noise reduction."

> "The second reason for an aggressive noise reduction retrofit program is that the noise of the current fleet of aircraft is a deterrent to the development of new airports, the extension of existing runways, and the continued full use of the airport system in the United States. The airport system is a vital national asset and its health directly affects the health of the entire air transportation system. The FAA, therefore, regards an effective noise reduction retrofit regulatory program as being necessary in the broad public and national interest not only because of the relief it will bring to airport neighbors under Public Law 90-411 and the National Environmental Policy Act of 1969, but also because aircraft noise reduction retrofit is directly related to the further promotion, encouragement, and development of civil aeronautics."

The above statements clearly indicate FAA awareness that the public health and welfare needs protection from noise and, also, that the growth of aviation will be inhibited unless noise reduction is accomplished. Furthermore, the FAA stated that current technology was available for a feasible retrofit program:

> "In summary, research and development done to date has demonstrated that the basic concepts of noise suppression of turbofan engines are valid acoustically, and that materials and fabrication technologies may be developed to translate these concepts into hardware that could provide economically reasonable and technologically practicable means of significantly reducing the noise generated by certain currently certificated turbofan powered airplanes."

In this announcement the FAA identified a number of problem areas in which broad public participation and assistance was invited. One problem area, the first identified by the FAA, was the regulatory method to be used:

> "The means by which operators, including foreign operators, should be regulated with respect to the modification. Under one possible alternative, a completely acoustical "fix" or modification would be prescribed, or referred to, as in an airworthiness directive, together with all modification details necessary to insure the safety of the installation. This alternative might provide for some use of alternate means of compliance by the operator, but would provide the operator with a clear means of compliance. Under another possible alternative no precise design change would be prescribed. Rather, the operator would be required only to achieve a specified acoustical objective, either in terms of a prescribed noise reduction or an absolute noise level. The means of compliance would be left with the operator and would not be specified. This alternative, to be successful, would require a general availability of acoustical and materials knowledge and technology. This alternative would have the positive value of permitting the maximum freedom in the development of means of reducing noise, and might thus be more effective than the alternative mentioned above."

B. Fleet Noise Level, ANPRM 73-3

After considering the comments received in response to ANPRM 7-44, the FAA published in 1973 another proposal (ANPRM 73-3) on "Civil Airplane Fleet Noise (FNL) Requirements" (Reference 15).

This advance notice stated that the FAA was considering proposing the adoption of regulations that would prevent escalation of fleet noise levels (FNL), would require a reduction in FNL on or before 1 July 1976, and would require airplanes to comply with FAR Part 36 on or after 1 July 1978. The proposal would apply to aircraft operated in interstate commerce by air carriers, supplemental air carriers, and commercial and air taxi operators operating turbojet powered airplanes with maximum weights of 75,000 pounds or greater. The proposal would not apply to airplanes engaged in foreign air commerce and airplanes operated in overseas air commerce.

The major elements of the FNL concept are:

(a) Determining the noise levels for each type of airplane in the operator's fleet,

(b) Determining the total number of operations (takeoffs and landings), for each airplane type for a representative 90-day period.

(c) Calculating a fleet noise level based on a mean logarithmic equation, and

(d) Establishing a precise limit on fleet noise levels.

Beginning on its effective date, the impact of the rule would be to immediately "freeze", and prevent any further escalation of, the FNLs that are now being generated and to achieve a positive FNL reduction on and after 1 July 1976. This would be done by:

(a) Requiring each operator to submit the data information necessary to establish the FNLs actually generated by the operator during a representative 90 consecutive days during the 12 months preceding that date of the rule,

(b) The FAA determination of the initial FNLs, and

(c) Requiring that the initial FNLs not be exceeded.

Beginning on 1 July 1976, the rule would require that the FNLs originally established for each operator be reduced to a level that is halfway between the original level and the level that would exist if each airplane covered by this proposal was type certificated under FAR Part 36.

Beginning on 1 July 1978, the FNL concept would expire. In its place, the regulation would require each operator to restrict all of his operations covered by this proposal to airplanes type certificated under Part 36, Appendix C.

Although ANPRM 73-3 introduced the FNL concept as a possible means of regulating aircraft noise, the FAA explicitly left open the possibility of further consideration of a straight retrofit rule, such as ANPRM 70-44.

Where preference was clearly expressed in the responses to the FNL requirements proposal the responders were, in the main, in favor of a straight retrofit rule. Those in favor included the Environmental Defense Fund (EDF), the National Organization to Insure a

Sound-Controlled Environment (NOISE), the Aviation Consumer Action Project, the Coalition Against Noise, the Sierra Club, the Air Transportation Association (with the implied endorsement of its 25 members and explicit endorsement by Seaboard World Airlines and United Airlines), the International Air Transport Association on behalf of its members, the City of Boston Air Pollution Control Commission, and the Commonwealth of Pennsylvania.

Only the Douglas Aircraft Company and the General Electric Aircraft Engine Group indicated a clear preference for a FNL type regulation.

During the course of the preparation of the report to Congress on Aircraft/Airport Noise, the EPA Task Group 5 studied and evaluated both of the FAA proposals (ANPRM 70-44 and ANPRM 73-3). The Task Group 5 report (Reference 6) indicated preference for an FNL type regulation as indicated by the following statement:

> "The concept and structure of the FNL proposal appears adequate to effectively exploit the current technology (nacelle retrofit) and to allow and encourage the near future technology (refan retrofit) to contribute as it becomes operable, and to encourage the phaseout of existing aircraft by the introduction of new wide-body and other quiet aircraft. In adition, the FNL concept would periodically provide a great deal of useful information to the Government on air-carrier fleet size, mix, and utilization. However, there are several features in the proposal that weaken its effectiveness and should be removed. There are several features that would add strength if included."

> "In consideration of the preceding discussion and of the requirements of PL 92-574, the Task Group 5 report reccommendation is that the FNL proposal (ANPRM 73-3) be prescribed as a regulation with the following exceptions:

1. Omit exemption for airplanes engaged in foreign air commerce except supersonic transports.

2. Omit exception for airplanes engaged in overseas air commerce,

3. Omit expiration date of 1 July 1978, and continue the FNL concept indefinitely to permit the implementation of technological advancements (e. g., refan) as they become available.

4. Include airplanes engaged in intrastate air commerce,

5. Include FNL requirements for sideline noise as well as takeoff and approach.

A fleet noise level rule would be superior to and obviate the need for a straight retrofit rule such as considered in ANRPM 70-44."

The above recommendations became the official EPA position and were included in the report to Congress (Reference 1).

C. Fleet Noise Requirements, NPRM 74-14

After considerating the comments received in response to ANPRM 73-3, the FAA published a notice of proposed rule making (NPRM) for public review and comment entitled "Civil Aircraft Fleet Noise Requirements" (Reference 16). This latest action by the FAA proposes an operating rule under FAR Part 91 which has the same objectives during the same time periods as ANPRM 73-3 without some of its objectionable features. The draft NPRM satisfies a substantial portion of the EPA requirements as identified in Reference 1 and, for that reason, is supported. The remainder of the EPA requirements can be accomplished by separate regulatory action, the rationale for which will be developed in Section 5 ("Analysis").

The proposed rule would require that subsonic turbojet engine-powered airplanes with maximum weights of 75,000 pounds or more be retrofitted to comply with FAR 36 or be replaced in certain fleet operations. The proposed requirements, when implemented, will bring significant relief to the public exposed to the noise of subsonic turbojet engine-powered airplanes with maximum weights of 75,000 pounds or more. Furthermore, there is no disagreement with the FAA that the proposed requirements of FAR Part 36 represent noise levels that can be achieved with available technology and at reasonable cost.

The proposed rule is considered a substantial step in the right direction and should be promulgated promptly with, however, two modifications as follows:

(a) The requirement to meet the noise standards of FAR Part 36 by 30 June 1978 should be extended to include civil turbojet propelled airplanes of 75,000 lbs. or less, regardless of category.

(b) Paragraph 91.307 should be modified to require that, unless airworthiness is jeopardized, at least one-half of the engines/nacelles must be installed on operational aircraft and not merely be included in the fleet operator's inventory (e.g., warehouse). The Environmental Protection Agency is cognizant of aircraft fleet engine/nacelle intermix problems and the safety aspects relating to unbalanced weight, thrust, and drag. The EPA also recognizes that noise reduction for a single airplane is not fully accomplished until all of its engines/nacelles are retrofitted. However, progress is assured when the retrofit is implemented as soon as practical after the engines/nacelles are available. Withholding retrofit for an airplane until all of its engine/nacelle combinations are on hand, would deny some needed relief to the aircraft noise impacted public.

In summary, the Department of Transportation should act promptly in promulgating the proposed rule with the proposed modification discussed above. The target dates (30 June 1976 and 30 June 1978) for implementation are reasonable.

Also, there is no disagreement with the FAA "...that issuance of the proposed regulations would not preclude the later issuance of additional fleet noise requirements,...". To this end, therefore, the EPA has developed an additional proposed regulation for the FAA to prescribe that is proposed to take effect on 1 July 1978.

5. ANALYSIS

A. Technology Options and Applications for Source Noise Control

Source noise control, as defined in Section 2, is the application of basic design principles or special hardware to the engine/airframe combination which will minimize the generation and radiation of noise. The technology of source noise control is time-dependent in the sense that it is based upon the results of past, present and future programs of research, development, and demonstration, which can be classified as follows:

(1) Current technology includes shelf item hardware and commonly known (state of the art) techniques and procedures which have been used by some manufacturers.

(2) Available Technology represents the results of research and development which have not been put into common practice but are available for implementation. Some performance testing may still be necessary but this technology has been certificated for airworthiness or, by adequate ground and/or flight testing, determined to be capable of being certificated.

(3) Future technology represents the results of research now in progress which have not been fully tested but the results to date indicate high potential to a reasonable degree of confidence. Included are present programs which are being conducted with sufficient resources of manpower, funding, and time to carry the programs to conclusion. Definitive results are expected in the near future for acoustical and operational performance, economics, and flight safety. The nature

of the expectations is positive or, at the least, neutral, because predictions of non-viable results would have been cause for termination of the programs.

The application of source noise control technology is directed to either existing or new aircraft. In the case of existing aircraft, source control is applied by retroactively fitting (retrofitting) acoustical treatment to the engines/nacelles during a non-operative or shutdown period.* In the case of new production aircraft, source control is applied during the manufacturing process to older type design aircraft that have had no flight time or to new type design aircraft.

The source control measures available for existing and for newly produced aircraft of the same type design will be essentially the same. Acoustical treatment that is effective for one will be effective for the other as well. Also, there is opportunity for making some, but limited, changes in the basic engine/airframe design of the older type aircraft. The extent of these changes will be governed by the amount of their influence on the function of other parts of the aircraft and on overall safety, performance, and cost. For example, modifying an aircraft for a higher thrust to weight ratio would require larger size engines which might require revisions to the landing gear, pylons, wing and tail structure, the addition of ballast, etc.

The most effective use of technology to achieve maximum noise control is in the design and development of new aircraft types.

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*As used here, acoustical treatment means any hardware or mechanical device, applied either singly or combined to the inlet and primary and secondary exhausts, that either will absorb sound or otherwise effect a noise reduction at the FAR 36 measurement positions.

Applications of basic design principles and acoustical treatment for the control of noise can be exploited optimally when they can be integrated into the overall aircraft/engine design. Modifications such as retrofit hardware are always the less efficient, but often necessary, use of technology.

Regulations for the control of aircraft noise should be constructed to be responsive to the three classifications of technology options and to three types of applications, listed as follows:

(a) Technology Options

(1) Current

(2) Available

(3) Future

(b) Applications

(1) Existing Aircraft

(2) New Production Aircraft-Older Type Design

(3) New Production Aircraft-New Type Design

The two existing aircraft source noise regulations (discussed in Section 4 "Background") are stringent only to the extent of requiring state of the art technology. Applications of available or future technology as it develops will not be required unless these regulations are amended or supplemented by additional ones. Furthermore, the existing regulations relate to new production aircraft only.

The remainder of this section on "Analysis" will be devoted to providing technical support for the development of regulations which will be responsive to all nine combinations encompassed by three applications of the three technology options.

B. Nacelle Retrofit Technology

In May 1967, NASA contracted with the McDonnell Douglas Corporation and the Boeing Company to investigate nacelle noise control modifications for operational Douglas and Boeing transports powered by JT3D turbofan engines. The NASA program successfully demonstrated, by flight tests in 1969, conceptual feasibility of nacelle modifications for controlling both approach and takeoff noise of JT3D propelled aircraft.

In June 1971, the FAA initiated a nacelle noise control project directed to retrofit of the current fleet of narrow body aircraft. This project extended the NASA program to include research and development of takeoff and approach noise control for both JT3D and JT8D propelled aircraft. The purpose of this project was to provide test data to assist in determining whether certain classes of turbofan propelled airplanes in the current fleet could be modified for meaningful noise reduction in a feasible manner. Feasibility, in this case, pertained to compliance with the regulatory constraints of safety, economics, and technology, contained originally in PL 90-411 and carried over in the Noise Control Act (PL 92-574).

The research and development work was directed to providing acoustical treatment for engines/nacelles which would permit compliance with specified noise reduction goals and which would be flight weight, flight worthy, and capable of being certificated. The acoustical treatment, as defined previously, is any hardware or mechanical device applied, singly or combined, to the inlet and primary and secondary exhausts which will absorb sound or otherwise effect a noise reduction at the FAR 36 measurement points. Noise levels measured at the FAR 36 points will not completely evaluate the total capability of acoustical treatment but they are sufficient to judge relative merits.

The FAA project was implemented by means of three separate contracts with appropriate airframe manufacturers. The first with Boeing Wichita on 707 aircraft, the second with Boeing Seattle on 727 and 737 aircraft, and the third with Douglas on DC-9 aircraft. In addition, all three prime contractors had subcontracts with Pratt and Whitney on engine compatibility testing; Boeing Wichita had a subcontract with Douglas on 707/DC-8 nacelle generality studies; and Douglas had a subcontract with Rohr on fabrication and ground testing of DC-9 nacelles. The FAA, therefore, had most aspects of nacelle retrofit feasibility investigations for JT3D and JT8D aircraft covered by the airframe, engine, and nacelle manufacturers most involved with the narrow-bodied civil aircraft fleet.

The FAA established a task force to direct and monitor the progress of the retrofit feasibility contracts. The task force consisted of representatives from the research and development, regulatory, and airworthiness services of the FAA. It is most important that the latter area was thoroughly covered to insure that a judgment of the feasibility of noise abatement retrofit modifications was based upon production hardware and commercial operations that would not compromise safety in any way.

The results of the FAA nacelle retrofit project produced flight performance and cost data for 707, DC-8, 727, 737, and DC-9 type airplanes equipped with acoustical treatment which would permit compliance with the FAR 36 noise levels. The acoustical treatment investigated included sound absorption material (SAM) and a combination of SAM and some sort of jet noise reducer (JNR). The least complex system consisting of SAM alone will enable the airplanes to achieve the FAR 36 noise levels or even slightly lower in some cases. The more complex systems consisting of SAM+JNR have the capability of decreasing the noise to levels appreciably lower than the requirements of FAR 36.

The FAA project on nacelle retrofit yielded noise control technology for nacelle modifications that represents the maximum state of the art. There are no obvious ways in which nacelles can be designed that will control noise any better than those developed by the FAA contractors. It must be clearly understood that the reference here is to acoustical treatment, as previously defined, which is added on to a nacelle or to an engine flow passage. A modified nacelle that permits compliance with the FAR 36 levels is referred to as a Quiet Nacelle (QN) and does not include any modifications to engine components.

Quiet Nacelles containing SAM have a negligible effect on aircraft performance and would insure that the older narrow-bodied commercial aircraft would comply with FAR 36. There would be no appreciable degradation in field length requirements and direct operating costs but possibly a small loss in range. There would be a meaningful reduction in airport community noise exposure: mainly for approach operations for JT8D propelled aircraft and for both takeoff and approach operations for JT3D propelled aircraft.

Quiet Nacelles containing SAM+JNR, in addition to costing more per shipset, would introduce substantial degradation in performance. These performance losses, however, are not necessarily irreversible. Uprating the airframe for loading and the engine for thrust (e.g., JT8D-9 to JT8D-15) will increase the range and reduce the required field length to values approaching those of the baseline production version.

Figures 1, 2, and 3 illustrate Quiet Nacelles for the Boeing family of JT3D and JT8D propelled airplanes. Table 1 lists the noise and performance comparisons of the QN and baseline airplanes. For 727 and 737 airplanes, the treatment is minimal; the noise reduction benefits are negligible for sideline and takeoff but significant on approach, and the costs and performance losses are so modest that it is unreasonable not to include such treatment on all new aircraft. For 707 aircraft, the treatment is much more extensive: the noise reduction benefits are substantial at all three measuring positions but especially dominant at approach; the performance losses are small; and the costs are significant but not necessarily unreasonable from a cost effectiveness viewpoint (which will be discussed later in detail). The data included in the Figures and Table were taken from Reference 17.

Quiet Nacelles with SAM are also available for the Douglas family of JT3D and JT8D propelled airplanes. The QN technology is state of the art and the first nacelles for all candidate airplanes could be ready for implementation about six months after the effective data of a retrofit regulation.

C. Refan Retrofit Technology

The Refan source noise control option is significantly different from nacelle retrofit inasmuch as it involves modification and replacement of certain engine as well as nacelle components. The most important, but not the only, engine component to be replaced is the bypass fan; thus the program is referred to as "Refan".

The Refan program, as established under NASA sponsorship in August 1972, benefits from, and is based upon, both engine and noise technology developed since 1968. At that time, when it became apparent that efficient and effective jet noise reduction could be achieved through reduction of the primary jet exit velocity, Pratt and Whitney Aircraft (P&WA) began their studies on the JT3D engine. Variations of this basic engine are used on the Boeing 707 and the McDonnell Douglas DC-8 series of aircraft. This engine, as opposed to the JT8D, was investigated first as it was the more conservative design and therefore had the greater possibility of doing additional work which is fundamental to the Refan concept.

Early parametric studies of potential single-stage and two-stage fans showed that the Refan requirements could be satisfied by either two-stage fans of moderately larger diameter or single-stage fans with a greater increase in diameter. The initial engine studies resulted in the JT3D Configuration III. This configuration had a larger diameter two-stage fan, which increased the engine length and installed weight. Although this engine provided a moderate reduction in jet noise, there was no improvement in performance and it was not considered an acceptable figure at that time. Study of the refanning of the JT3D engine continued with internal funding on an intermittent basis until 1972. During the period 1968 to 1972, P&WA studied 10 possible configurations of this engine. The direct studies also benefited from the P&WA JT9D engine (powerplant for the Boeing 747 aircraft) development as well as an FAA sponsored study of low, medium, and high, fan tip speed noise characteristics. The ninth configuration of the JT3D studied by P&WA had an increased diameter single-stage fan and no inlet guide vanes. This configuration formed the basis for the NASA sponsored Refan program when proposed.

Prior to initiation of the NASA program, it was determined that, with modification, the JT8D could also be refanned. This engine is used on the various models of the Boeing 727 and 737 and the McDonnell Douglas DC-9 aircraft. Within the initial scope and funding of the NASA Refan Program, Phase I contracts were let for design and analysis of the engine and nacelle modifications with three major contractors: Pratt and Whitney Aircraft; The Boeing Company; and the Douglas Aircraft Company. Small contracts were also let with American Airlines and United Airlines for consulting work to assure that the modifications being considered incorporated as many requirements of the user airlines as possible.

In January 1973, program funding curtailment forced limiting the scope of the program to only one engine type. The joint NASA/DOT/FAA decision was to proceed with the JT8D rather than the JT3D. The basic reason given for this choice was that the JT8D-powered aircraft will have a larger impact on the aircraft noise exposure in the 1980's.

The concept of Refan retrofit is to reduce the jet noise by means of a transfer of energy from the jet exhaust stream to the bypass fan stream. This requires starting with an engine (such as the JT8D) that was conservatively designed so that additional work can be extracted from the engine core component (e.g., turbine).

In order to lower the primary jet noise by reducing the primary jet velocity without losing thrust requires that more of the primary engine gas stream energy be converted into the low velocity bypass fan stream, as shown in Figure 4. This conversion can be accomplished by either increasing the fan pressure ratio, or the bypass flow, or by increasing both. Increasing the bypass airflow is the more desirable route because it also provides increased total engine thrust and reduced fuel consumption. This route is feasible since the JT8D low pressure turbine has the capability of doing more work to absorb more primary gas stream energy. Furthermore, the gains in jet design technology since the initial design of this engine supports the feasibility of a new fan that would absorb the additional low pressure turbine work.

While refanning is primarily directed toward reducing the primary jet noise, redesign details, such as number of stages, spacing between the rotating and stationary elements, number of rotor blades, and stator vanes, are also studied in order to minimize the turbomachinery noise portion of the spectrum. After this has been accomplished, nacelle modification and treatment with sound absorbing material (SAM) is added in order to further reduce the noise levels.

The noise reduction techniques utilized for the NASA Refan Program, when considered singly, are current or state of the art technology. However, the effectiveness of these techniques, when combined as a system, has yet to be demonstrated. Hence, Refan retrofit at this time must be classified as near future technology. The potential appears high for achieving the NASA program objectives for the narrow-body fleet of JT8D propelled airplanes. Reference 23 states the original objectives:

> "The program objectives are to demonstrate through development of retrofit kits that the noise produced by the narrow-body fleet can be reduced to 5 to 10 EPNdB below FAR-36 while retaining demonstrated engine reliability and maintainability, causing no degradation of aircraft performance or safety, and all at an acceptable fleet retrofit cost."

D. Noise Comparisons (JT3D/JT8D)

Noise level estimates are given in Table 2 for the typical airplane types (707, DC-8, 727, 737, DC-9) considered as candidates for Quiet Nacelle and Refan retrofit (References 17 through 22). The noise levels relate to the measuring points and conditions of FAR 36 and include values for: the FAR 36 requirements; the baseline (unretrofitted) airplanes; the Quiet Nacelles; and Refan. Figures 5(a), (b), and (c) show the same information in the form of bar charts from which direct visual comparisons can be made.

Sideline noise comparisons are shown in Figure 5(a) where it is seen that, for all five airplane types, the baseline noise levels are below the FAR 36 requirements. Quiet Nacelles would accomplish very little noise reductions; about three or four decibels for JT3D airplanes and none for the JT8D types. On the other hand, the estimates for Refan retrofit indicate very substantial noise reductions, varying from 8-decibels for the 727 to 15.5-decibels for the 737.

Takeoff (with thrust cutback) noise comparisons are shown in Figure 5(b) where it is seen that Quiet Nacelles would be very effective for the JT3D airplanes: about 10 or 11 decibels. Quiet Nacelles would accomplish very little reduction for the JT8D airplanes, varying from 0 to 4 decibels which is sufficient, however, to result in levels below the FAR 36 requirements. The estimates for Refan retrofit indicate significantly more benefit for the JT8D airplanes, varying from 7 decibels for the 727 to 12 decibels for the 737.

Approach noise comparisons are shown in Figure 5(c) where it is seen that this is the measuring point where Quiet Nacelles would have their greatest effectiveness. The reductions are 12 to 14.5 decibels for the JT3D airplanes and 7 to 9 decibels for the JT8D airplanes. Conversely, this is the measuring point where Refan is estimated to have the least effectiveness; varying from 7 decibels for the 717 to 10 decibels for the DC-9.

In summary, the estimated noise reductions that would be accomplished by Quiet Nacelles and Refan are dependent upon the FAR 36 measuring point. For the two JT3D propelled airplanes, Quiet Nacelles, which are the only retrofit option, accomplish noise reductions that vary from modest at sideline (3 and 4 dB), to substantial at both takeoff (10 and 11 dB) and approach (12 and 14.5 dB). For the three JT8D propelled airplanes, refanning is clearly superior at sideline (8 to 15.5 dB) and takeoff (7 to 12 dB). However, for the approach measuring point, Quiet Nacelles and Refan are estimated to accomplish about the same noise reductions (7 to 10 dB).

E. Cost Comparisons (JT3D/JT8D)

Cost estimates for Quiet Nacelles and Refan are compared in Table 3. The unit costs, which include twenty percent for spares, represent the price per airplane that would be paid for installations wherever it was done. No allowance is included for flight costs to and from the installations site nor for loss of service revenue.

The number of airplanes listed in each category probably is the maximum that would be available for retrofit; no assumption was made for attrition or phaseout. The unit costs are based upon numbers of shipsets somewhat less than those shown for "US only". Consequently, the unit costs would be somewhat lower if the numbers listed for the United States were realized, and substantially lower still for the world fleet.

The investment costs shown are probably conservative in the sense that they pertain to more airplanes than actually would be retrofitted. Some attrition and phaseout will occur and not all of the world fleet would be involved. These figures, therefore, represent the upper limit of costs for each category. On the other hand, it is possible that the "on order" estimates may be low for a number of reasons not clearly identifiable at this time. If so, the degree of conservatism may not be so high as first expected.

One point that must be kept in mind is that the costs for the "on order" (OO) airplanes would not pertain to a straight retrofit rule applicable to Quiet Nacelles. The reason is that new production aircraft are now automatically covered by the existing regulation on newly produced airplanes (Reference 13). Consequently, comparisons of the costs of retrofit between Quiet Nacelles and Refan should be on the basis of on hand (OH) for the former and total (OH+OO) for the latter.

For example, consider retrofit of the United States JT8D fleet, which would have an investment cost of about 215 million dollars for Quiet Nacelles as a direct result of a straight retrofit rule. Alternatively, refanning would cost about 1.925 billion dollars or 8.95 times as much if all of the airplanes (OH+OO) were retrofitted. Obviously, the large difference in investment cost between Quiet Nacelles and Refan demands that very careful consideration be given to demonstrated benefits of the latter in terms of noise reduction and performance gains. Considering the combined fleet of JT8D and JT3D propelled airplanes, the cost multiple is not so striking. For the United States fleet, retrofit by Quiet Nacelles (OH airplanes) would cost about 648 million dollars and by Refan (OH+OO airplanes) about 2.36 billion dollars or 3.64 times as much. For the world fleet, the comparable retrofit costs for Quiet Nacelles and Refan would be about 1.14 and 3.87 billion dollars, respectively, or 3.38 times as much.

In regard to the rest of the world fleet, the costs of retrofit (for those airplanes involved) would not be borne by any segment of the United States. On the contrary, United States manufacturers furnishing retrofit kits and installation services would be the beneficiaries. The benefits could be as much as 496 million dollars for Quiet Nacelles and 1.51 billion dollars for JT3D Quiet Nacelles and JT8D Refan.

F. Miscellaneous Retrofit Technology

The JT3D and JT8D engines power about two thirds of the current air carrier fleet. Of the remainder, approximately 20 percent are powered by reciprocating engines and turboprops which are not being considered for nacelle retrofit. The pure jet 707, DC-8 and 880 (approximately 150 aircraft) are scheduled to be retired from the fleet by the end of the decade and no consideration is being given to the development of retrofit kits for these aircraft. The BAC 111 and the 747's delivered prior to December 1971 are expected to remain in the fleet well into the 1980's; therefore, potential nacelle retrofit options for these aircraft are discussed below.

The BAC 111 is powered by the low bypass Rolls Royce (RR) Spey engine and these aircraft currently do not meet the FAR 36 noise standards. A joint program between BAC and RR has been initiated to develop retrofit kits for the BAC 111 enabling the aircraft to meet the FAR 36 requirements (with tradeoff). The kit includes a six-chute suppressor exhaust nozzle, an acoustically lined 40-inch jet pipe extension, and an acoustically lined engine intake and bypass exhaust duct. A development kit is planned for testing in 1974 with production kits planned for 1976 availability. The weight of the kit is approximately 400 lbs. with an estimated performance penalty of 1 percent loss in takeoff thrust and 3.3 percent increase in specific fuel consumption (SFC).

Early models of the 747-100 (delivered prior to December 1971) were not subject to the FAR 36 Appendix C noise requirements. Later models of the 747 have been certificated to these requirements. A joint Boeing/P&WA noise reduction program is currently underway to determine the potential for further noise reduction for the early 747's as well as for future growth versions. Initial test results indicate additional inlet noise reduction is possible with the addition of splitter rings. Current research effort on improved acoustic materials, providing higher effectiveness at reduced weight, is a potential option for future engine growth programs.

All models of the McDonnell Douglas DC-10 and Lockheed L1011 aircraft have been certificated below the noise level requirements of FAR 36. However, similar R&D activity, as indicated above, has been initiated for these aircraft which also provides the potential for noise reductions for future growth engine programs.

Approximately 20 percent of the aircraft in the general aviation jet fleet (represented by two aircraft - the Falcon 20 and the Cessna Citation) are powered by moderate bypass turbofan engines and have been certificated in accordance with the FAR 36 requirements. The remaining 80 percent are powered by turbojet or very low bypass turbofan engines (with noise characteristics similar to that of the straight turbojet).

The Gulfstream 2, the largest aircraft in this class, utilizes a version of the Spey engine having a bypass ration of 0.64. The take-off and sideline noise levels are in excess of the FAR 36 requirements. Grumman, in concert with Rolls Royce, has defined a program to develop a noise suppression kit for the Gulfstream 2 aircraft, utilizing hardware developed by RR for the F-28 and BAC 111 aircraft, which is expected to meet the FAR 36 requirement. Acoustic linings are not included in the program at this time but are being considered as backup, if necessary.

The rest of the aircraft in the General Aviation fleet are powered by small (3000 to 3500 lbs. thrust) turbojet engines that are extremely compact engines. Since small engines are less tolerant of disturbances to the basic thermodynamic cycle, small size in itself can be a problem with regards to the application of sound absorption materials (SAM) in the engine nacelle. This type of acoustic treatment is concerned only with the audible frequencies, and turbomachinery, combustion noise, fan multiple pure tones, etc., generally fall into the same frequency ranges regardless of engine size. SAM, therefore, fabricated as a resonator cavity type sound absorber will not vary substantially in thickness from one engine to another. As a result, the weight and costs associated with small engine SAM treatment will undoubtedly represent a larger share of the total propulsion system installation than those for large engines. Further, a higher overall penalty to airplane performance will result, not only due to the extra weight, but also to the increased nacelle and engine flow passage drag.

For those aircraft that are marginally shy of meeting the FAR 36 standards (Learjet, for example) a modified exhaust nozzle may be all that is necessary to meet the current standard. Such a program is being conducted with the potential to certify the Learjet to the FAR 36 noise requirement with a redesigned exhaust nozzle.

A noise suppression kit has been developed for the HS125-600 aircraft. Development flight testing is planned with the objective of meeting the noise requirements of FAR 36 for new production aircraft. For the Jetstar, Sabre and Westwind, the performance penalties associated with the amount of acoustical nacelle treatment that would be required to enable these aircraft to meet the FAR 36 noise levels may degrade their operational effectiveness to an intolerable level. There are, however, reengine options available to these aircraft that might permit compliance with FAR 36.

There are currently several small turbofan engines that can be considered for possible retrofit in existing turbojet aircraft. One such program has already been announced, the replacement of the JT12 turbojet engines currently in the Jetstar with the moderate bypass Garrett 731 turbofan. It is estimated that not only will the noise level of the reengined Jetstar comply with the FAR 36 requirements but the range/payload characteristics will be significantly enhanced.

The Learjet has been test flown with the Garrett 731 engine, providing still another retrofit option possibility. The General Aviation Division, Rockwell Corporation, is proceeding with the development of a turbofan powered Sabreliner with the CF 700 engine (used on the Falcon 20) which could offer a retrofit possibility for the existing Model 60 and 70 Sabreliners.

In addition to the Garrett 731 and the GE CF 700 engine, the Lycoming ALF502D and the UAC-Canada JT15D turbofan engines are available for possible retrofit.

G. Future Technology

Extensive noise source research and development has been and continues to be conducted by Government and Industry. The areas of this R&D can be identified as follows.

(1) Component Technology

(a) NASA Quiet Engine Program

(b) Sonic Inlets

(c) Core Engine Components

(d) Aerodynamics

(2) Engine Technology

(a) Air Carrier CTOL Engines

(b) STOL Engines

(c) VTOL Engines

(d) General Aviation

(e) SST Engines

Details of this work are included in Reference 5 and the highlights are given below.

The NASA Experimental Quiet Engine Program, utilizing technology developed in part by the engine manufacturers, has successfully demonstrated the feasibility of realizing significant reductions in source noise in future engine developments. The capability now exists within industry to produce advanced-technology engines with source noise levels limited only by the core engine noise component. With appropriate incentives and funding, these vehicles could be operational in the 1980's.

The same degree of noise reduction has not been demonstrated for the smaller engines that are compatible with business jet aircraft. Comparable research and development in noise abatement concepts and acoustical treatment for this class of engines and aircraft has not been accomplished.

All of the noise control advancements, from the pure turbojet to the high-bypass-ratio turbofan engines, were the result of technology developments for rotating machinery (fan component) and/or sound absorption materials. No comparable advancements have been experienced for the core engine noise of the high-bypass-ratio engines in current production. Rotating machinery and sound absorption noise control technology have continued to advance to the point where further progress may be ineffective unless the core engine noise is controlled as well. As visualized now, core engine noise is the floor which establishes the limit of effectiveness of the current noise control state of the art as it pertains to aircraft engines.

The FAA is currently sponsoring a Core Engine Noise Control Program, the purpose of is which to provide theoretical and experimental data to assist the designers in developing future technology aircraft capable of conforming to lower noise levels than are now required by FAR Part 36. The effort is directed to identifying, evaluating, and controlling the component noise sources inherent in the core engine (the gas generator).

Large reductions in engine-generated noise may have limited effectiveness, however, since it appears that a noise floor, due to external aerodynamic flow over the airframe, is present during approach and landing procedures. This is due to the relatively dirty (flaps and wheels down) configuration in which the flow over these appurtenances has been estimated to generate noise levels approximately 5 to 10 EPNdB below the FAR 36 criteria at the approach measuring position.

New propulsion system concepts, particularly for reduced and short takeoff or landing (R/STOL) aircraft, are in the early stages of development. Very high-bypass fans, such as the prop-fan, are being evaluated for future air carriers and general aviation. Aircraft component developments, such as blown flaps and helicopter rotor systems, while requiring additional development and demonstration testing, include design considerations to minimize future noise environments.

II. Noise and Cost Summary

Figures 6(a), (b), and (c) summarize the noise levels of the turbojet (and turbofan) propelled airplanes. Included are noise levels for: the JT3D propelled narrow body transports (baseline and quiet nacelles); the JT8D propelled narrow body transports (baseline, quiet nacelles, and refan); a supersonic narrow body transport (Concorde); the wide body transports (747, DC-10, L-1011); and various general aviation airplanes (business jets). Table 4 identifies these airplanes, gives their maximum weights, and lists their baseline noise levels whether measured or estimated (Reference 24). Superposed on Figures 6 are lines showing the FAR 36 requirements and lines showing these requirements minus 10-decibels. The purpose of the latter is to establish the lower bounds of a range representing feasible noise level goals for turbojet propelled aircraft.

The noise level range bounded by the lines in Figures 6 represent the design goals for new aircraft identified in the EPA report to Congress (Reference 1):

> "The combined research, design, and development efforts of the National Aeronautics and Space Administration, Department of Transportation, Department of Defense, and industrial members of the aviation community have provided a demonstrated technology base which, if full exploited, can provide a family of new aircraft for both the commercial and business jet fleets starting in the 1978-1980 time frame. The noise characteristics of these new aircraft (depending upon aircraft type and measurement point) could be 5-10 decibels below the present values in Appendix C of FAR 36 and thus, significantly quieter and more acceptable than the current narrow-body jets."

Incidentally, this range includes the objectives of the NASA Refan Program as discussed earlier and reported in Reference 23. Although this noise level range has been identified as goals for new airplane types, it has been met by the wide body transports and some of the business jets. The range is also a reasonable goal for retrofit of all turbojet airplanes except the Concorde.

Sideline noise comparisons are shown in Figure 6(a) where it is seen that all transport airplanes except the BAC-111 and the Concorde have baseline values within or lower than the design goal range. Refan retrofit is estimated to permit JT8D propelled airplanes to achieve noise levels lower than the design goal range. Quiet Nacelle retrofit will have no effect on the JT8D airplanes and only modest effect on the JT3D airplanes. Five of the ten business jets shown have baseline noise levels above the range, three within the range, and two below.

Takeoff noise comparisons are shown in Figure 6(b) where it is seen that baseline noise levels within the design goal range can be achieved by only one narrow body transport, four wide body transports, and two business jets. One business jet, the Citation, can achieve a level lower than the range. Quiet Nacelle and/or Refan retrofit will permit all JT8D and JT3D propelled narrow body transports to achieve noise levels within or lower than the range.

Approach noise comparisons are shown in Figure 6(c) where it is seen that baseline noise levles within the design goal range can be achieved by only four wide body transports and five business jets. Again the Citation can achieve a level lower than the range. Quiet Nacelle and/or Refan retrofit will permit all JT8D and JT3D propelled narrowbody transports to achieve noise levels within the range.

There is no retrofit technology available for the Concorde which will permit it to comply with the FAR 36 noise criteria levels. However, retrofit technology is available for all other transports and some of the business jets. The remainder of the business jets could comply with the FAR 36 levels or lower by implementation of one of the re-engine options.

Estimated costs of retrofit for the United States fleet of JT3D and JT8D propelled airplanes are given in Table 3. Considering the combined fleet of these airplanes, Quiet Nacelles would cost about 648 million dollars, and the combination of Quiet Nacelles for JT3D and Refan for JT8D would be about 2.36 billion dollars, or about 3.64 times as much. The former cost is based upon on hand (OH) airplanes, and the latter cost includes both on hand and on order (OH+OO) airplanes for the reasons discussed previously.

Estimated costs of modifying the United States business jet fleet to comply with FAR 36 levels are given in Table 5. The seven airplanes listed are those exceeding the FAR 36 criteria, as shown in Figure 6. Two of the airplanes (HS-125 and Gulfstream 2) can be made to comply by modifying the exhaust nozzles to include noise suppression devices. The other airplanes can comply only by replacing the existing straight turbojet or low bypass ration turbofan engines with high bypass ration turbofan engines which are substantially quieter.

The benefits available from the business jet retrofit options are not specifically identified in Figure 6 but the resulting levels would be somewhere within the design goal range. This would mean a noise reduction at the FAR 36 measuring points of as much as 5 to 10 EPNdB for some airplanes (e.g., Westwind and Gulfstream 2). The estimated maximum investment cost for FAR 36 compliance for the 657 airplanes listed in Table 5 is about 307 million dollars.

I. FLEET NOISE LEVEL CONCEPT

A straight retrofit rule would be adequate for exploiting state of the art technology and inadequate for the future. The fleet noise (FNL) concept originated by the FAA can be a very powerful tool for continuously evaluating aircraft noise and controlling it to any desired level. Therefore, the FNL concept when properly structured as a regulation, could be an effective "rachet" for lowering noise levels whenever future technology becomes current.

A regulation incorporating the FNL concept should be proposed. This proposal should be similar to FAA ANPRM 73-3 but should include modifications designed to be responsive to future technology opportunities, in particular Refan retrofit. The key issues of the sample regulation are presented in the following discussion.

(1) Scope

The FNL proposal would apply to all subsonic turbojet powered airplanes of United States registry operated in air commerce. This would include airplane fleets operated by air carriers engaged in air transportation under a certificate of public convenience and necessity or other appropriate economic authority issued by the Civil Aeronautics Board (CAB); the above-mentioned air carriers when engaged in charter flights or other special service operations; supplemental air carriers and commercial operators engaged in the carriage of persons or property in air commerce for compensation or hire; certain air taxi operators; and all business fleets.

(2) The Fleet Noise Level (FNL) Methodology

The FNL concept is based on the principle that the noise level of any given fleet is a function of the jet engine noise of each airplane in that fleet and the total number of takeoffs and landings of each airplane in that fleet. The major elements of the FNL concept are:
(1) determining the noise levels for each airplane type in the fleet:
(2) determining the total number of operations (takeoffs and landings) for each airplane type for a representative 90-day period:
(3) calculating a fleet noise level based on a mean logarithmic equation:
(4) establishing a precise limit on fleet noise levels.

The first element (determination of the sideline, takeoff, and approach noise levels) would be calculated under the same sideline, takeoff and approach noise measurement terms and conditions as are used in Part 36 type certification. These terms and conditions have received wide review and will ensure that the noise levels are of the same quality and have the same meaning as those that are determined during type certification. Also, in order to ensure that the effects of sideline, takeoff, and approach noise are discretely accounted for, no tradeoff between sideline, takeoff, and landing noise would be permitted. As in type certification, any weights less than maximum weight or design landing weight that are used in determining the sideline, takeoff, and approach noise levels of an airplane for the purpose of determinining FNL would be required to be established as operating limitations for the airplane. The noise level generated by each airplane would be required to be submitted within 30 days following the prescribed 90-day period.

Noise levels typical of each type and model may be submitted; it is not necessary that each airplane be measured.

The second element of the proposed regulation (the summary of total number of individual takeoffs and landings for any given 90-day period) would be required to be submitted every 90 days.

The third element (calculation method for determining fleet noise levels) is proposed as an Appendix of Part 121. The calculation for FNL is based upon a logarithmic mean formula that includes the number of operations and the noise levels of each airplane. FNL is calculated separately for sideline, takeoff, and approach operations. The formula weights (or emphasizes) noise level more heavily than number of operations as can be seen in Figure 7(c) and as discussed in Appendix D.

The fourth element (the limiting FNL value, one each for sideline, takeoff, and approach) would be imposed as legal limitations on each fleet. These limiting FNL values are derived, for each operator's fleet, under the prescribed logarithmic mean equation in Appendix C, using the 90-day summary of takeoffs and landings of each airplane in the fleet. The limiting FNL requirements are contained in Section 121.807 and are discussed below.

(3) <u>Rules beginning on July 1, 1978 (proposed Section 121-807)</u>

The purpose of this section would be to immediately "freeze", and prevent any further escalation of the fleet noise levels that are generated at that time and to provide a procedure for achieving a positive FNL reduction on and after July 1, 1978. This would be done (a) by requiring each operator to submit the data and information necessary to establish the FNLs actually generated by him during a representative 90 consecutive days during the 12 months preceding the effective date of this rule, (b) by the operator's determination of the initial FNL's and (c) by requiring that the initial FNL's not be exceeded (after a reasonable period for challenge). The challenge provisions would function as follows: The FNL data and information, submitted on or before 1 July 1978, would be published in the Federal Register. For operators for which no FNL can be established because of matters such as a strike or merger, the FAA would publish in the Federal Register an FNL determined by the Administrator to be equitable and representative of that operator's experience. These values could be challenged by the operator within the 30 days following Federal Register publication. The values would be amended and republished if the Administrator agreed that the published FNLs were not equitable or representative. Initial published FNL values would become legal limits for each operator 60 days after their publication in the Federal Register unless challenged, in which case the Administrator's decision on the challenge would become legally binding 30 days after publication of that decision.

(4) Fleet Noise Level Example

Table 6 lists the values of EPNL for the five narrow body transport types that are candidates for retrofit. The EPNL values are given relatiave to each of the three FAR 36 measuring points (S/L, T/O, and App.) and for the four noise level options (FAR 36, baseline, Quiet Nacelles only, Refan, and Refan combined with Quiet Nacelles). These values also are listed in Table 2. A fleet was assumed equal to the national fleet of 1,732 airplanes, and the FNL was computed and listed in Table 6 for the twelve cases.

The FNLs for the sideline point indicate that the baseline value is 3.6 dB below the FAR 36 value which reflects the condition shown in Figure 6(a) for identification numbers 1 thru 5 (all baseline EPNLs are less than the FAR 36 levels). The option of Quiet Nacelles does not have much effect on the sideline point, achieving a reduction of less than one decibel below the baseline. The option of Refan combined with Quiet Nacelles, however, has a significant effect, reducing the level nearly 6 dB below the baseline which is almost 9.5 dB below the FAR 36 value.

The FNLs for the takeoff point indicate that the option of Quiet Nacelles reduces the level more than 9 dB below the baseline which is slightly more than 1 dB below the FAR 36 value. The option of Refan combined with Quiet Nacelles is slightly more effective (1.2 dB) than Quiet Nacelles alone.

The FNLs for the approach point indicate that the option of Quiet Nacelles is superior, effecting a reduction of 11.5 dB below the baseline which is 3.4 dB below the FAR 36 value. The option of Refan combined with Quiet Nacelles is slightly less effective (0.2 dB) than Quiet Nacelles alone, which reflects the case for the 727 shown in Figure 6(c).

J. Day-Night Level (Ldn)

Day-Night Level (Ldn) is a single number rating of the measured or predicted cumulative noise intruding into airport communities. The results of the computations are most useful when the Ldn values at individual positions on the ground are combined into equal Ldn contours and plotted on maps of the airport and its neighborhoods.

Ldn predicted contours result from estimates and generalizations of aircraft categories, mix of aircraft, runway utilizations, number of operations, individual aircraft flight paths, noise levels, and atmospheric conditions. Considering the assumptions, the contours can be considered to have an accuracy no better than plus or minus five Ldn units (decibels).

The Ldn prediction methodology is a computational procedure for combining the important factors contributing to noise exposure into a form suitable for use:

- By airport and community planners as an aid in planning land use and building construction in the vicinity of airports.
- For determining the relative merits of aircraft and engine design, aircraft operating procedures, and runway utilization in reducing aircraft noise exposure.
- As part of a coordinated program of aircraft noise control and airport and community planning to limit the total noise exposure to values commensurate with health and welfare requirements.

The Ldn contours permit the land areas enclosed within them to be evaluated for various types of use, compatible with the noise exposure. Not the least important is the information available to the building designer for providing appropriate sound insulated structures. It is generally accepted that land areas exposed to less than 60 Ldn will not have major noise problems. Building structures in these areas used for sensitive activities such as schools, churches, hospitals, and auditoria, may need some extra noise insulation consideration but the problems, if they exist, can be handled by standard design techniques.

It is the interpretations associated with Ldn contours, and not the methodology, that sometimes result in controversy, particularly those that are so simplified as to leave the erroneous impressions that the contours represent a sharp division between more or less noise critiical zones. In addition, interpretations based upon predicted human response are sometimes accused of being too suggestive in the sense that people often tend to respond in the manner they believe they are supposed to respond.

The methodology for Ldn is based upon the methodology for NEF presented in Appendix E. The relationship between the two is assumed to be Ldn = NEF +35 which is sufficiently accurate to make reasonable comparisons between Ldn/NEF and FNL. The procedures of Appendix E were used to compute the values listed in Table 6. The mix of aircraft was chosen to be one-tenth of the national fleet of narrow body transport airplanes that are candidates for retrofit. The EPNL values therefore, are those listed in Table 6 and are related to the EPNL values used to compute the FNL values. It is important to examine the relative differences in FNL and Ldn/NEF decibels between the noise level options are very close and, consequently, the conclusions made for FNL are equally valid for Ldn/NEF. In summary, the FNL and Ldn/NEF for the assumed fleet of aircraft are equally effective in judging the relative effectiveness of various noise level options. Ldn/NEF, however, pertains to the cumulative noise at a specific location and can be related to health and welfare. FNL, on the other hand, is an abstract level pertaining to a fleet of aircraft which may be widely scattered. Therefore, the absolute levels of FNL cannot be directly related to health and welfare but they can be equally effective as Ldn/NEF as relative value indicators.

6. Health, Welfare and Economic Considerations

The regulation under consideration here has both investment and operational cost impacts on this nation's commercial airlines. The extent of these impacts must be estimated under a broader scope than the subject of this regulation. EPA's overall objective is the attainment and maintenance of a noise environment around airports that is consistent with yet to be established Public Health and Welfare requirements. To achieve such requirements, a balance must be struck amongst the noise reduction alternatives and their respective effectiveness and costs of achieving acceptable noise levels at airports. Three classes of alternatives exist to achieve such noise environments; these are source, path and receiver options. One series of questions to be addressed is how much source noise abatement, when, and what types are justified under the criteria of minimizing the costs of attaining and achieving acceptable noise environments around the nation's airports. Another aspect to be examined is how source noise abatement alternatives can be financed without disrupting the economic health of the airlines.

Subsequent discussion will cover the following areas:

- the disbenefits of noise,
- the costs of retrofit alternatives,
- resource requirements of achieving and maintaining a noise environment consistent with Public Health and Welfare requirements,
- cost incidence and timing problems associated with financing any of the retrofit alternatives.

A. The Disbenefits of Noise

In its report to Congress (Ref. 1) the EPA recognized that the direct primary effects of noise on Public Health and Welfare are, the potential for producing a permanent loss in hearing acuity, interference with speech communications, and the generation of annoyance. The possibility of indirect effects of noise is also admitted, but there does not exist sufficient evidence for their citation at this time.

These noise effects influence such factors as an involuntarily exposed person's daily activity schedule and enjoyment. It follows that if the presence of noise affects these factors, then a person's utility function is affected adversely. When these adverse effects are aggregated to an impacted public around a noisy airport, it follows that activities can be affected not only in the impacted area but also at an exposed person's place of employment.

Typical results of the primary effects of noise are:

- the relative attractiveness of real estate can be affected;
- the delivery of pulic services is affected, e.g., interruptions of educational instruction;
- interpersonal relationships can be aggravated;
- continual or repetitive annoyance can manifest itself as tension and stress;
- on the job performance, i.e., productivity, can be affected.

These results demonstrate the insidious nature of noise on a person's or community's physiological, social and economic well-being.

Reduction of the noise environment will reduce the magnitude of these cited results. However, the relationship between reducing noise environments and the magnitude of noise impact reductions is not known. There exists a national estimate of the number of people exposed to various cumulative aircraft generated levels of noise as is shown in Figure 10. However, there does not exist an understanding of what it means in terms of benefits of removing one person from an 80 Ldn environment vis-a-vis removing two persons from a 70 Ldn environment. The reason for this situation is that insufficient research to quantify the benefits of noise reduction has been performed to date.

Not having quantitative estimates of the benefits of noise reduction precludes any analyses of the amount of noise environment reduction that is justified on a cost-benefits basis. Consequently, the subsequent analyses will use a cost-effectiveness analytic framework.

B. Costs of Achieving Cumulative Noise Levels

Achievement of any desired day-night exposure level can be realized by combinations of reducing source nose impacts and protecting noise sensitive receivers. Noise impacts are defined as population exposed to various day-night noise levels.

Reduction of noise impacts can be accomplished by retrofitting the commercial aircraft fleet with source noise abatement technology, implementing noise abatement takeoff and landing procedures, and exercising airport operational controls such as preferential runways, restrictions on flight frequencies, etc. Protection of noise sensitive receivers can be accomplished through the soundproofing of residential and other sensitive structure or through the relocation of existing incompatible land uses. In essence, achievement of a desired cumulative day-night noise exposure level implies separation of incompatible, noise sensitive land uses from specified levels of noise impact.

Actions to reduce noise levels by existing aircraft source abatement and operational options may not totally eliminate noise impacts at a given cumulative noise level. In such cases, additional actions must be taken to either soundproof the structures in the noise sensitive areas, or relocate the incompatible land uses which remain after the source noise impact options have been implemented. It should be recognized, however, that there exists a limit to the effectiveness of soundproofing technology. For those receivers exposed to noise which cannot be effectively reduced to compatible levels by soundproofing, the only remaining alternative is relocation. The technological limitations of soundproofing and the associated cost of same may be found in Chapter 4 of Reference 5.

The cost of achieving any given Ldn level is defined as being the cost of implementing noise source abatement technology and airport/aircraft operational options, plus the resource requirements of soundproofing or relocating those noise sensitive receivers which remain impacted at some noise exposure level after technological and operational options have been employed. As previously mentioned, the economic question addressed here is what combinations of these option result in the most efficient or cost-effective, approach to realize several values of Ldn (e.g., 80, 70, 60) around the nation's airports.

To implement a soure noise reduction alternative into the existing fleet requires time to fabricate, demonstrate, certify and install the kits on the aircraft. This time element plays an important role in the dynamics of noise level achievement in that the total costs of a retrofit program, the fleet mix, levels of operations and urban growth vary with time. As an example, by the 1978-80 time period, fleet noise levels are expected to be relatively lower than those of today's fleet because not as many, if any, straight jet aircraft will be operating in the fleet and the capaciaty represented by these aircraft, and all other retired aircraft, will have been replace by "quieter" aircraft. Lower fleet noise levels translate into reductions in the areas of Ldn contours around airports which in turn imply less impacted populations, if and only if, land use development around airports does not result in increased population densities surrounding the airport. Also, with the passage of time, the retrofit candidate set of noisy aircraft should also decrease because they are the vintage aircraft in the current fleet. These are the general trends used in the subsequent analysis.

(1) Cost Analyses of Retrofit

To determine the impacts of the proposed retrofit alternatives on airline industry economics, several assumptions had to be made on how the economy is expected to perform and whether the industry will become more efficient during the time period of interest. The DOT studies from which this analysis has been performed assumed that the economy would continue to grow at a rate of four percent real growth per annum. In addition, an industry average flight load factor of 55 percent was assumed to be reached by 1978 (Reference 25).

Under these assumptions, estimates were developed of passenger and cargo traffic growth on an annual or specific future year basis. Given the productivity of each type of aircraft, their respective numbers in the current fleet, and individual airline equipment retirement and acquisition schedules, estimates of the fleet mix at points in time are made. From these data, candidate fleets which would be affected by each retrofit alternative can be identified. Table 7 shows the retrofit candidate fleet mixes resulting under the above assumptions (Reference 26).

The effects of the energy supply shortfall situation on the assumptions used and the candidate fleet mix estimates are such that these estimates might be viewewed as optimistic. The real growth rate of the economy over the next several years will be significantly below the long term rate of 4 percent per annum that was assumed in the cited studies. The situation should result in depressing traffic demand estimates for the time period of interest. In addition, recent flight frequency cutbacks and apparent transportation modal substitutions have resulted in load ally discounted the current dollar values of each cost element by the assumed 3% per annum inflation rate. The resulting 1973 dollar values of each cost element were then divided by the number of aircraft associated with a retrofit option such that an average cost element per aircraft resulted. Shown in Table 7 are the unit values used in calculating total retrofit costs. Shown in Table 8(a) are the maximum case estimates of the total retrofit costs of each alternative for the U.S. fleet. The costs to the rest of the world fleet are also included here to reflect the maximum financial impact of a regulation requiring implementation of any of the retrofit alternatives.[1]

Shown in Table 8 (b) are the estimates of total retrofit alternative costs assuming the retrofit candidate fleet mixes listed in Table 7. The estimates are presented in 1973 dollars and current dollars, assuming a 3 percent rate of inflation. These current dollar calculations were presented to illustrate some problems in estimation and cost analysis.

One problem is that most of the expenditures for source, path and receiver options will at least be initiated at different periods of time; consequently, to put these expenditure streams on a comparable basis the finaancial technique of discounting these streams should be used. But to estimate a current dollar, one needs to know something about the rate of inflation expected to occur over a given period of time. For the past several years, attempts to control inflation have not been

1 In actuality, the entire foreign fleet will not require a retrofit to comply with any of the contemplated regulations. Foreign flag compliance will have to be negotiated under existing institutions and conventions.

successful and will be significantly greater than the historical rate of inflation. In addition, there are indications that actual or distributional shortages in materials will occur and further distort prices. With such factors creating aditional uncertainty in the future, assuming a particular rate of inflation does not appear prudent.

Another problem is that there are currently no time of achievement dates established for any environmental noise goal. This situation presents the calculation problem of not knowing when land use and receiver treatments options must be implemented. Not knowing this, one cannot determine the appropriate current dollar to be used or the time period with which to discount the expenditure stream.

Given these types of situations, 1973 dollars have been used in all the estimates developed. These estimates provide sufficient order of magnitude accuracy to enable the objectives of this analysis to be met.

(2) Cost Analysis of Protecting Impacted Populations

As delineated in Reference 8, persons exposed to exterior cumulative noise levels of Ldn = 80dB are subject to a significant risk of a decrease in hearing acuity. Persons subject to exterior noise levels of less than this amount exhibit behavior over the range from extreme annoyance to no activity interference at all. The degree of annoyance decreases with corresponding decreases in exterior cumulative noise levels where an exterior Ldn = 60dB appears to be the threshold where activity interruptions are of such a nature that significant annoyance is not exhibited.

For this analysis, the assumption was made that protection to the public health and welfare requires that any person exposed to Ldn > 55dB must be protected to this level or less. This level is assumed here to be the long term environmental noise goal. Actions taken to reduce a person's environment to these levels range from relocation to insulating structures.

For levels of Ldn ≥ 80dB, no structure treatment technologies are feasible. Therefore, the only feasible land use alternative is the conversion of the existing land uses to those which are noise compatible. This would require the purchase, relocation (at no expense to the affected people), razing, and redevelopment of real estate that is currently in residential use.

For Ldn < 80dB, there exist structure treatment technologies which, if implemented, will insure that noise intrusion will not affect the daily activiaties of the public inside the treated structures. Shown in

Figure [illegible] are the per capita protection costs per unit (dB) of cumulative noise exposure. The lower curve represents the minimum land use and receiver costs with no allowance for public choice of the protection option. That is, this curve does not allow one the choice between having one's structure soundproofed or to leave the high noise environment at no cost. The upper curve has been developed to reflect a more reasonable outcome of having the public choose its protection techniques. A full explanation of this unit cost curve development may be found in Chapter [illegible] of Reference 5.

Given this unit cost curve, the estimated national distribution of population exposed to various levels of noise in 1972 (Figure 10), and the percentages of exposed population that are annoyed, one can develop a national estimate of the costs to protect the public from noise pollution using <u>only</u> land use and structural treatment technologies. Utilizing such data, the total cost of using only land use and receiver treatment options to protect the public as exposed in 1972, is estimated to be in the range of 21 to 31.5 billions of 1973 dollars. How these costs cumulate by Ldn increments of 5dB are shown in Figure 12.

C. Cost-Effectiveness of Options to Achieve Several Cumulative Noise Levels

As previously stated, the reduction in the number of people living in aircraft/airport noise impacted areas is the major criterion for assessing the effectiveness of any noise abatement option. The population estimates used here are based on the 1970 census where no attempt was made to forecast population changes for future years.

Estimates of the population residing in the noise impacted areas for six airports as a function of eight different options have been made in Reference 23. The curves of Figure 13, compiled from References 25 and 26, show the percent reductions in impacted population within an aircraft noise generated 75 Ldn contours with time, and by noise reduction strategy. Note that adopting a "do-nothing" strategy and allowing for aircraft retirement will itself reduce the impacted population within the contour. Adoption of a 2-segment approach will reduce population impacts even further. Retrofit of source noise abatement technologies can be seen to be highly effective in reducing population impacts even further. Retrofit of source noise abatement technologies can be seen to be highly effective in reducing population impacts.[1] One should recognize that the lower the population impacts, the lower are the land use and structural treatment costs to achieve a given cumulative noise level.

1 It is recognized that the relative effectiveeness of the options investigated is highly sensitive to the airport being analyzed. However, the six airport set on which these data are based represent a reasonable spectrum of the impacts. For this reason the developed impact variation estimates are felt to be representative.

This normalized curve of population impacts, along with another for Ldn = 65dB, were applied against the static data on the national estimate of impacted population by (Ldn) level (Figure 10) to estimate the remaining population impacted, after the passage of time and exercising each of the noise abatement options.[2] From these data on population remaining in an impacted area after an option has been exercised, one can develop estimates of the land use and structural treatment costs to achieve any level of cumulative noise. It is in this manner that the data for both the costs and effectiveness of the different combinations of options to achieve a cumulative environmental noise level have been developed.

Shown in Table 9 are the national estimates of percentage reduction of airport noise exposed population by implementing six aircraft noise abatement options and the cost implications of achieving three separate day-night levels (Ldn). See Note 4 of Table 9(b) for business jet impact.

Before discussing the effectiveness and environmental noise level achievement cost estimates, a basic shortcoming in the data must be outlined. Briefly, the set of airport noise reduction options, which minimize the population exposed, is unique at each airport due to the local topography, demography, runway orientation, flight frequencies, etc. This uniqueness precludes an accurate extrapolation to a national estimate at this time because sufficient data on the effectiveness of each option for an adequate number of airports are not available. The "best

2 For a full discussion of this national extrapolation see Chapter 4 of Reference 5.

estimate" of the combined national effectiveness of these airport options is that as much as a 50 percent reduction in the remaining impacted land area can be expected; the remaining impacted land area is that residual remaining after adjustments for source and path alternatives have been made. Implementing these options will incur additional costs which are not estimated here, such as increased operating costs resulting from possible curfews or flight frequency limitations.

Some of the data in this Table may be revised as more specific data becomes availbale, but the relative relationships shown are expected to remain.

For the situation where no source abatement options are implemented, there will be reductions with time in the constant dollar costs of achieving average day-night noise environments of 60, 70, and 80 decibels for the 1978-1980 time period as compared to those for achieving the same results in 1972 (Option a, Table 9). The assumed gradual retirement of noisy narrow body jet aircraft and their replacement with new quieter aircraft results in a reduction of the 1972 impacted areas to the extent that the impacted 1972 populations for the 60, 70, and 80 levels of day-night average noise are reduced by 19, 17, and 50 percent respectively.*

To implement a national, all weather, two-segment approach (Option b of Table 9) the aircraft must be retrofitted with the requisite instrumentation and the airports must also adjust and/or install attendant

*This assumes no change in population distribution with time in the impacted areas.

instrumentation. These requirements are estimated to cost some 67 millions of 1973 dollars to implement (shown as 100 million in Table 9 due to rounding) (Reference 3). Implementing this option will reduce the number of people exposed to the Ldn levels of 60, 70, and 80 decibels by 22, 23 and 50 percent respectively in 1978 as compared with 1972 estimates. The cost to achieve outdoor environments of Ldn = 60, 70, and 80 decibels for those people still impacted are estimated to be 22.3, 13.2 and 1 billion dollars, respectively. Note the achievement costs for a 70 Ldn environment have dropped from 15.5 billions to 13.3 billions of 1973 dollars. Thus, if 70 Ldn was the level to be achieved, implementing a two-segment approach would be desirable since the savings in achievement costs more than offsets the implementation costs of the two-segment approach.

Retrofitting the entire commercial fleet with Quiet Nacelles (QN) and implementing the two-segment approach, all of which can be accomplished by 1978, will reduce even further the levels of 1972 impacted population and the achievement costs. The combined costs of implementing the requisite hardware and instrumentation, plus the resulting increase in operating expenses and lost productivity to the airlines, are estimated to be nearly one billion 1973 dollars. For these technology transfer costs, the 1978 impacted populations at 60, 70, and 80 Ldn reflect a reduction of 25, 35, and 100 percent*, when compared to 1972 estimates, respectively. Costs of achieving the Ldn levels for

* Due to the estimating procedure it is acknowledged that particular airport problems will result in residual population remaining. For 80 Ldn it is estimated that less than 50,000 people will be exposed to such levels where the percent reduction is stated as 100.

the remaining population are estimated to be 20.4, 11.1, and 0.9 billions of 1973 dollars. Again it should be noted that these achievement costs may be significantly reduced by the effective implementation of airport operator options.

Retrofitting aircraft with refanned engines would start at a later date and not be completed until 1981. In addition, the investment and operating costs of this technology option are significantly higher than those of the previous options discussed. Offsetting these costs is their increased effectiveness in reducing the percentage of 1972 population exposed. Consequently, the total implementation costs (including residual land use costs) of achieving various outdoor noise levels decreases. In every case, the savings in achievement cost exceeds the cost of aircraft modifications. These data may also be found in Table 9.

These decision data on the effectiveness and cost effects of the various noise reduction options can be used as a base to design an effective airport environment noise reduction program. Different design strategies can be developed taking into account technology transfer and total achievement costs plus various degrees of risk. Table 9 indicates that there are potentially greater reductions in impacted population with Refan retrofit than with QN retrofit options. However, the QN technology can be implemented earlier at lower cost and the resulting noise reductions are more reliably known. A decision to rely entirely upon Refan retrofit will result in a minimum three year delay of relief for some of the population. In addition, if the Refan's performance is less than predicted, then the final population results and costs of achievement will be less favorable than expected.[1] The considerations for QN retrofit are earlier relief via demonstrable technology but higher land use costs to achieve a compatible noise level. However, reliance only on the QN retrofit may preclude the possibility of a more effective and financially equitable solution by not allowing for the technological potential of the Refan Program. There is an intermediate strategy which would accommodate a continuous program of further noise relief via technology.[2] This is to initiate prompt actions to retrofit the fleet with Quiet Nacelles. If the NASA Refan Program is demonstrated to be successful, then that portion of the fleet which has not already been retrofitted with QN could be retrofitted with the Refan technology. The NASA Refan Program should be accelerated, if evaluation of the potential results should indicate that this will maximize, in a cost effective manner, reduction in airport noise exposure. <u>This strategy could be achieved effectively under an FNL type regulation.</u>

To achieve any cumulative noise level, the more rapid the technology and airport options are implemented, the smaller will be the land use option financial requirements. This fact suggests that in order to minimize the costs of achieving a given level (Ldn) of noise exposure, the feasible options of a noise reduction program must be expedited.

1 The current series of DOT 23 airport studies are using the minimum Refan effectiveness numbers as inputs. The expected results are that population reduction impacts will not be as drastic as indicated in Table 9 which is based on maximum Refan effectiveness.

2 It may be economically reasonable, and desirable, to subsequently Refan the entire JT8D portion of the fleet.

In terms of the economic question of which combinations of options are the most efficient to achieve a desired cumulative outdoor noise environment level, the following findings can be stated:

- The costs of transferring aircraft source noise abatement technology into the civil aviation fleet are always less than the costs of achieving a cumulative noise level without such transfers.
- Aircraft source noise reduction technology alone cannot eliminate the outdoor noise environment problem around the nation's airports.
- Two-segment approach procedures cannot be fully implemented into the civil aviation fleet until 1978 at the earliest; however, intermediate relief can occur before this period by the effective exercising of other fleet operational procedures, airport operator options, and local government land use options. Such intermediate relief must occur, especially the curtailment of further encroachment of population around airports, if the costs of achievement are to be kept at a minimum.

D. Cost Allocation and Financing

Now that the relative contributions of each option to achieve a level of cumulatiave noise exposure have been established, two issues with respect to retrofit must be addressed: (1) who should pay for the costs of retrofit, and (2) how should such a program be funded or financed?

There are a number of cost allocation alternatives which can be determined by various legal/institutional plans. The first is to let the costs fall where they may. Under such a system, the aircraft operator along with the passenger and shipper would absorb the cost of noise control devices. A second possible allocation plan would shift the cost of noise control abatement to the general taxpayer through governmental subsidies to airlines for the implementation of noise control technology. Due to market or institutional imperfections, the cost allocation method selected may never exist in pure form. For example, attempts to shift cost to general taxpayers or air transport consumers may not be wholly successful, due to the legal inability in either the short or long term to adjust landing fees, tax rates, or government subsidies.

Furthermore, the distinction must be made between short term financing problems vs. the issues of long-term cost allocations. To install noise abatement equipment creates serious short-term capital finance problems for the airlines. Solution of this problem is a separate though related matter from the question of how such noise abatement cost will ultimately be allocated. Both issues must be addressed and solved.

(1) Allocation of Costs

In economic terms, aircraft noise is a "technological externality". That is, the public costs of noise are not included in the price of air transportation services. Because of this price system defect, these costs therefore fall on economic activities other than those which produce the cost. Economic "welfare" doctrines hold that if the beneficiaries of a given level of air transportation could fully compensate those persons subject to the noise impacts thereof, and still acquire some net benefit, then that level of aviation which produces the noise externality would be economically justifiable. [1]

In order to promote the most efficient and rational use of air transportation, economic "efficiency" criteria dictate that air transport beneficiaries must pay the full cost of providing air service, including seccondary costs such as those of abating pollution. Economic principles suggest that where such costs are fully internalized, i.e., are included in the price of the service, consumers can more rationally choose among different modes of transportation (Ref. 27). Only if all costs, including those engendered by noise, are internalized into the aviation industry, will users, beneficiaries and operators of air transport be able to adequately balance all factors in making the most efficient investment and operational decisions. However, in the case of aviation, a large measure of the research and development has already been accepted as proper expenditure on the part of the Federal govern-

1 For a detailed discussion of welfare criteria, W. Baumol, "Welfare Economics and the Theory of the State". Harvard University Press, 1962.

ment, and thus that portion of the cost of control is being borne by the public at large, as a public benefit charge. Likewise, since financing of major projects such as airport land redevelopment may involve the use of traditional methods of financing, the cost of interest and bond retirement may be broadly spread beyond a purely classic internalization of costs. The following [illegible] also highlights the practical side of this complex issue.

(2) Financing of Costs

Information available at this point indicates that development and implementation of noise control and abatement strategies necessary to achieve specific noise exposure levels will require substantial financial resources. While a few strategies, such as new operating procedures, would not incur large capital investment or increased operating costs, a comprehensive source noise abatement program -- including research and development of engine noise control technology, and retrofit -- will necessitate a major commitment of financial resources and the development of financing methods. Without adequate financing mechanisms, expeditious implementation of a comprehensive program to alleviate the most severe airport noise impact problems will be impossible.

Implementation of such a retrofit program will entail commitment of financial resources in a number of public and private sector expenditure areas. For these areas of expenditure, financing methods must be found if the contemplated comprehensive noise reduction program is to be successful. A variety of mechanisms have been suggested to fund these expenditure areas (Ref. 2). The basic alternative is private marked funding of the program elements. However, depending upon the degree of source noise reduction requirements, private funding capability is estimated to be exceeded.[1] In this case, other retrofit financing alternatives must be employed. Examples of such alternatives are:

- A passenger head tax and freight tax, of a set amount (e.g., per person and per pound) imposed on all commercial air transport, either "at the gate", or as a surcharge on tickets and freight invoices.[2]
- Head and freight tax imposed only at noise-impacted airports.
- Expanded use of the Airport and Airway Development Act Trust Fund, for use in grants to airlines for noise abatement.
- A surcharge on the aircraft fuel tax.
- A general fare increase, either by a fixed amount (e.g., $1 a ticket) or, on a percentage basis (e.g., 1 percent per ticket).
- Grants to airlines financed by general tax revenues.
- Government-guaranteed loans to airliness.

Since it is estimated that the airlines cannot finance the contemplated retrofit program, the natural inclination is to recommend that tariffs be allowed to increase such that a reasonable rate of return can be realized by the industry so as to attract private financing for the retrofit

1 Reference 28 estimates that the airline industries financial health is such that private financing of retrofit is not feasible. Reference 29 corroborates these estimates.

2 The head tax at the gate scheme has just been prohibited by Congress in the recent (P.L. 93-44) AADA two-year appropriation act.

program. In fact, if the CAB allowed a general tariff increase for this reason, windfall profits would be realized by some airlines. This results from the fact that a retrofit requirement will affect the airlines differentially (Ref. 24). Government guaranteed loans will most likely not result in the desired alternative of private financing because the added debt structure will also be differential across the airlines. For these reasons, it appears that some sort of a plan is necessary to collect and distribute funds generated from increased tariffs for retrofit so as not to alter the competitive and financial relationships in the airline industry. The structure of such a fund must be determined from the answers to the following questions:

- Who has authority to adopt the plan?
- How could it be designed and administered?
- What would be the cost incidence -- that is, if adopted, who would ultimately pay for the cost of the noise abatement expenditures so financed?
- How appropriate is the plan for financing the expenditures required for a fleet retrofit?

Answers to these questions have not yet been developed. However, from the options delineated it appears that Federal legislation and/or administrative action might be required to establish the fund, prescribe the uses, designate the agency responsible for disbursement, set the amount of the charge, identify methods of collection, and determine the life or time period of the fund.

As an example of the types of answers to the questions posed, Reference 25 investigated a user tax approach to financing retrofit of several noise abatement technologies. This study found that a 1% domestic passenger tax, plus a 1% domestic cargo tax plus a $1 international enplanement tax could possibly generate sufficient funds to finance the fleet retrofit over a period of six to nine years. However, the CAB required ROI was not considered, nor the administrative costs of the fund. For these reasons, the tax rates and enplanement charges should be expected to be larger. The period over which the fund exists should also be shortened to more realistically reflect the remaining operational life of the retrofitted fleet, e.g., 5 years.

Finally, retrofit as an effective strategy to achieve an environmental noise goal around an airport is to some extent dependent on international cooperation. This is so due to the level of foreign flag air-carrier activity at a number of domestic airports. Questions as to whether, and how these nations would comply with a domestic regulation requiring retrofit have not been addressed in this analysis. It is hoped that in subsequent development efforts of this project report, that these factors can be considered.

7. CONCLUSIONS

The capability for aircraft source noise reduction is time dependent and based upon an effective program of technology research, development, and demonstration. The fact that the capability exists does not mean, however, that it will be implemented. Some motivation is necessary to insure that the aviation community will use the technology as it becomes available and to continue to develop new technology for future use.

Regulations are the most effective technique for exploiting available noise control technology and, if properly constructed and implemented, they can provide the necessary incentive to insure continuing effort directed to technological advancements.

State of the art technology has progressed to the point where viable options of Quiet Nacelles are available to retrofit existing JT3D and JT8D propelled airplanes for compliance with FAR 36. Furthermore, the FAA has published a NPRM which would be adequate (with only minor changes) to insure that state of the art technology was implemented within a reasonable period of time. The time period and technology is also adequate to retrofit all other U.S. registry civil airplanes that are expected to be engaged in air commerce at the end of that time period.

Near future technology is represented by the NASA Refan program which is directed to JT8D propelled airplanes. The potential is high that airplanes with refanned engines can achieve with performance benefits lower noise levels than the same airplanes with Quiet Nacelles.

However, several more years are required for development, test demonstrations, performance assessments, airworthiness certifications, and tooling before the potential is verified and Refan becomes available as a retrofit option. It is conceivable that Refan could be judged viable for new production airplanes and not for the existing fleet, so that the time required for completion should not be cause for cancellation of the program.

Furthermore, it is not necessarily unreasonable to consider a re-retrofit (or double retrofit) program for JT8D propelled airplanes because Quiet Nacelles can be installed at modest cost. If JT8D refan retrofit should have significant demonstrated capabilities for noise reduction and performance gains, the health and welfare benefits might far outweigh the financial loss resulting from scrapping the Quiet Nacelles that have already been installed.

For example, Table 3 shows that the unit costs of Quiet Nacelles would be relatively small compared to refanning; the range is from 10 to about 18 percent, depending upon the airplane (727, 737, and DC-9). Also from Table 3, the investment cost of Quiet Nacelles for the United States JT8D fleet is seen to be only 215 million dollars or about 11 percent risk in investment funds for Quiet Nacelles while retaining the option of an additional retrofit of refanned engines.

The FAA NPRM would be of no help in exploiting near or far future technology. Therefore, an additional regulation is necessary to insure that the results of programs such as Refan, quiet engine, and core engine can be implemented as soon as they are feasible. A regulatory concept such as Fleet Noise Level (FNL) appears adequate for that purpose.

8. RECOMMENDATIONS

The FAA NPRM given in Appendix A is a proposed operating rule (Part 91) which would require retrofit or replacement of large subsonic turbojet engine-powered airplanes. Such a rule, with slight modifications, would be effective in bringing significant relief to the public exposed to the noise of these airplanes. It is recommended, therefore, that the FAA should act promptly in publishing a rule based upon that NPRM with the modifications incorporated in the NPRM forwarded with this project report.

Paragraph 91.301 of the EPA proposed rule specifies that the regulation would be applicable to airplanes with maximum weights of 75,000 pounds or greater. However, there are a substantial number of jet propelled airplanes with lesser maximum weights that do not comply with the FAR 36 levels. These airplanes, generally known as business jets, are capable of compliance with FAR 36 by applications of various retrofit or reengine options. In fact, all newly produced business jet airplanes must comply by 1 January 1975, in accordance with the noise standards identified as Reference 13. The EPA recommended NPRM includes requirements for retrofit of the business jet fleet.

This rule would be adequate for exploiting state of the art technology such as Quiet Nacelles for the JT3D and JT8D transports, reengining for business jets, and applications of SAM or suppressor devices for miscellaneous large and small jets, or, where appropriate, replacement of noisey aircraft. However, this rule would not provide incentives for applying the results of near or far future technology. An additional regulation is necessary to insure that the results of noise research and development programs such as Refan, quiet engine, and core engine will be implemented as soon as they are feasible. Therefore, another NPRM which utilizes the regulatory concept of Fleet Noise Level (FNL) is proposed and is also forwarded with this project report.

The NASA Refan program, representing near future technology, is directed to JT8D propelled airplanes. The potential is high that Refan retrofit will be superior to Quiet Nacelles in terms of lower noise levels and performance benefits. The costs, however, would be much higher and several more years are needed before refan technology would be demonstrated superior and be feasible retrofit option.

The alternative is to proceed with straight retrofit of the existing fleet by means of appropriate state of the art technology. Refan retrofit, when demonstrated viable, could be introduced into the retrofit implementation cycle. A Fleet Noise Level rule, such as proposed herein, would be an effective "ratchet" for lowering noise compliance levels in conformance with the capabilities of the Refan technology.

JT8D Refan technology might have significant demonstrated capabilities beyond Quiet Nacelles for noise reduction and performance gains. If so, the health and welfare benefits would require that careful consideration be given to a re-retrofit (or double retrofit) program for those JT8D propelled airplanes previously retrofitted with Quiet Nacelles. The estimated maximum cost of Quiet Nacelles for these airplanes would be 293 million dollars which would be less than 12 percent of the maximum Refan cost (see Table 9).

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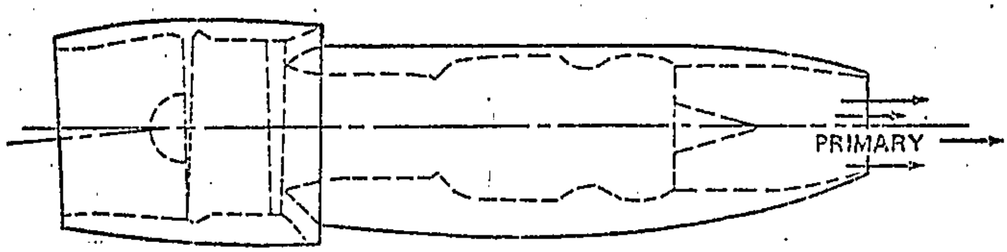
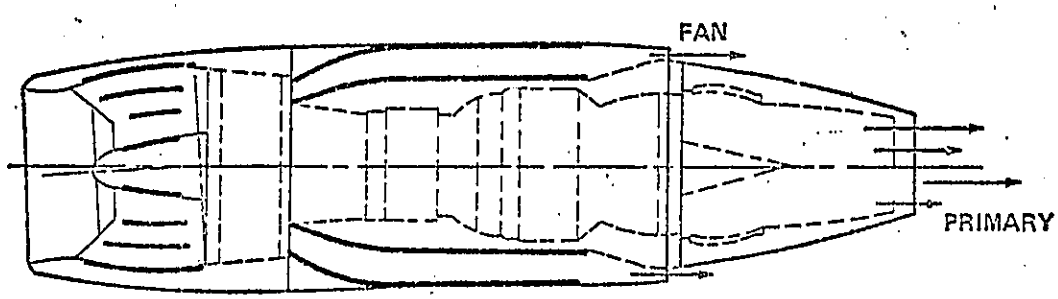


PRODUCTION STANDARD NACELLE



FAA STUDY QUIET NACELLE
(FAA CONTRACT FA71WA-2628)

—— ACOUSTIC TREATMENT

FIGURE 1. 707 NACELLE CONFIGURATIONS

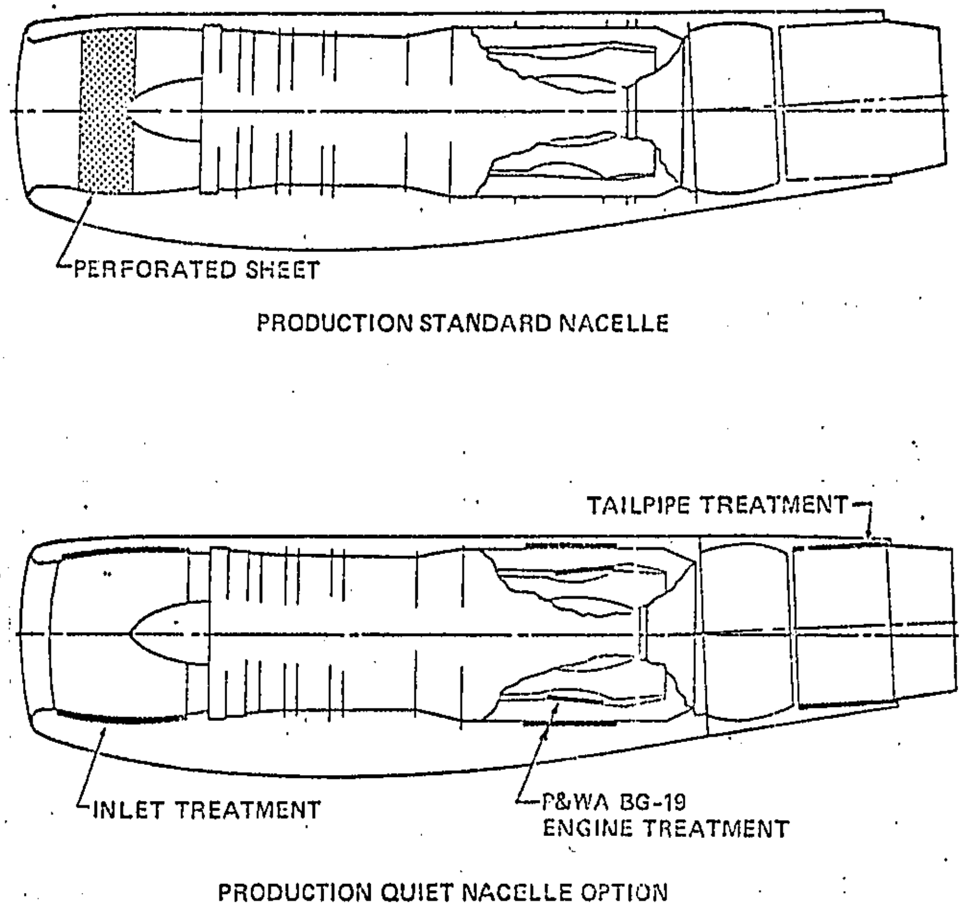


FIGURE 2. 727 NACELLE CONFIGURATIONS

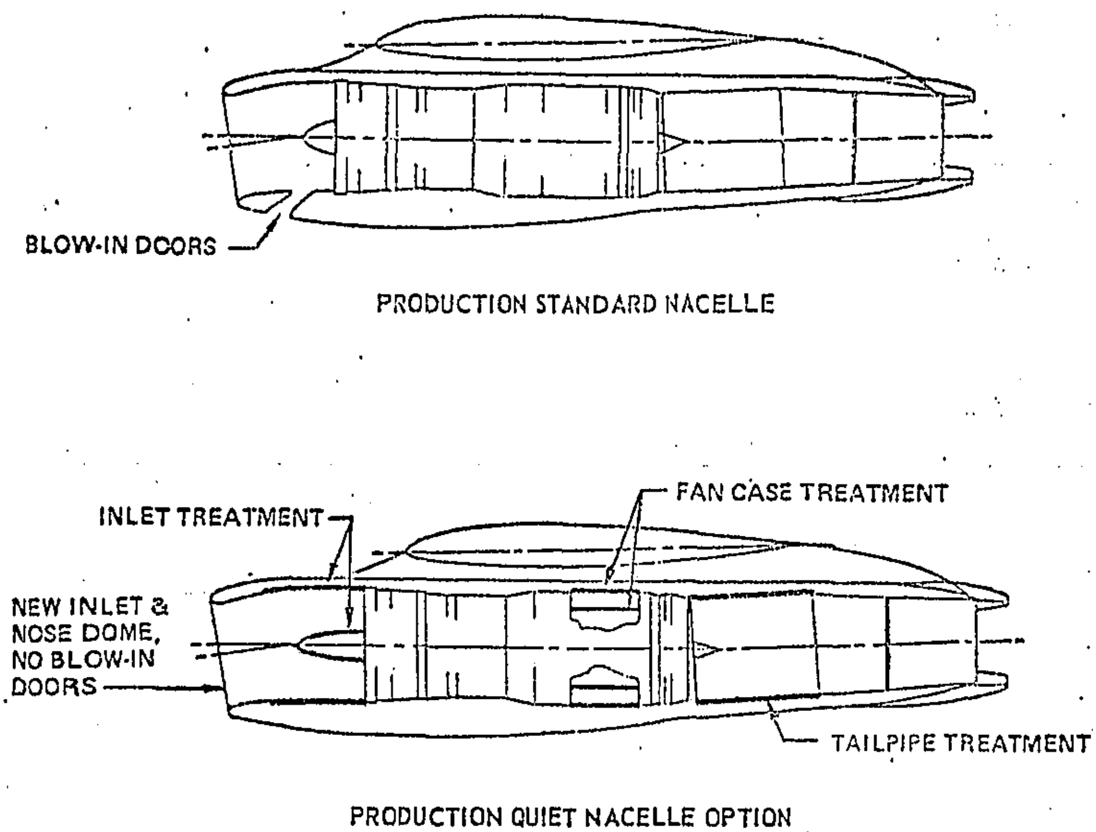


FIGURE 3. 737 NACELLE CONFIGURATIONS

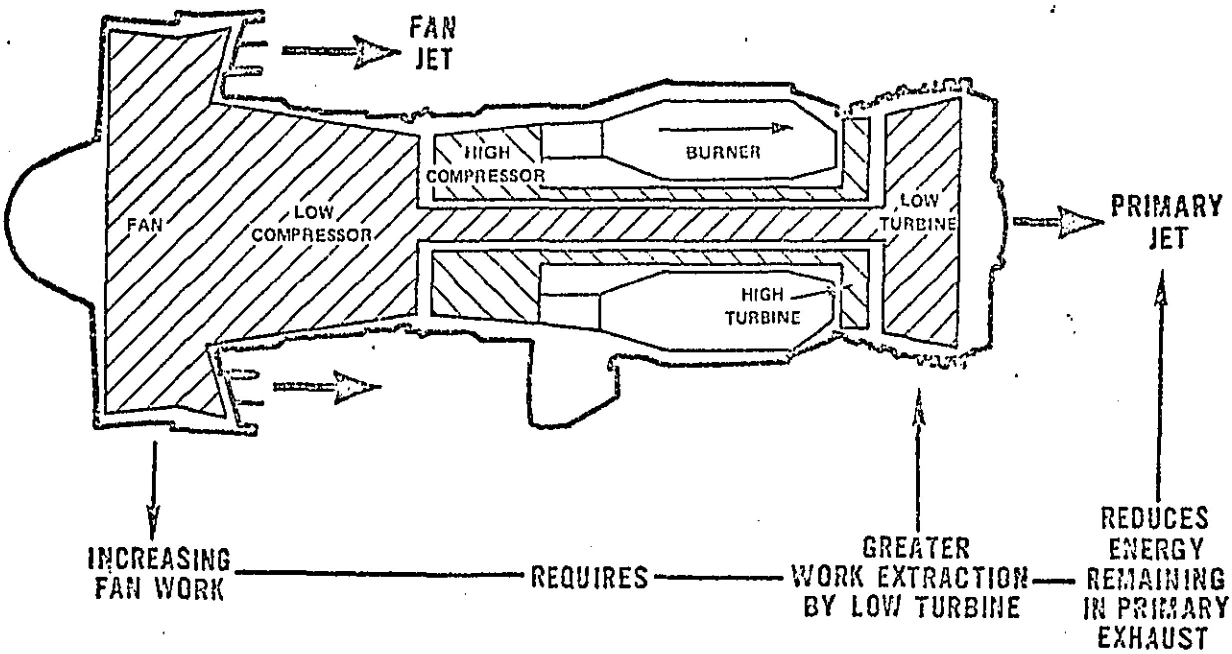


FIGURE 4. REFAN RETROFIT CONCEPT FOR JT8D ENGINES.

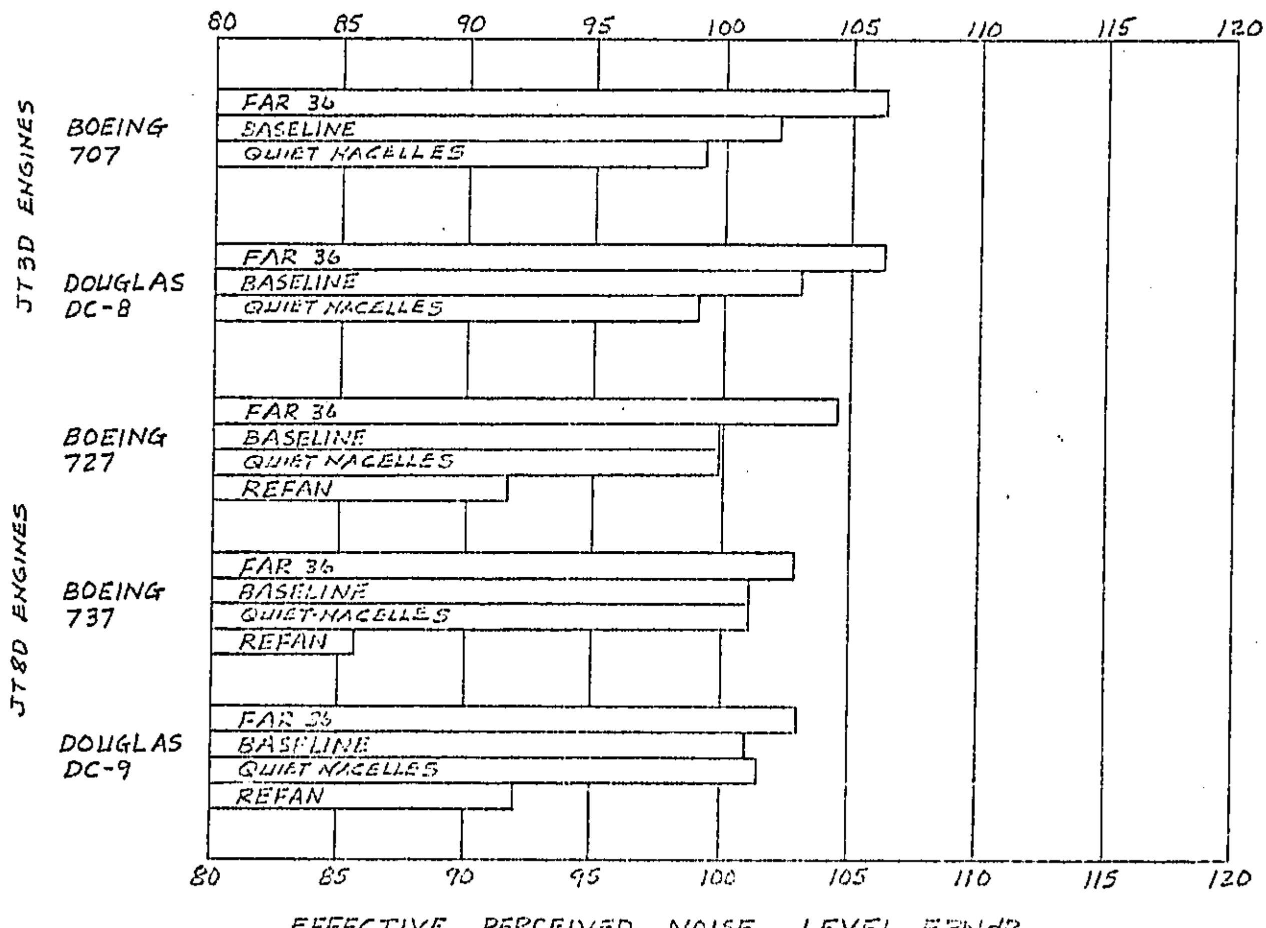


FIGURE 5. NOISE LEVELS AT FAR 36 MEASURING POINTS.
(a) SIDELINE.

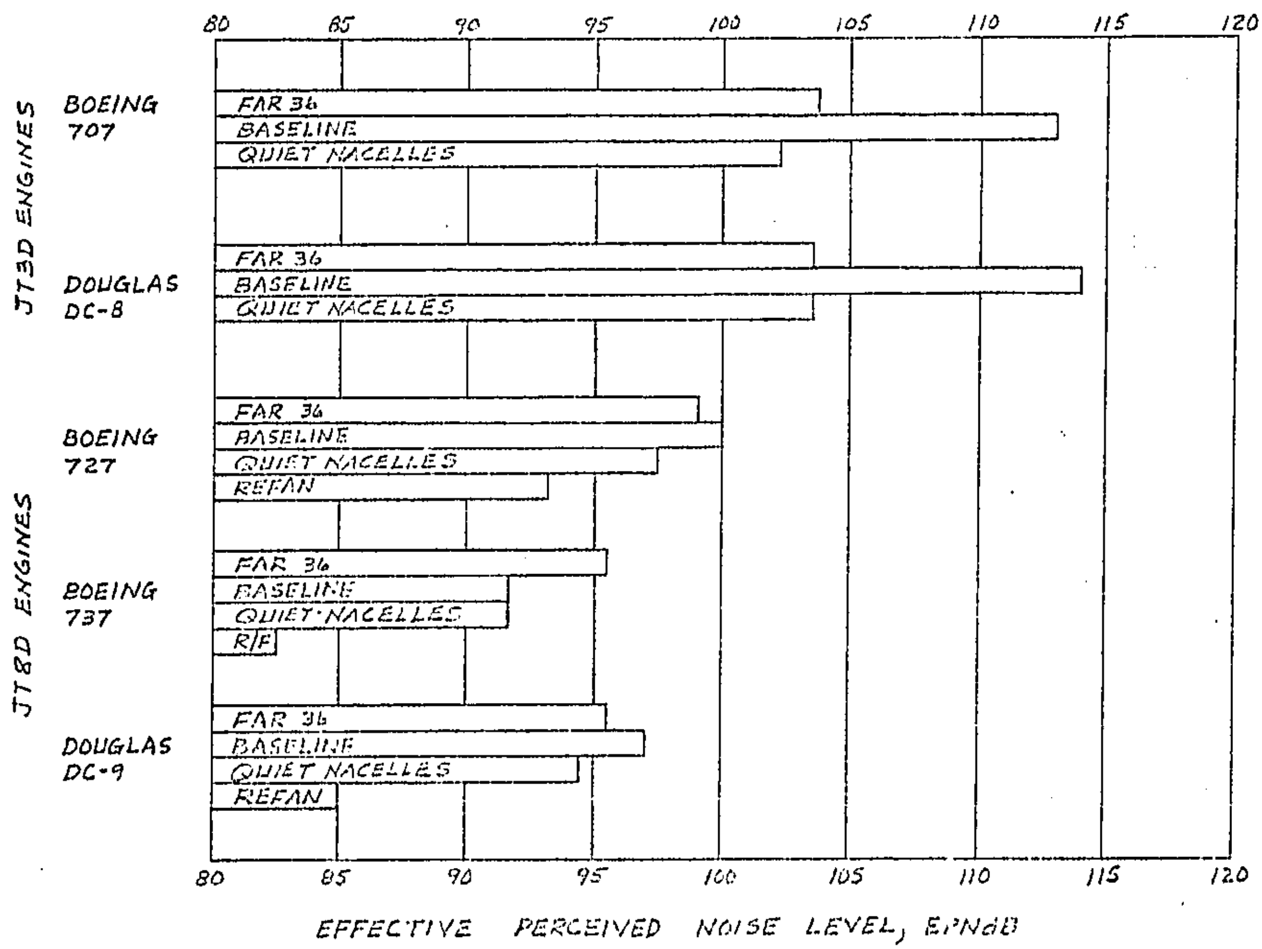


FIGURE 5. NOISE LEVELS AT FAR 36 MEASURING POINTS.
(b) TAKEOFF WITH CUTBACK.

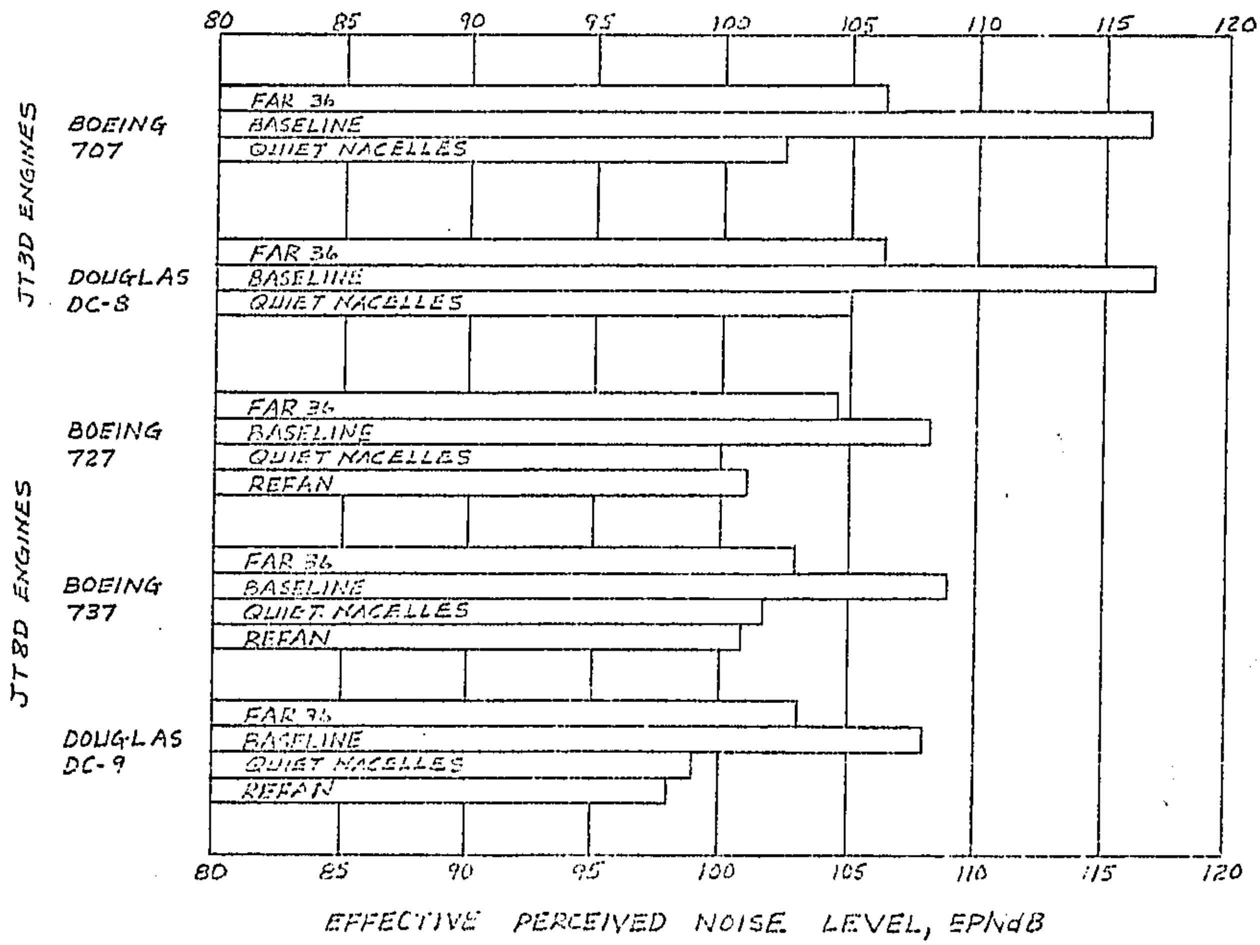


FIGURE 5. NOISE LEVELS AT FAR 36 MEASURING POINTS.
(C) APPROACH.

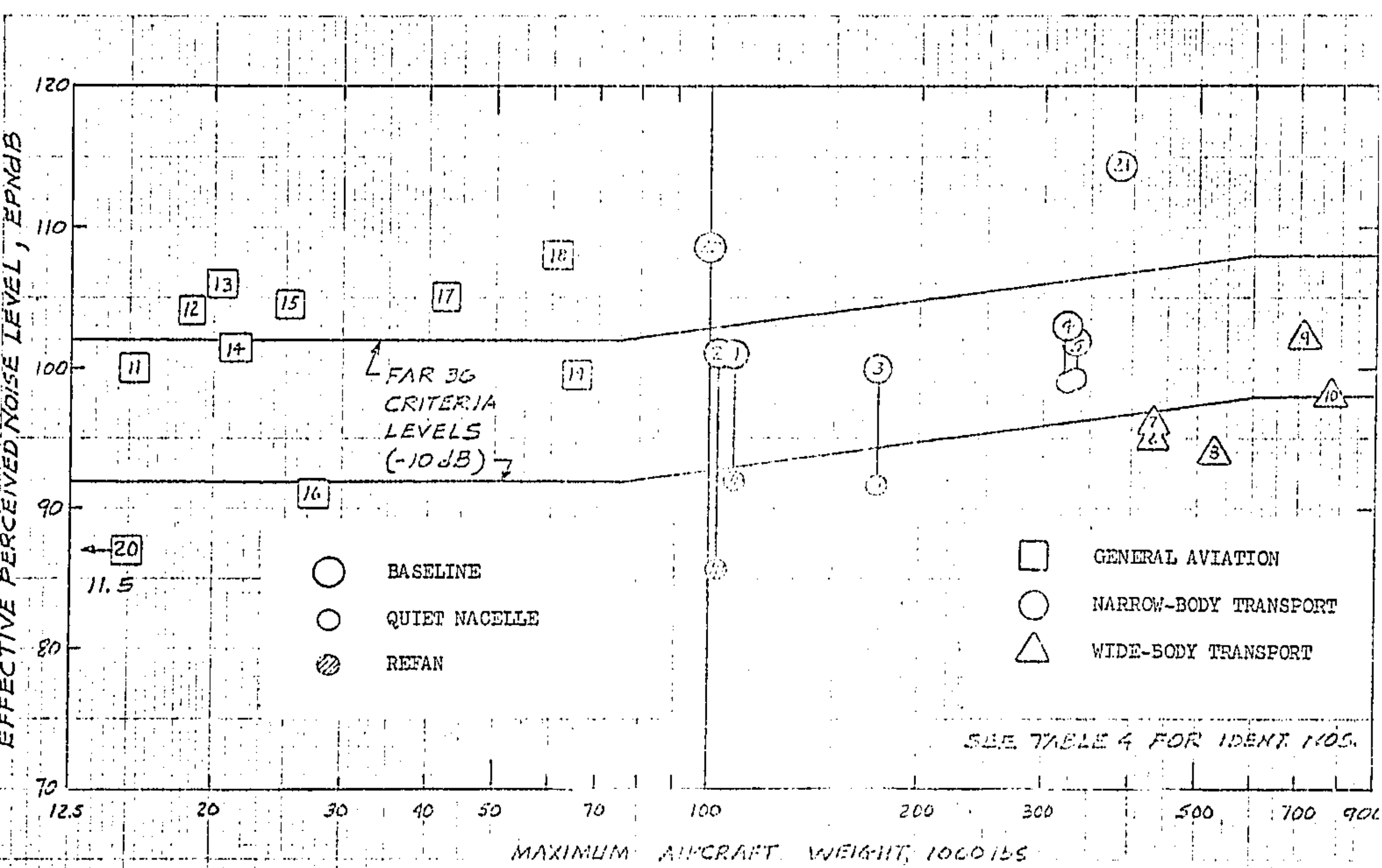


FIGURE 6. NOISE LEVELS FOR TRANSPORT AND BUSINESS JET AIRPLANES.
(a) SIDELINE.

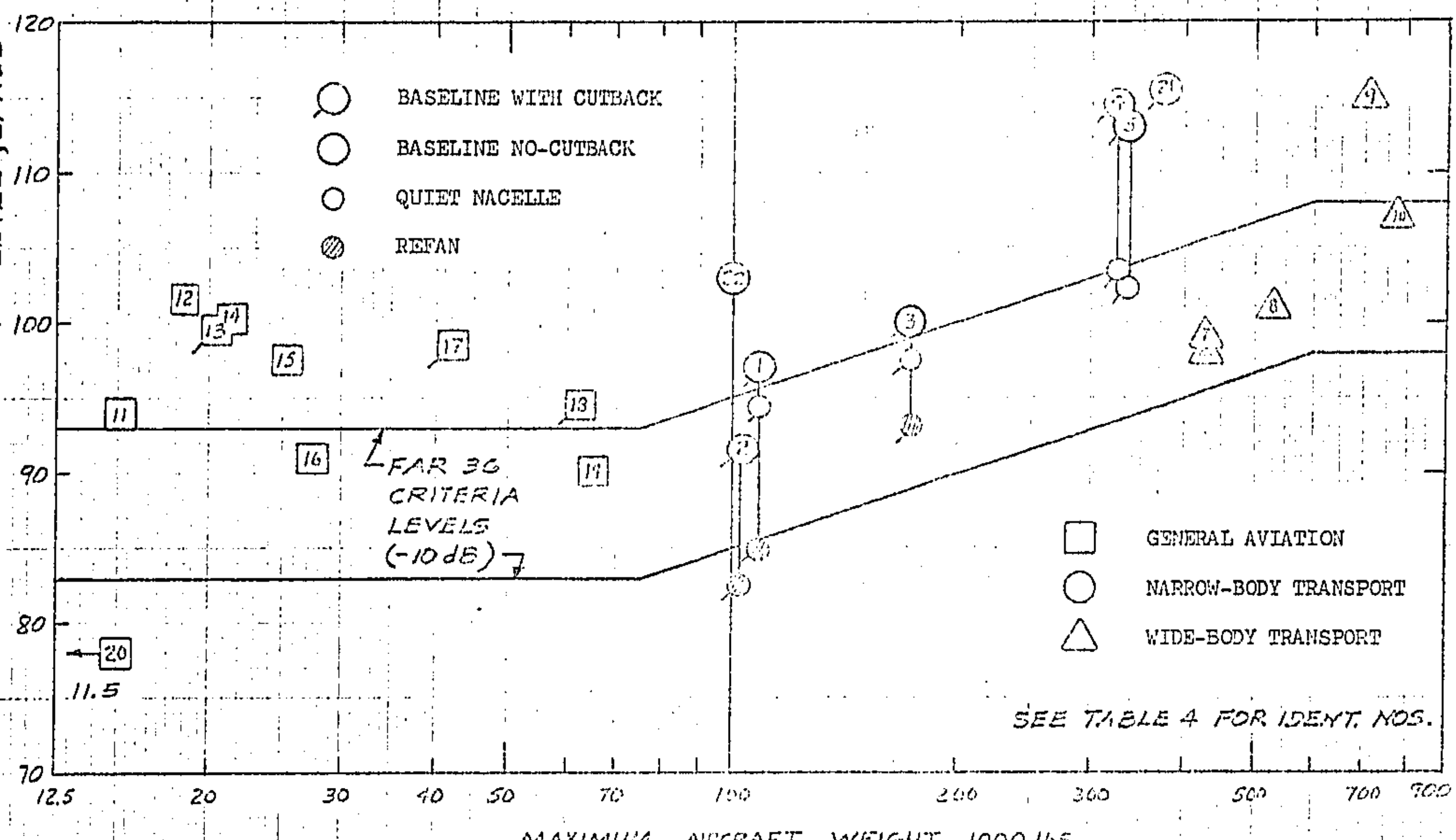


FIGURE 6. NOISE LEVELS FOR TRANSPORT AND BUSINESS JET AIRPLANES.
(b) TAKEOFF.

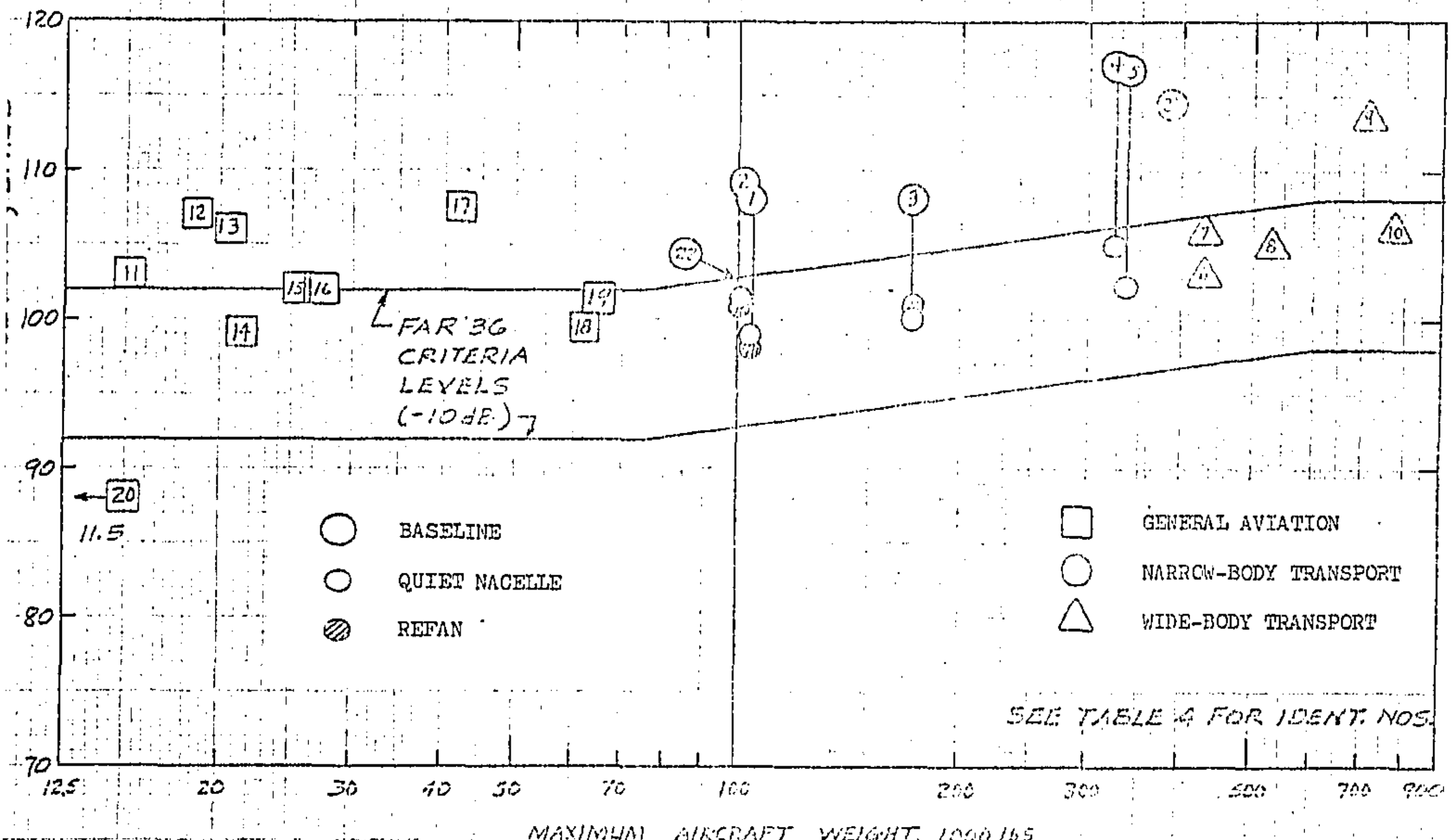
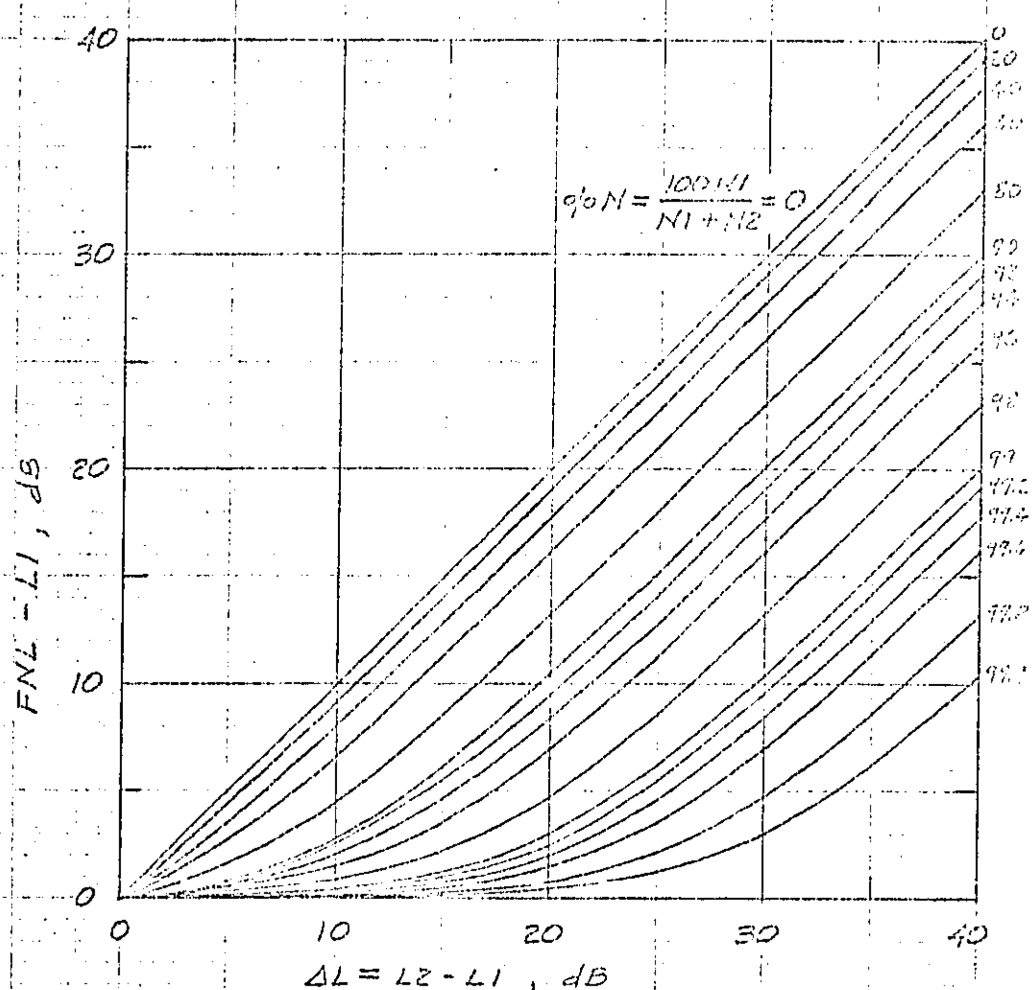


FIGURE 6. NOISE LEVELS FOR TRANSPORT AND BUSINESS JET AIRPLANES.
(c) APPROACH.



L1 = level of least noisy aircraft, dB (EPNdB)
N1 = number of operations of least noisy aircraft.
L2, N2 = same as above for noisier aircraft.
FNL = Fleet Noise Level, dB (FNdB).

FIGURE 7. FLEET NOISE LEVELS FOR TWO AIRCRAFT.
(a). VERSUS ΔL FOR 0-40 dB RANGE.

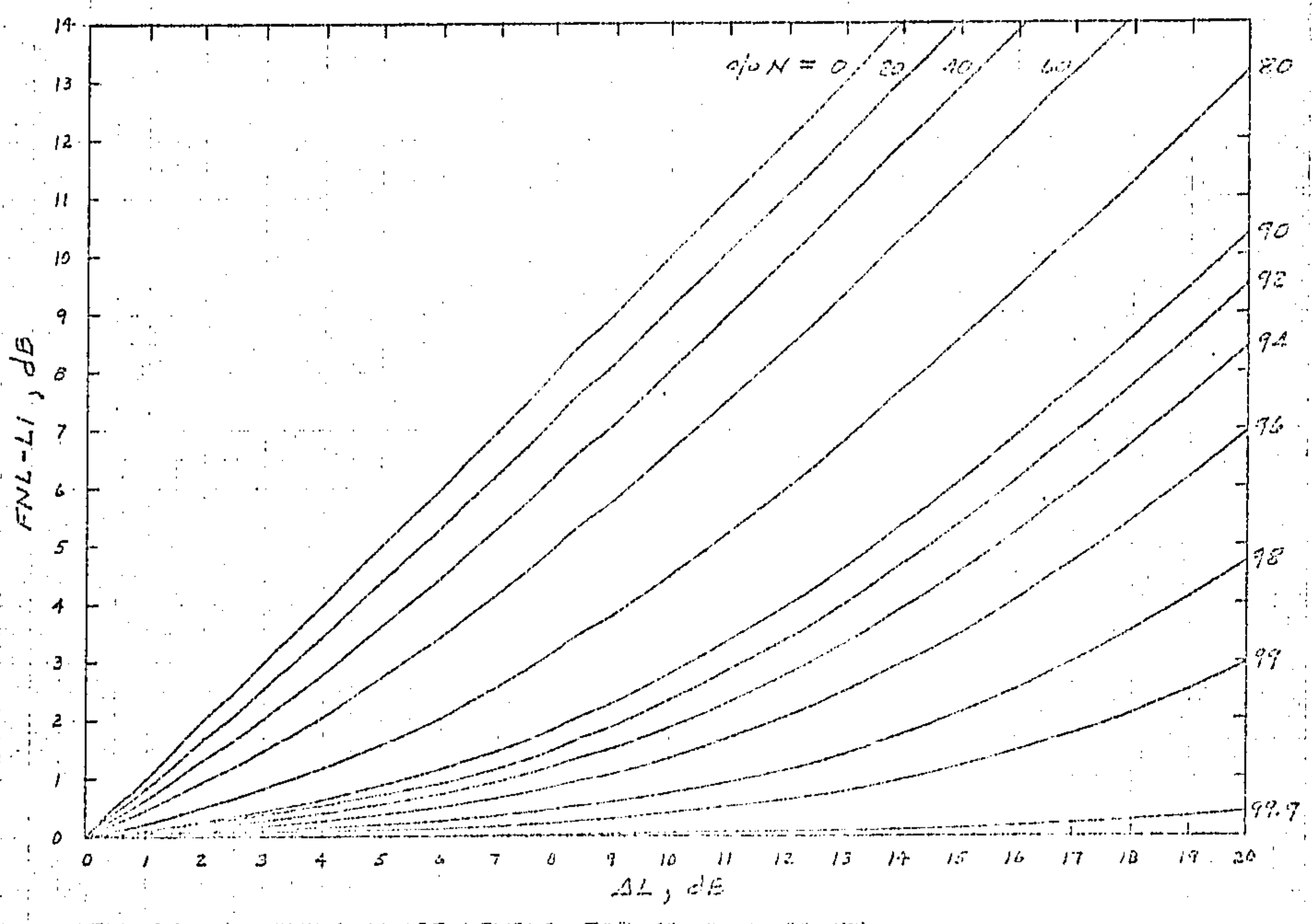


FIGURE 7. FLEET NOISE LEVELS FOR TWO AIRCRAFT.
(b) VERSUS ΔL FOR 0-20 dB RANGE.

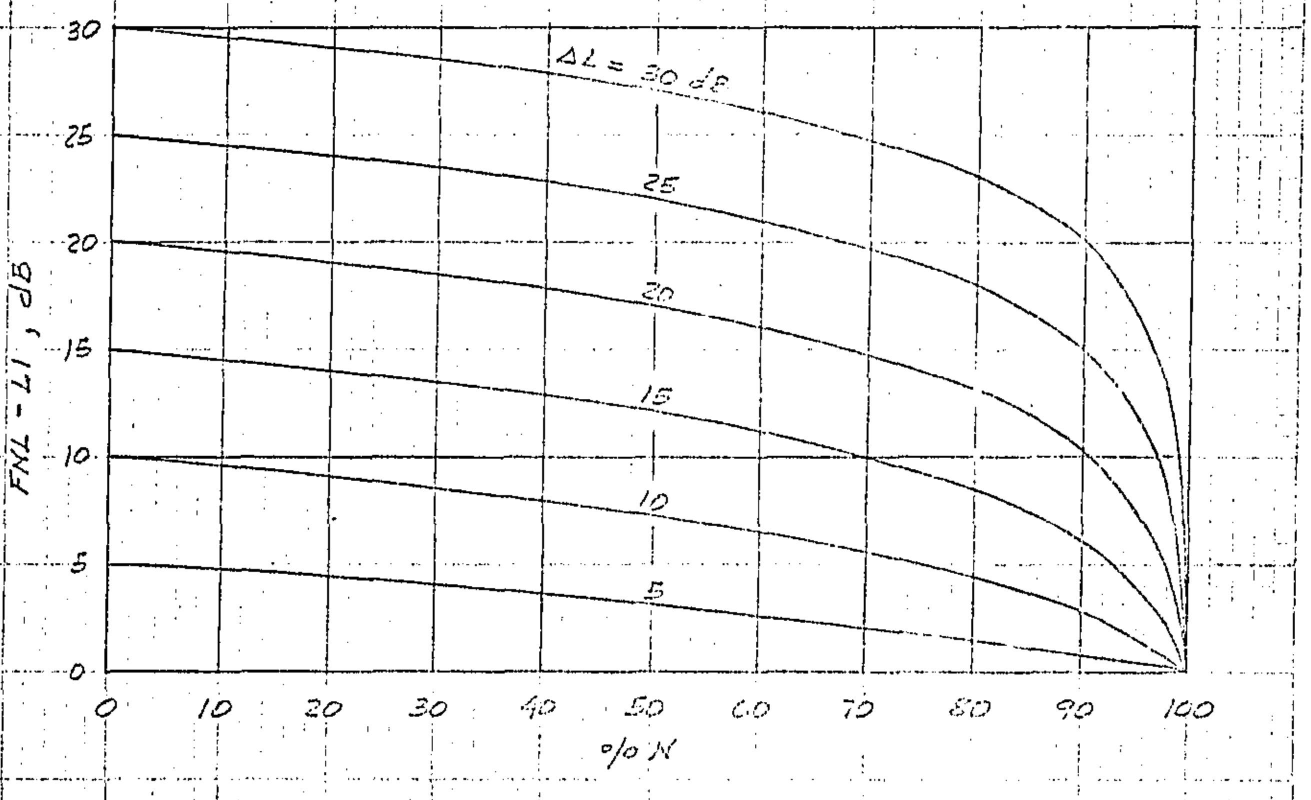


FIGURE 7. FLEET NOISE LEVELS FOR TWO AIRCRAFT.
(C) VERSUS % N

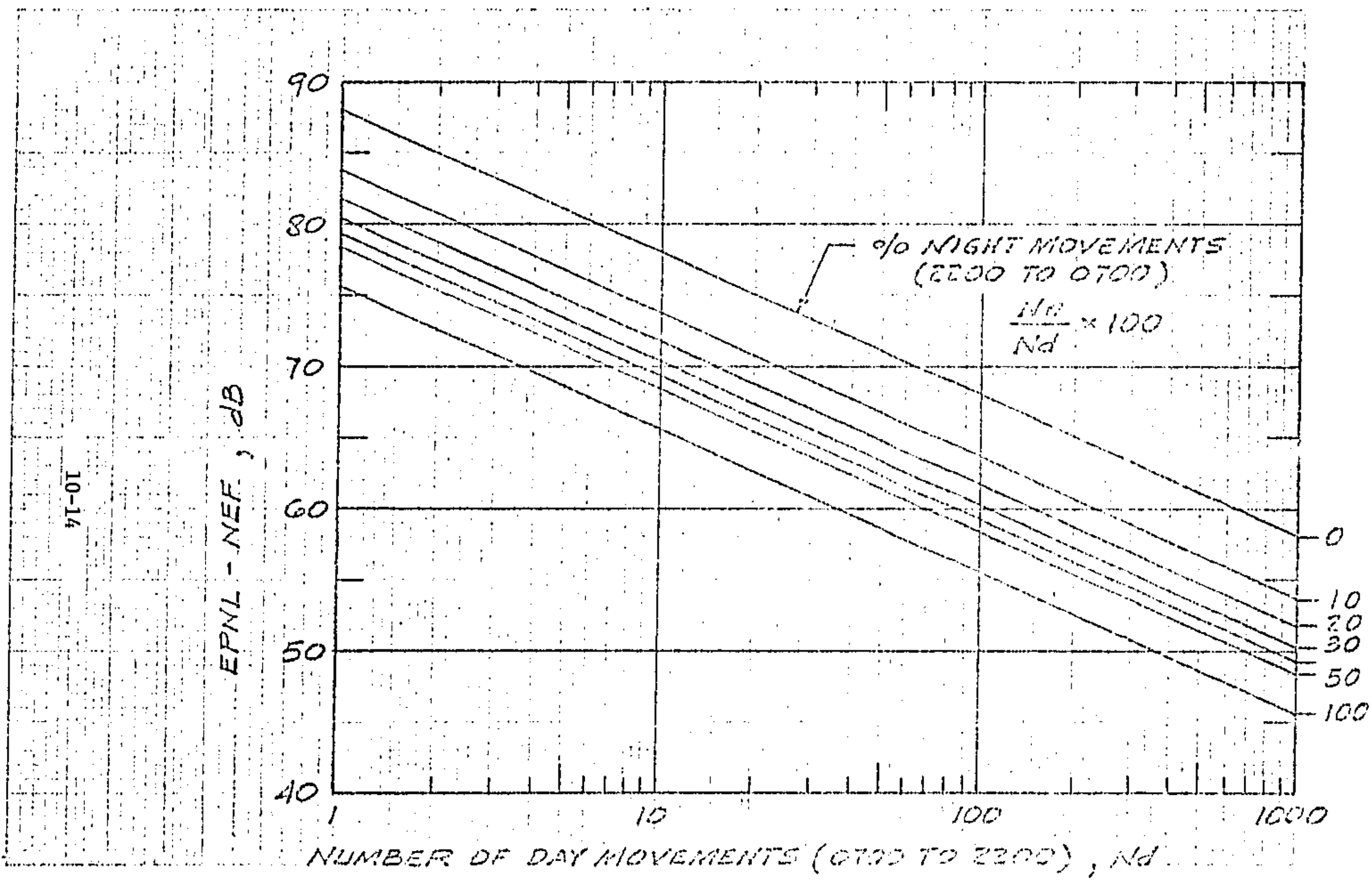


FIGURE 8. EPNL AND NEF RELATED TO NUMBER OF MOVEMENTS FOR A SINGLE AIRCRAFT.

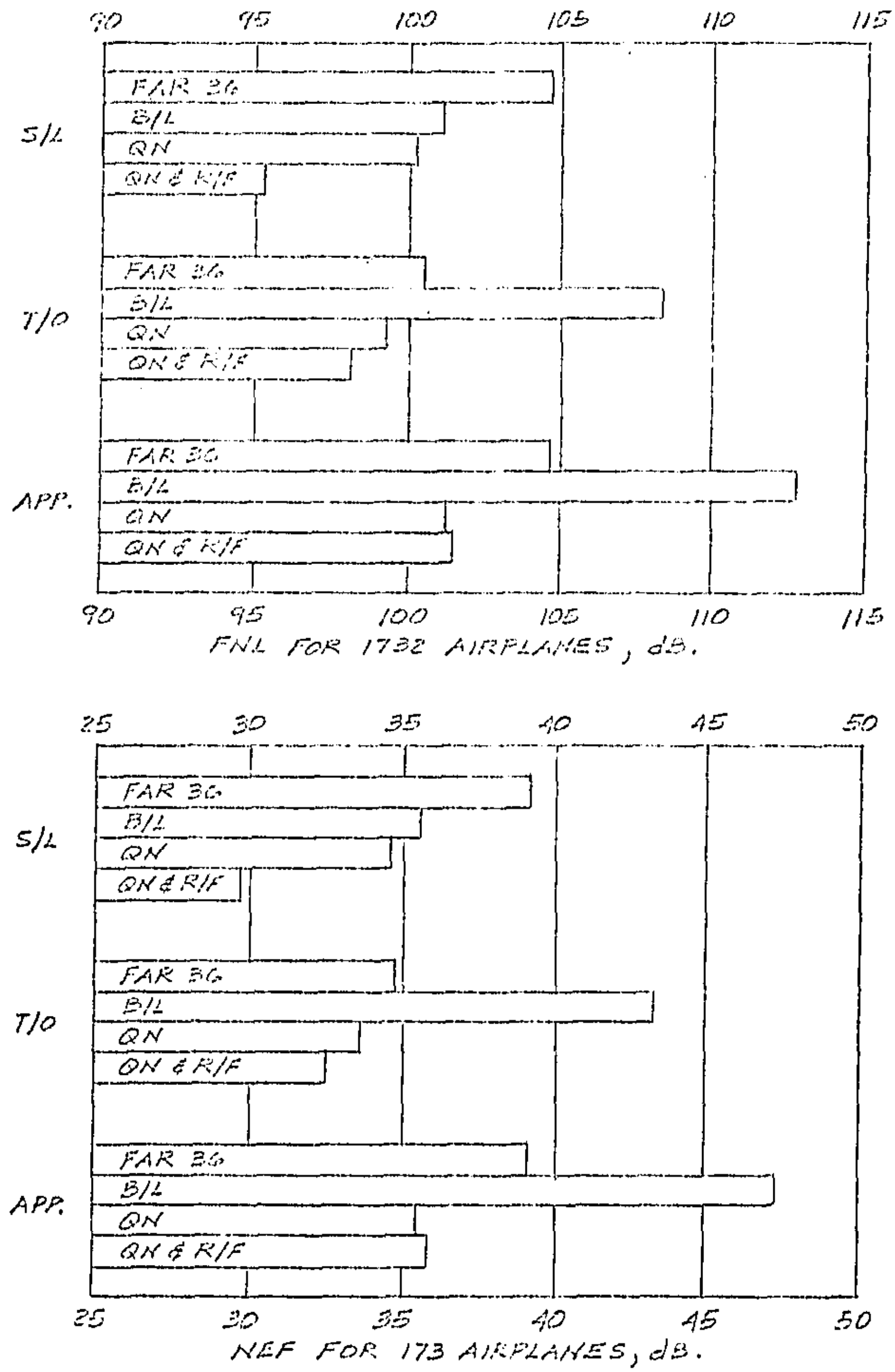
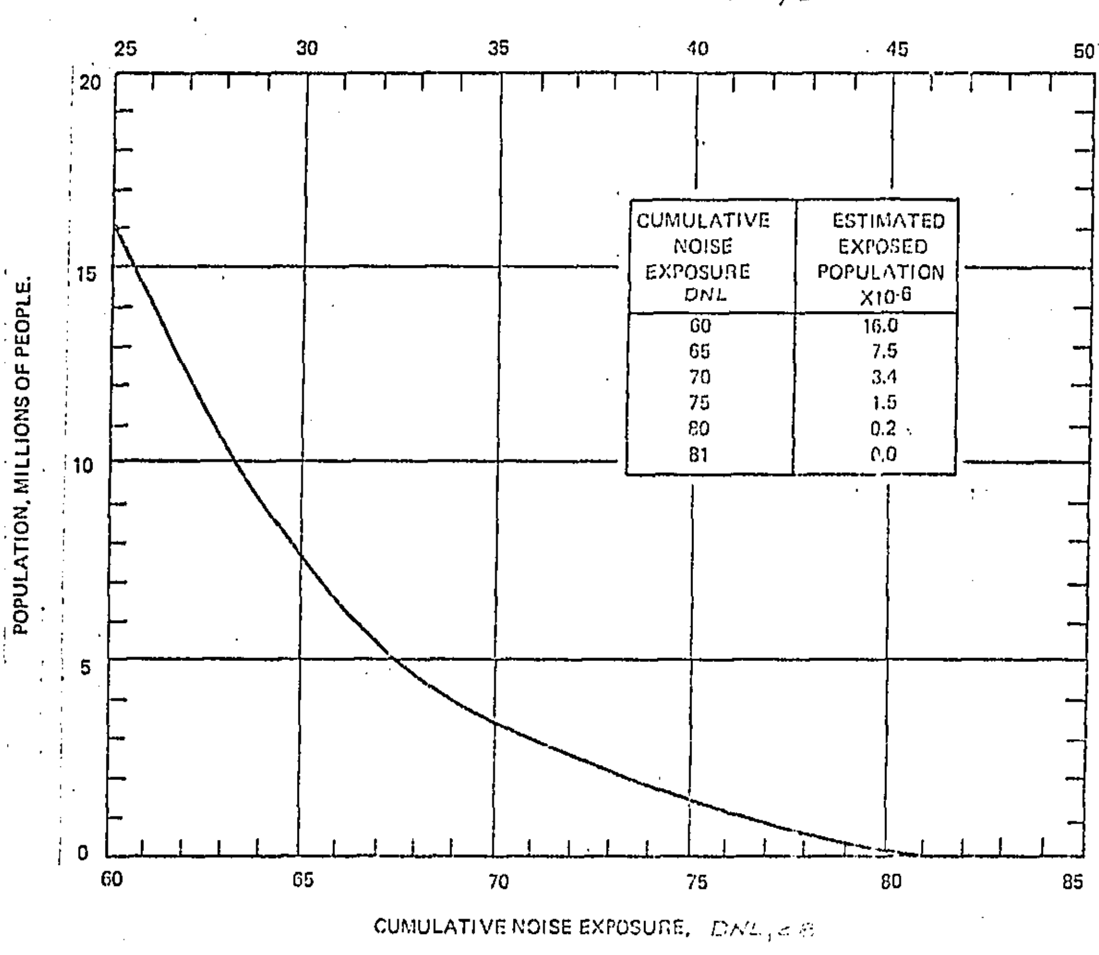
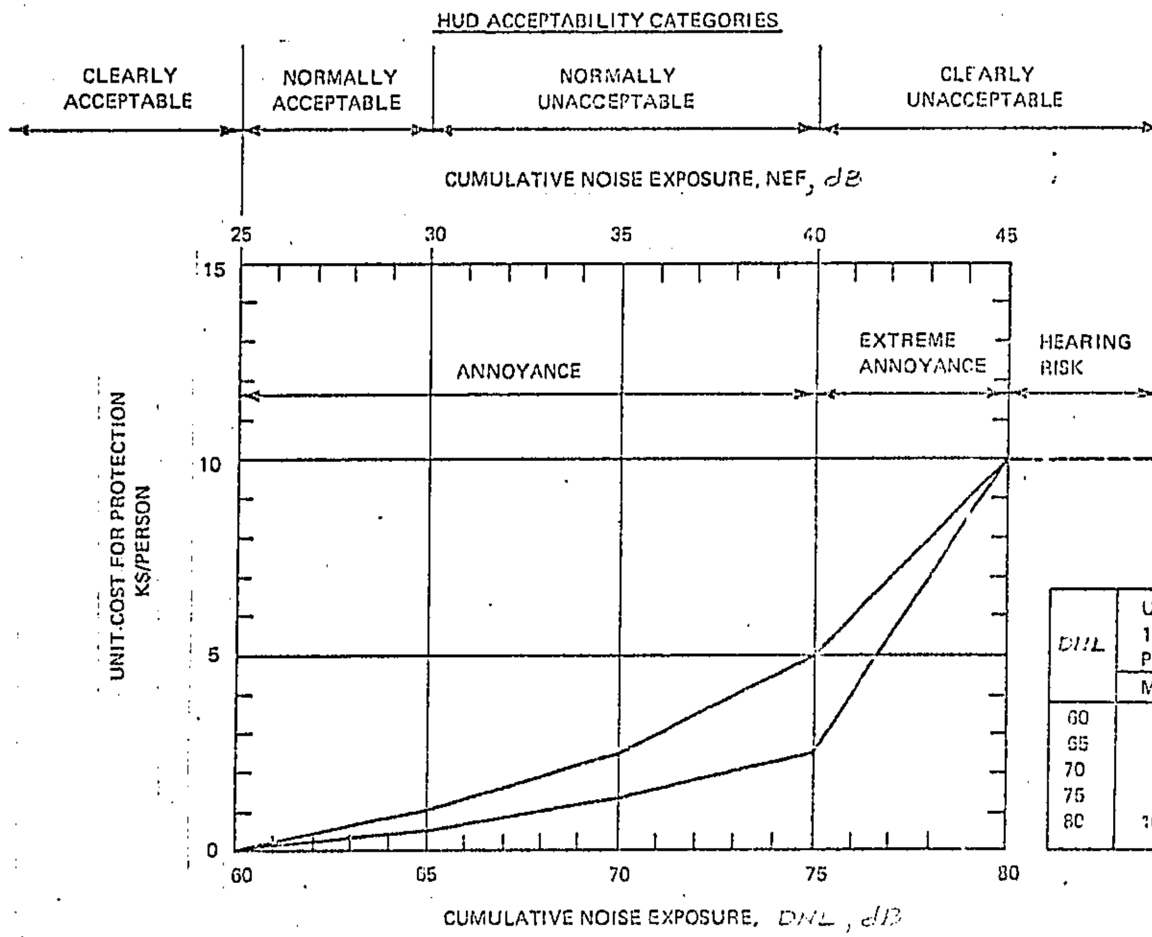


FIGURE 7. FLEET NOISE LEVEL (FNL) AND NOISE EXPOSURE FORECAST (NEF) FOR NATIONAL FLEET OF JT3D AND JT8D PROPELLED AIRPLANES.



CUMULATIVE NOISE EXPOSURE DNL	ESTIMATED EXPOSED POPULATION X10-6
60	16.0
65	7.5
70	3.4
75	1.5
80	0.2
81	0.0

FIGURE 10. NUMBER OF PEOPLE IMPACTED BY AIRCRAFT NOISE - 1972 BASELINE



DNL	UNIT COST 1000 $ PER PERSON	
	MAX	MIN
60	0	0
65	1.0	0.5
70	2.5	1.4
75	5.0	2.5
80	10.0	10.0

FIGURE 11. UNIT COSTS FOR NOISE COMPATIBLE LAND USE CATEGORIES.
(a). COST DATA

Clearly Acceptable:	The noise exposure is such that both the indoor and outdoor environments are pleasant.
Normally Acceptable:	The noise exposure is great enough to be of some concern but common building constructions will make the indoor environment acceptable, even for sleeping quarters, and the outdoor environment will be reasonably pleasant for recreation and play.
Normally Unacceptable:	The noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment tolerable.
Clearly Unacceptable:	The noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable.

FIGURE 11. UNIT COSTS FOR NOISE COMPATIBLE LAND USE CATEGORIES
(b) HUD ACCEPTABILITY CATEGORIES FOR PROPOSED HOUSING SITES.

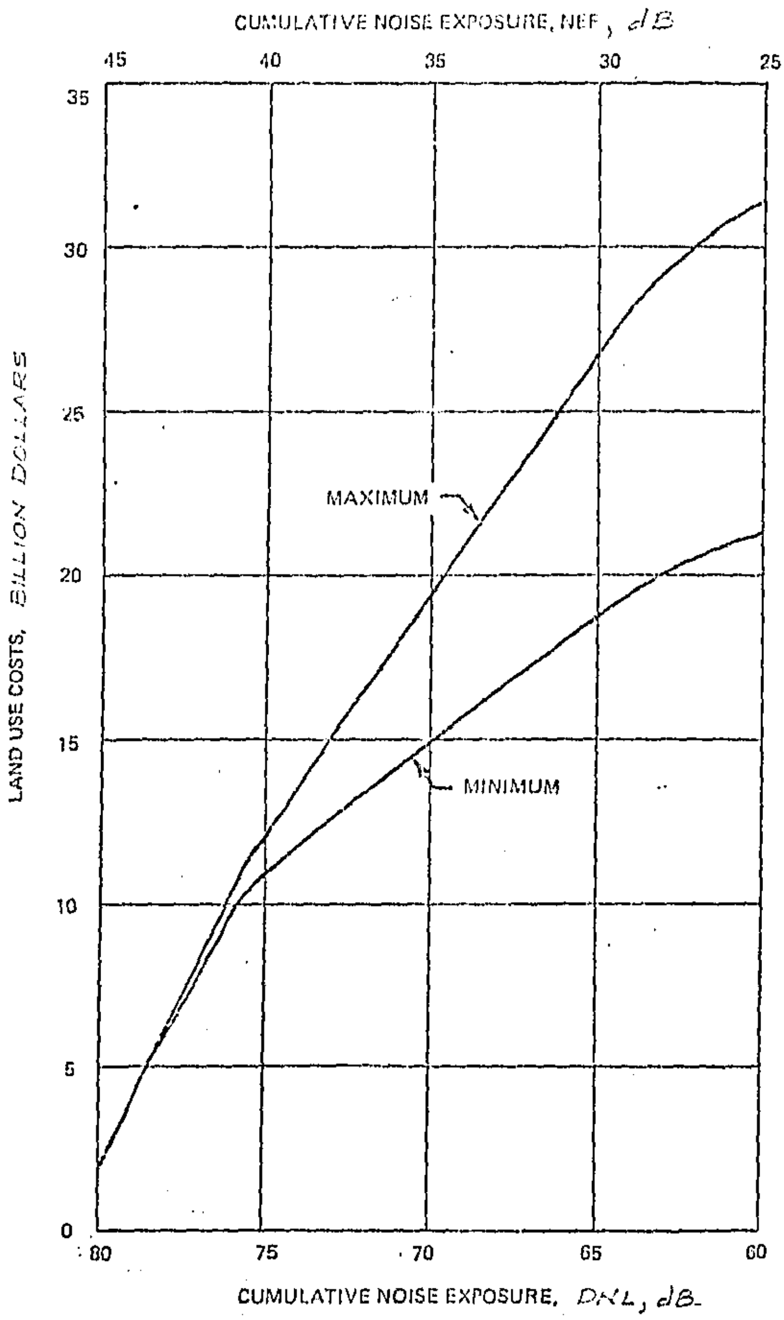


FIGURE 12. CUMULATIVE LAND USE COSTS.

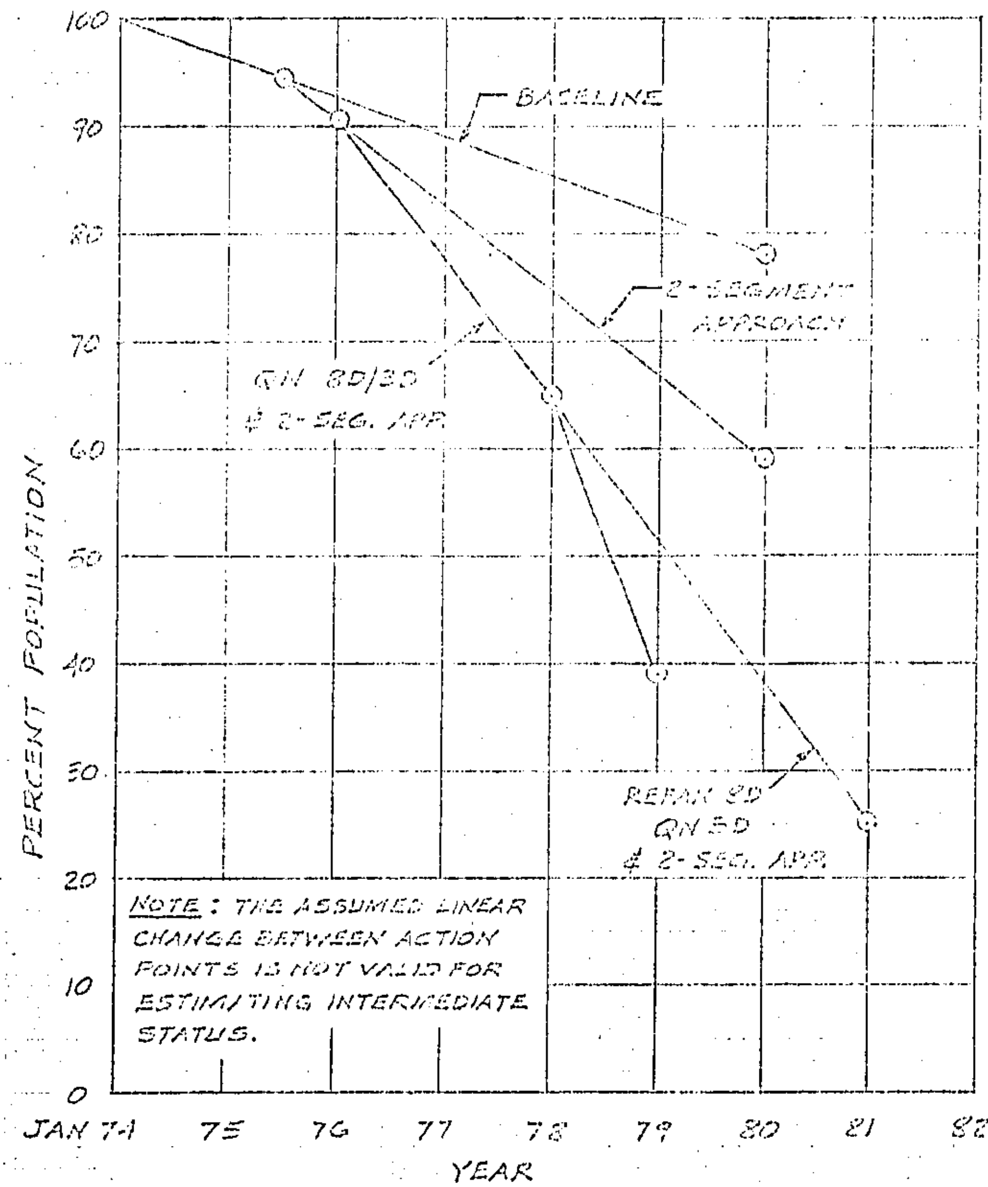


FIGURE 13. PERCENT POPULATION IMPACTED BY AIRCRAFT NOISE-INSIDE 75 DNL (40 NEF) CONTOUR.

AIRPLANE		707-300B/C		ADV. 727-200		ADV.737-200	
ENGINE		JT3D-3B		JT8D-9		JT8D-9	
BRGW (LBS)		333,600		172,500		103,500	
LDGW (LBS)		247,000		142,500		98,000	
NACELLE CONFIG.		FIGURE 1		FIGURE 2		FIGURE 3	
CONDITION							
TAKE OFF	FLAP POS.	14°		5°		1	
	Fn/δ (LBS)	14,750		12,400		12,800	
	ALT. (FT)	980		1535		2450	
	VEL. (KTAS)	185		178		163.5	
EPNL	Q.N.	110.8		106.6		100.0	
	BASELINE	113.6		107.4		100.0	
CUTBACK	FLAP POS.	14°		5°		1	
	Fn/δ (LBS)	10,700		8050		6400	
	ALT (FT)	910		1400		2270	
	VEL (KTAS)	184.5		177.5		163.3	
EPNL	Q.N.	102.2		97.5		91.7	
	BASELINE	113.0		100.0		91.7	
SIDELINE	SIDE. DISTANCE	0.35 N.Mi.		0.25 N.Mi.		0.25 N.Mi.	
	FLAP POS.	14°		5°		1	
	Fn/δ (LBS)	14,700		12,300		12,600	
	ALT.(FT)	720		820		1030	
	VEL.(KTAS)	184.5		176.0		160.5	
EPNL	Q.N.	99.2		99.9		101.1	
	BASELINE	102.1		99.9		101.1	
APPROACH	FLAP POS.	50°	40°	40°	30°	40	30
	Fn/δ (LBS)	6,350	5,160	6,300	4,320	5,140	3,630
	ALT. (FT)	370	370	370	370	370	370
	VEL (KTAS)	150.3	152.3	139	142	138	142
EPNL	Q.N.	104.5	102.2	103.2	100.0	107.0	101.6
	BASELINE	118.5	116.8	109.5	108.1	110.9	108.9

NOTE: Noise and performance to FAR 36 rules.

TABLE I. NOISE AND PERFORMANCE OF BOEING AIRPLANES WITH QUIET NACELLES (QN).

RETROFIT CASE	FAR 36 MEASURING POINTS	EFFECTIVE PERCEIVED NOISE LEVEL IN EPNdB FOR AIRPLANE MANUFACTURER, TYPE, AND MAXIMUM WEIGHT				
		BOEING 707-300 B/C 333.6 KLB.	DOUGLAS DC-8-61 325 KLB.	BOEING 727-200 ADV. 172.5 KLB.	BOEING 737-200 ADV. 105.5 KLB.	DOUGLAS DC-9-32 108 KLB.
FAR 36 LEVEL REQUIREMENTS	SIDELINE	106.3	106.2	104.4	102.9	103.0
	T/O WITH C/B	103.8	103.6	99.0	95.3	95.6
	" NO "	"	"	"	"	"
	APPROACH	106.3	106.2	104.4	102.9	103.0
BASELINE	SIDELINE	102.1	103.0	99.9	101.1	101.0
	T/O WITH C/B	113.0	114.0	103.0	91.7	97.0
	" NO "	113.6	—	107.4	100.0	—
	APPROACH	116.8	117.0	103.1	105.9	108.0
QUIET NACELLES	SIDELINE	99.2	99.0	99.9	101.1	101.5
	T/O WITH C/B	102.2	103.5	97.5	91.7	94.5
	" NO "	110.8	—	106.6	100.0	—
	APPROACH	102.2	105.0	100.0	101.6	99.0
REFANNED ENGINES	SIDELINE	NA	NA	91.7	88.7	92.0
	T/O WITH C/B			93.1	82.5	85.0
	" NO "			98.4	—	—
	APPROACH			101.0	100.8	98.0

T/O = TAKEOFF
C/B = CUTBACK
NA = NOT APPLICABLE

TABLE 2. NOISE LEVELS FOR JT3D AND JT8D PROPELLED AIRPLANES.

AIRPLANE						COST IN MILLIONS OF 1973 DOLLARS							
PRATT & WHITNEY ENGINE	TYPE	QUANTITY				UNIT COST (INSTALLED WITH SPARES)		INVESTMENT COST (UNIT COST x NUMBER OF AIRPLANES)					
		STATUS	US ONLY	REST OF WORLD	TOTAL			ON - 3D & 8D			ON - 3D & R/F - 8D		
						ON	R/F	US ONLY	REST OF WORLD	TOTAL	US ONLY	REST OF WORLD	TOTAL
JT3D	BOEING 707	OH	327	224	551	0.90	NA	294.3	201.6	495.9	294.3	201.6	495.9
		OO	0	17	17			0	15.3	15.3	0	15.3	15.3
	DOUGLAS DC-8	OH	180	217	397	0.77	NA	138.6	167.1	305.7	138.6	167.1	305.7
		OO	0	0	0			0	0	0	0	0	0
	TOTAL JT3D	OH	507	441	948	NA	NA	432.9	368.7	801.6	432.9	368.7	801.6
		OO	0	17	17			0	15.3	15.3	[illegible]	15.3	15.3
		TOT.	507	458	965			432.9	384.0	816.9	432.9	384.0	816.9
JT8D	BOEING 727	OH	724	233	957	0.17	1.70	123.1	39.6	162.7	1230.8	396.1	1626.9
		OO	75	53	128			12.8	9.0	21.8	127.5	90.1	217.6
	BOEING 737	OH	157	164	321	0.20	1.45	31.4	32.8	64.2	227.7	237.8	465.5
		OO	2	24	26			0.4	4.8	[illegible]	2.9	[illegible]	[illegible]
	DOUGLAS DC-9	OH	344	316	660	0.175	0.96	60.2	55.3	115.5	330.2	303.4	633.6
		OO	6	54	62			1.1	9.5	10.9	5.8	51.8	57.6
	TOTAL JT8D	OH	1225	713	1938	NA	NA	214.7	127.7	342.4	1788.7	937.3	2726.0
		OO	83	143	226			14.3	23.6	37.9	136.2	175.2	311.4
		TOT.	1308	856	2164			229.0	151.3	380.3	1924.9	1112.5	3037.4
TOTAL ALL AIRPLANES JT3D & JT8D		OH	1732	1154	2886	NA	NA	647.6	496.4	1144.0	2221.6	1306.0	3527.6
		OO	83	160	243			14.3	40.9	55.2	136.2	190.5	326.7
		TOT	1815	1314	3129			661.9	537.3	1199.2	2357.8	1496.5	3854.3

NA = NOT APPLICABLE.
OH = ON HAND.
OO = ON ORDER.

ON = QUIET NACELLES (SAM ONLY).
R/F = REFANNED ENGINES WITH NACELLES (INCLUDING SAM).
SAM = SOUND ABSORPTION MATERIAL.

TABLE 3. COSTS OF QUIET NACELLES AND REFANNED ENGINES.

IDENT. NO.	AIRPLANE TYPE	AIRPLANE MAXIMUM WEIGHT LBS	BASELINE NOISE LEVELS IN EPNdB SIDELINE	TAKEOFF WITH CUTBACK	TAKEOFF NO CUTBACK	APPROACH
1	DC-9-32	108 000	101	97	—	108
* 2	737-200 ADV	103 500	101.1	91.7	100	108.9
* 3	727-200 ADV	172 500	99.9	100	107.4	108.1
4	DC-8-61	325 000	103	114	—	117
* 5	707-320B	333 600	102.1	113	113.6	116.8
* 6	L-1011	430 000	95	—	98	103
* 7	DC-10-10	430 000	96	—	99	106
* 8	DC-10-40	530 000	94	—	101	105
* 9	747-100	710 000	101.9	—	115	113.6
* 10	747-200 B/F	775 000	98	—	107	106
11	LEARJET 25 B/C	15 200	100	—	94	103
12	WESTWIND 1121	18 500	104	—	101.5	107
13	" 1123	20 500	106	99.5	—	106
14	SABRE 70	21 500	101.5	—	100	99
15	HS 125-601	25 200	104.5	—	97.5	102
16	FALCON 20	27 300	91	—	91	102
17	JETSTAR	42 000	105	98.5	107	107.5
18	GULFSTREAM 2	62 000	102	93.5	102.5	99.5
* 19	F-28	65 000	99.5	—	90	101.5
* 20	CITATION	11 500	87	—	78	88
* 21	CONCORDE	385 000	114.2	115.4	—	114.5
22	BAC-111 (500)	100 000	103.5	102	—	102.5

* CERTIFICATED OR MEASURED TO FAR 36 RULES

TABLE 4. BASELINE NOISE LEVELS FOR MISCELLANEOUS TRANSPORT AND GENERAL AVIATION AIRPLANES WITH TURBOJET/TURBOFAN ENGINES.

factors nearing the 55 percent long term goal. This increase in efficiency, if it can be maintained, combined with the possible reductions in traffic demand could translate into reduced flight equipment requirements. Replacement equipment demand can also be affected due to fuel conservation factors. Basically, for fuel efficiency reasons there have been some equipment substitutions of narrow bodied aircraft for wide body aircraft by the airline industry. One result of these actions and the ever increasing jet fuel prices is that the economic lives of these narrow bodied aircraft could be increased; thereby, stretching out planned retirement and replacement schedules of the airlines.

For these reasons, the fleet as of the last quarter of 1973 shall be used as a maximum case in estimating the total costs of each retrofit alternative.

Total retrofit alternative costs are defined to be the sum of the following cost elements:

- the investment costs necessary to develop, certificate and install these modifications on all candidate aircraft;
- the revenues lost due to the additional down time to retrofit the aircraft;
- the increased operating costs associated with the retrofit over remaining life of the aircraft;
- a lost productivity charge resulting from changes in performance and calculated by assuming that in any time period the available ton-miles produced must be unchanged from that produced if the fleet were not retrofitted; therefore, either the number of aircraft flown per day must increase or the daily aircraft utilization rate must increase accordingly, thereby resulting in increased costs.

Each cost element for every retrofit alternative has been calculated from data provided in Reference 26. The calculation procedure basic-

AIRPLANE			COST IN MILLIONS OF 1973 DOLLARS			
TYPE & MANUFACTURER	ENGINE (EXISTING) & MANUFACTURER	QUANTITY (US ONLY)	UNIT COST (INSTALLED WITH SPARES)		INVESTMENT COST (UNIT COST × QUANTITY)	
			REENGINE	SUPPRESSOR	REENGINE	SUPPRESSOR
LEARJET GATES LEARJET	2 CJ610-6 GENERAL ELECTRIC	81	0.360	—	29.2	—
WESTWIND 1121/23 ISRAEL A/C IND.	2 CJ610-9 GENERAL ELETRIC	134	0.360	—	48.2	—
SABRE ROCKWELL INT.	2 JT12A-8 PRATT & WHITNEY	63	0.490	—	30.9	—
HS-125 HAWKER SIDDELEY	2 VIPER 601 ROLLS ROYCE	142	—	0.100	—	14.2
JETSTAR LOCKHEED	4 JT12A-8 PRATT & WHITNEY	124	1.350	—	167.4	—
GULFSTREAM 2 GRUMMAN	2 SPEY MK 511-8 ROLLS ROYCE	113	—	0.150	—	17.0
		657			275.7	31.2
					306.9	

TABLE 5. COSTS OF REENGINE OR SUPPRESSOR RETROFIT FOR BUSINESS JETS.

AIRPLANE			FAR 36 MEAS. POINT	NOISE LEVELS, EPNdB			
PRATT & WHITNEY ENGINE	TYPE	QUANTITY (US ONLY)		FAR 36	BASELINE	QN-8D & RS	QN-8D R/F-8D
JT3D	BOEING 707	327	S/L	106.8	102.1	99.7	99.2
			T/O	108.8	115.9	103.2	102.2
			APP.	106.3	116.8	102.2	102.2
	DOUGLAS DC-8	180	S/L	106.2	103.0	99.0	99.0
			T/O	103.6	114.0	103.5	103.5
			APP.	106.2	117.0	105.0	105.0
JT8D	BOEING 727	724	S/L	104.4	99.9	99.1	91.7
			T/O	99.0	103.6	97.5	93.1
			APP.	104.4	108.1	100.2	101.0
	BOEING 737	157	S/L	102.9	101.1	101.1	85.7
			T/O	92.8	91.7	91.7	88.5
			APP.	105.[illegible]	105.4	101.0	100.8
	DOUGLAS DC-9	344	S/L	102.0	101.0	101.5	92.0
			T/O	95.6	97.0	94.5	85.0
			APP.	103.0	105.0	99.0	98.0
NATIONAL FLEET = 1732							
FNL FOR NATIONAL FLEET (1732 AIRPLANES), FNdB.			S/L	104.7	101.1	100.2	95.3
			T/O	100.5	103.4	99.3	93.1
			APP.	104.7	112.8	101.3	101.5
NEF FOR 0.1 NATIONAL FLEET (173 AIRPLANES BETWEEN 0700 & 2200 HOURS), NEFdB.			S/L	37.1	35.8	34.6	29.7
			T/O	24.9	42.2	33.7	32.5
			APP.	37.1	47.2	35.3	28.9

TABLE 6. FLEET NOISE LEVEL (FNL) AND NOISE EXPOSURE FORECAST (NEF) FOR NATIONAL FLEET OF JT3D AND JT8D POWERED AIRPLANES.

AIRPLANE					COST PER AIRPLANE IN THOUSANDS OF 1973 $								
PRATT & WHITNEY ENGINE	TYPE	QUANTITY (US ONLY)			HARDWARE (INSTALLED WITH SPARES)		CHANGE IN CASH DOC		LOST TIME		LOST PRODUCTIVITY		
		MIN. EST.		MAX. EST.									
		QN	R/F	QN or R/F	QN	R/F	QN	R/F	QN	R/F	QN	R/F	
JT 3D	BOEING 707	217	NA	327	900	NA	129.0	NA	50.2	NA	140.7	NA	
	DOUGLAS DC-8	129	NA	180	770	NA							
JT 8D	BOEING 727	683	570	799	170	1700	19.7	278.4	23.1	23.5	5.8	155.5	
	BOEING 737	154	156	159	300	1450							
	DOUGLAS DC-9	345	322	350	175	940							

TABLE 7. UNIT COSTS ASSUMED FOR RETROFIT PROGRAM.

	PROGRAM OPTION	COST IN MILLIONS OF 1973 DOLLARS									
		INVESTMENT		CHANGE IN CASH DOC		LOST TIME		LOST PRODUCTIVITY		TOTAL PROGRAM	
		US ONLY	REST OF WORLD	US ONLY	REST OF WORLD	US ONLY	REST OF WORLD	US ONLY	REST OF WORLD	US ONLY	REST OF WORLD
1	QN - 3D	432.9	384.0	65.4	57.1	15.8	13.8	71.3	64.5	[illegible]	571.4
2	QN - 8D	229.0	153.5	25.7	16.9	30.2	19.9	7.6	5.0	292.5	195.1
3	QN - 3D & 8D	661.9	537.3	91.1	73.0	[illegible]	38.7	[illegible]	69.5	[illegible]	716.5
4	R/F - 727 QN - OTHERS	1884.3	974.9	276.8	150.0	45.9	33.8	[illegible]	112.4	[illegible]	1271.1
5	R/F - 8D	1924.9	1130.5	[illegible]	[illegible]	[illegible]	20.3	[illegible]	[illegible]	[illegible]	1524.4
6	QN - 3D R/F - 8D	2357.3	1514.5	429.5	[illegible]	41.1	34.1	[illegible]	[illegible]	[illegible]	2065.8

TABLE 8. PROGRAM COSTS ASSUMED FOR RETROFIT OPTIONS.

(a). MAXIMUM COSTS IN 1973 DOLLARS.

PROGRAM OPTION		COST IN MILLIONS OF DOLLARS FOR US FLEET ONLY									
		INVESTMENT		CHANGE IN CASH DOC		LOST TIME		LOST PRODUCTIVITY		TOTAL PROGRAM	
		1973 $	C'NT $	1973 $	C'NT $	1973 $	C'NT $	1973 $	C'NT $	1973 $	C'NT $
1	QN - 3D	294.6	334.7	41.3	57.4	16.1	17.8	45.6	55.5	[illegible]	415.2
2	QN - 8D	207.7	233.8	23.2	27.5	43.7	[illegible]	6.7	8.7	283.6	317.7
3	QN - 3D & 8D	502.3	568.5	67.6	87.2	58.8	64.4	53.4	66.9	681.1	787.0
4	R/F - 727 QN - OTHERS	1355.2	1630.0	301.0	411.5	50.7	59.2	501.0	759.7	[illegible]	[illegible]
5	R/F - 8D	1504.3	1850.9	382.1	532.5	33.5	43.0	613.8	902.1	[illegible]	[illegible]
6	QN - 3D R/F - 8D	1798.9	2155.6	422.4	576.7	49.5	57.7	991.1	958.5	[illegible]	3778.0

TABLE 8. PROGRAM COSTS ASSUMED FOR RETROFIT OPTIONS.

(b). MINIMUM COSTS IN 1973 AND CURRENT DOLLARS.

	PROGRAM OPTION	AVAILABLE DATE	TOTAL TECHNOLOGY COST (2)	CUMULATIVE NOISE LEVEL DNL	CUMULATIVE NOISE LEVEL NEF	PERCENT [illegible] [illegible] IN EXCESS OF LEVEL (4)	NOISE COMPATIBLE LAND-USE COST (5) (6)	COST OF PUBLIC PROTECTION TO LEVEL AT DATE (7)
a	NULL - DO NOTHING	1978	0.0	80	45	[illegible]	1.0	1.0
				70	35	[illegible]	[illegible]	15.5
				60	25	[illegible]	24.[illegible]	24.5
b	2-SEGMENT APPROACH	1978	0.1 (3)	80	45	[illegible]	1.0	1.1
				70	35	77	15.3	15.3
				60	25	78	22.[illegible]	22.4
1	QN - 3D	1978	0.7	80	45	0		0.7
				70	35	71	11.5	12.2
				60	25	71	20.8	21.5
2	QN - 8D	1978	0.4	80	45	0		0.4
				70	35	71	12.[illegible]	12.6
				60	25	70	[illegible]	21.3
3	QN - 3D & 8D	1978	0.9	80	45	0		0.9
				70	35	65	12.3	11.1
				60	25	75	19.5	20.4
4	R/F - 727 QN - OTHERS	1981	2.5	80	45	[illegible]		2.5
				70	35	31	5.5	8.0
				60	25	17	7.5	10.1
5	R/F - 8D	1981	2.6	80	45	0		2.6
				70	35	29	6.9	9.5
				60	25	17	7.2	10.8
6	QN - 3D R/F - 8D	1981	3.2	80	45	0		3.2
				70	35	21	4.3	7.5
				60	25	11	5.5	8.7

TABLE 9. TOTAL COSTS OF RETROFIT AND COMPATIBLE LAND USE. (1)

(a) COST DATA [SEE TABLE 10 (b) FOR NOTES]

1. Costs, availability dates, and population estimates are based upon References 22 and 23.

2. All costs are stated in billions of 1973 dollars. Technology costs include the following: investment, cash direct operating (DOC), lost time, and lost productivity. These costs represent the maximum case for the United States airplanes on hand plus on order.

3. The costs for 2-segment approach are estimated to be 67 million dollars, rounded off to 0.1 billion dollars. This cost is included in all six program options.

4. Estimates of population were made to the nearest 100,000 people. Zero population means less than 50,000 people nationally which, however, may result in a significant residual population at a few airports.

5. The costs for noise compatible land use include sound insulation of structures, relocations of people, and land development depending upon the noise reduction requirement. See Reference 5 for detailed discussion.

6. Operational restrictions imposed on aircraft at the airports may reduce noise impacted residential land areas by as much as 50 percent. Consequently, these costs would be reduced accordingly.

7. These costs may have to be increased by as much as 0.3 billion dollars for noise reengine or retrofit of business jets to accomplish the assumed population reductions.

TABLE 9 TOTAL COSTS OF RETROFIT AND COMPATIBLE LAND USE.

(b). NOTES FOR TABLE 10(a).

APPENDIX A

FAA DRAFT NPRM FOR STRAIGHT RETROFIT

The Federal Aviation Administration is considering amending the Federal Aviation Regulations to establish additional civil aircraft noise requirements. The proposed amendments would require that subsonic turbojet engine-powered airplanes with maximum weights of 75,000 pounds or more, having standard airworthiness certificates, and that are operated under Parts 91, 121, 123, and 135 of the Federal Aviation Regulations, comply with Part 36--"Noise Standards: Aircraft Type and Airworthiness Certification." The proposed amendments would be accomplished by adding a new Subpart E to read as follows:

Subpart E-Noise Requirements

91.301 Applicability

This subpart prescribes noise requirements for the operation of U. S. registered civil subsonic turbojet engine-powered airplanes with maximum weights of 75,000 pounds or more and having standard airworthiness certificates.

91.303 Relation to Part 36

Unless otherwise specified, all references in this subject to the requirements of Part 36 refer to Part 36 of this chapter, including Appendix C of that Part, as effective on December 1, 1969.

91.305 Noise requirements for all airplanes

After June 30, 1978, no person may operate any airplane covered by this subpart unless that airplane meets the requirements of Part 36 of this chapter.

91.307 Interim noise requirements for air carriers

After June 30, 1976, no domestic, flag, or supplemental air carrier or commercial operator holding a certificate under Part 121 of this chapter may operate, under that certificate, any airplane covered by this subpart and listed on the aircraft record required for domestic and flag air carriers or on the operations specifications required for the supplemental air carriers and commercial operators that is not shown to meet the requirements of Part 36 of this chapter unless at least one-half of the engine/nacelles for the airplanes covered by this subpart and listed for the certificate holder are of a type that has been demonstrated to permit those aircraft types to meet the requirements of Part 36 if the engine/nacelles were deployed in a full set.

APPENDIX B

SAMPLE REGULATION FOR STRAIGHT RETROFIT

The new Subpart E proposed by the FAA is repeated below with additional material added to Paragraph 91.307. The supplementary requirements are intended to clarify misconceptions relating to the use of both old and new engine/nacelles on an airplane.

Subpart E-Noise Requirements

91.301 Applicability

This subpart prescribes noise requirements for the operation of U. S. registered civil subsonic turbojet engine-powered airplanes with maximum weights of 75,000 pounds or more and having standard airworthiness certificates.

91.303 Relation to Part 36

Unless otherwise specified, all references in this subject to the requirements of Part 36 refer to Part 36 of this chapter, including Appendix C of that Part, as effective on December 1, 1969.

91.305 Noise requirements for all airplanes

After June 30, 1978, no person may operate any airplane covered by this subpart unless that airplane meets the requirements of Part 36 of this chapter.

91.307 <u>Interim noise requirements for air carriers</u>

(a) After June 30, 1976, no domestic, flag, or supplemental air carrier or commercial operator holding a certificate under Part 121 of this chapter may operate, under that certificate, any airplane covered by this subpart and listed on the aircraft record required for domestic and flag air carriers or on the operations specifications required for the supplemental air carriers and commercial operators that is not shown to meet the requirements of Part 36 of this chapter unless at least one-half of the engine/nacelles for the airplanes covered by this subpart and listed for the certificate holder are of a type that has been demonstrated to permit those aircraft types to meet the requirements of Part 36 if the engine/nacelles were deployed in a full set.

(b) The engine/nacelles listed for the certificate holder shall be installed on operational airplanes at the first maintenance shutdown when the downtime is adequate. The intermixture of existing and new engine/nacelles shall not prevent such installations unless safety would be degraded by factors such as unbalanced weight, thrust, and drag.

APPENDIX C

SAMPLE REGULATION FOR FLEET NOISE LEVEL (FNL)

A new Subpart X to the Federal Aviation Regulations is given below. This subpart is similar to that proposed by the FAA as ANPRM 73-3 but has been modified in accordance with the recommendations of the EPA report to Congress, Reference 1.

Subpart X - Fleet Noise Levels

121.801 Applicability

This subpart governs the operation of U.S. registered civil subsonic turbojet engine powered airplanes by operators when they are engaging in air commerce. This subpart includes only those turbojet engine powered airplanes (one or more) that are in the operator's operating specifications or aircraft listing.

121.803 Inspections by Administrator

The operator shall permit the Administrator to make all inspections of records, data, and facilities necessary to ensure continuing compliance with this subpart, and all records and data shall be maintained in current status by the operator for this purpose.

121.805 Relation to Part 36 of the Federal Aviation Regulations

(a) All data and information submitted under this subpart for the purpose of determining sideline, takeoff, and approach noise levels of individual airplane types shall be adequate to ensure compliance with Sections 36.3, 36.5, 36.101, 36.103, 36.1501, 36.1503, C36.1, C36.3, C36.7, and C36.9 of Part 36 of this chapter. All determinations of sideline, takeoff, and approach noise levels of individual airplane types by the Administrator under this subpart will be made in accordance with those sections.

(b) Unless otherwise specified, all references in this subpart to provisions of Part 36 refer to Part 36 as effective on the date of consideration.

121.806 Weight limits.

Any weights, less than maximum weight or design landing weight, that are used in determining the sideline, takeoff, and approach noise, respectively, for any airplane under this subpart must be established as operating limitations for that airplane.

121.807 Requirements beginning on July 1, 1978.

(a) On and after July 1, 1978, no person may operate an airplane covered by this subpart until he submits, and the Administrator accepts:

(1) All data and information necessary to determine the sideline, takeoff, and approach noise levels of each airplane covered by this subpart and operated by him during a representative 90-day period during the 12 months preceding the effective date of this rule; and

(2) The total number of takeoffs and approaches conducted by him with each of the specified airplanes during that 90-day period.

(b) Using the data and information submitted under paragraph (a), the operator shall determine and submit to the Administrator:

(1) The sideline, takeoff, and approach noise level of each airplane for which data and information are submitted; and

(2) The sideline, takeoff, and approach FNL's, computed under Appendix G of this part, that were generated by that operator for the 90-day period described in subparagraph (a)(1) of this section.

(c) The Administrator will publish in the Federal Register the sideline, takeoff, and approach FNL's computed under paragraph (b)(2) of this section for each operator. For an operator for which a representative FNL cannot be established, the Administrator will publish in the Federal Register, under paragraph (c) of this section, an FNL equal to the average of all FNL's computed under paragraph (b)(2) of this section, or by other means determined by the Administrator to be equitable and representative of that operator's experience. The operator may, within 30 days following that publication, challenge the published FNL's.

If the Administrator finds that the published FNL's are equitable and representative, he will so notify the operator. On and after 60 days following the date of publication of the initial FNL's or, if challenged, on and after 30 days after receipt of the Administrator's disposition of that challenge, no operator may operate an airplane covered by this subpart that is not type certificated under Part 36 (including compliance with Appendix C of that part) if he exceeds his original (or amended, as the case may be), FNL's in any consecutive 90-day period prescribed in paragraph (d) of this section.

(d) No person may operate an airplane covered by this subpart unless:

(1) He has submitted by 30 days following July 1, 1978, all data and information necessary to determine the sideline, takeoff, and approach noise levels of, and the number of takeoffs and approaches made by each airplane covered by this subpart during the 90 days preceding that date; and

(2) Thereafter, he has submitted by 30 days following each 90-day period subsequent to July 1, 1978, the data and information (as specified in paragraph (1) above) for that period.

APPENDIX - (OF PART 121) FLEET NOISE LEVEL CALCULATIONS

Section 1. General. This Appendix shall be used in determining the sideline, takeoff, and approach Fleet Noise Levels (FNL) of an operator's fleet in compliance with Subpart X of this Part.

Section 2. Mean Logarithmic Equation. The following mean logarithmic equation shall be used:

$$FNL = 10 LOG_{10} \left[\frac{\sum_{j=1}^{n} Nj \text{ antilog} (Lj/10)}{\sum_{j=1}^{n} Nj} \right]$$

Where:

FNL = Fleet Noise Level, in units of dB (FNdB).

Nj = The number of operations for the 90-day period (Airplane j).

Lj = The noise level of each airplane, determined as specified in 121.805, in units of dB (EPNdB).

APPENDIX D

FLEET NOISE LEVEL METHODOLOGY

1. Discussion

The mathematical expressions for fleet noise level (FNL) for the general case and specific cases of two, three, and n-aircraft follow this discussion. Figures 7(a), (b), and (c) illustrate the FNL relationships for the two aircraft case but which can be used for any number of aircraft by successively taking two aircraft at a time. Consequently, the curves for the two aircraft case can be used to examine the effects of the various components (noise levels and numbers of operations) on the cumulative FNL.

The influence on FNL of noise levels and number of operations can be seen by examining the two aircraft case plotted in Figure 7(c). For a given level of least noisy aircraft, FNL is dependent upon the percentage of operations of least noisy aircraft (%N) and the difference in levels between the two aircraft (ΔL). The relative effect on FNL of these two variables is dependent upon their values. To illustrate this, several examples will be chosen comparing the effects of reducing the level of the noisiest aircraft and increasing the number of operations of the least noisy aircraft to achieve a 5 dB FNL reduction.

Case 1: ΔL = 20 dB and %N = 20%. If the level of the noisier aircraft (L2) were reduced 5 dB and the level of the least noisy aircraft (L1) were unchanged, the FNL would be reduced almost 5 dB (actually 4.97 dB). To effect an equivalent reduction in FNL by increasing the number of operations of the least noisy aircraft (N1), the percentage of operations would have to increase from 20% to about 72.5%, as can be seen in Figure 7(c). The results of this case and three others are tabulated below.

COMPONENT	UNIT	CASE 1	CASE 2	CASE 3	CASE 4
ΔL	dB	20	20	10	10
% N	%	20	40	30	60
FNL - L1	dB	19.07	16.[illegible]9	9.14	6.63
ΔL	dB	15	15	5	5
% N	%	20	40	20	60
FNL - L1	dB	14.07	11.22	4.26	2.71
ΔL	dB	20	20	10	10
% N	%	72.5	80	30	91
FNL - L1	dB	14.07	11.22	4.30	2.71

The above examples clearly indicate that the addition of less noisy aircraft to an existing fleet will reduce the FNL. However, it is seen that reducing the level of the noisier aircraft is relatively more effective than increasing the number of aircraft (or number of operations) because of the large percentage increase required. For example, increases from 20 to 80 percent or from 60-91 percent are required to achieve reductions in FNL that can be obtained by a 5 dB reduction in the level of the noisier aircraft. Hence, the logarithmic summation process of the FNL methodology weights (or emphasizes) noise level more heavily than number of operations.

This feature of the logarithmic summation process may seem unfair on the basis that there might not be sufficient incentive for airlines to acquire quiet aircraft. This objection, however, is not valid because noise exposure reduction (in terms of NEF or DNL) cannot be accomplished by adding numbers of lesser noise sources. Merely adding lower noise level aircraft to an existing fleet will increase noise exposure, not cause a reduction. Nevertheless, adding such aircraft actually will reduce the FNL to a small extent, thus providing some incentive.

The logarithmic summation process is much more representative of the physical and subjective characteristics of noise than would be a linear summation procedure. Noise control is most effectively accomplished by reducing the major noise sources first. Then the minor sources become significant in terms of noise level (whether single event or cumulative exposure) and must be considered as the next set of major sources.

General Formula

$$FNL = 10 \log \left[\frac{\sum_{j=1}^{n} N_j \operatorname{ant}(L_j/10)}{\sum_{j=1}^{n} N_j} \right]$$

FNL = Fleet Noise Level, dB (FNdB)

N_j = Number of operations for airplane j.

L_j = Noise level of airplane j at [illegible] measuring points

Two Aircraft

$$FNL^{(II)} = 10 \log \left[\frac{N_1 \operatorname{ant}(L_1/10) + N_2 \operatorname{ant}(L_2/10)}{N_1 + N_2} \right]$$

$$FNL^{(II)} - L_1 = 10 \log \left[\frac{N_1}{\Sigma N} + \left(1 - \frac{N_1}{\Sigma N}\right) \operatorname{ant}\left(\frac{L_2 - L_1}{10}\right) \right]$$

L_1 = level of least noisy aircraft, dB (EPNdB).

N_1 = number of operations of least noisy aircraft.

L_2, N_2 = same as above for noisier aircraft.

$\Sigma N = N_1 + N_2$

The above relationship is plotted as Figures 7(a), (b), and (c).

Three Aircraft

$$FNL^{(III)} = 10 \log \left[\frac{N_1 \,\mathrm{ant}(L_1/10) + N_2 \,\mathrm{ant}(L_2/10) + N_3 \,\mathrm{ant}(L_3/10)}{N_1 + N_2 + N_3} \right]$$

$$FNL^{(III)} - FNL^{(II)} = 10 \log \left[\frac{N_1 + N_2}{\Sigma N} + \left(1 - \frac{N_1 + N_2}{\Sigma N}\right) \mathrm{ant}\left(\frac{L_3 - FNL^{(II)}}{10}\right) \right]$$

L_1 = level of least noisy aircraft, dB (EPNdB).

N_1 = number of operations of least noisy aircraft.

L_2, N_2 = same as above for next noisy aircraft.

L_3, N_3 = same as above for noisiest aircraft.

ΣN = $N_1 + N_2 + N_3$

$FNL^{(III)}$ = FNL for the three aircraft, dB (FNdB).

$FNL^{(II)}$ = FNL for the two least noisy aircraft, dB (FNdB).

n - aircraft

$$FNL^{(n)} = 10 \log \left[\frac{N_1 \, \mathrm{ant}(L_1/10) + N_2 \, \mathrm{ant}(L_2/10) + \cdots N_n \, \mathrm{ant}(L_n/10)}{N_1 + N_2 + \cdots N_n} \right]$$

$$FNL^{(n)} - FNL^{(n-1)} = 10 \log \left[\frac{N_1 + N_2 + \cdots N_{n-1}}{\Sigma N} + \left(1 - \frac{N_1 + N_2 + \cdots N_{n-1}}{\Sigma N}\right) \mathrm{ant}\left(\frac{L_n - FNL^{(n-1)}}{10}\right) \right]$$

L_1 = level of least noisy aircraft, dB (EPNdB).

N_1 = number of operations of least noisy aircraft.

L_2, N_2 = same as above for next noisy aircraft.

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L_n, N_n = same as above for nosiest aircraft.

ΣN = $N_1 + N_2 + \cdots N_n$

$FNL^{(n)}$ = FNL for the n - aircraft.

$FNL^{(n-1)}$ = FNL for all but the the noisiest aircraft.

APPENDIX E

DAY-NIGHT LEVEL (Ldn) and NOISE EXPOSURE FORECAST (NEF) METHODOLOGIES

1. General Formulae

The expressions for noise exposure forecast (NEF) for the general case of all types of aircraft and multiple usage of runways are as follows:

$$NEF\ (ij) = EPNL(ij) + 10 \log [Nd(ij) + 16.67Nn(ij)] - 88$$

$$NEF = 10 \log \sum_{i} \sum_{j} \text{ant}\ [NEF(ij)/10]$$

NEF = Noise Exposure Forecast, dB (NEFdB).

NPNL = Effective Perceived Noise Level, dB (EPNdB).

Nd = Number of day movements (0700-2200 Hrs.).

Nn = Number of night movements (2200-0700 Hrs.).

i = Aircraft type or class. Ant = Antilogarithm

j = Flight Path Segment.

Day-Night Level (Ldn) is a measure of the cumulative noise exposure for a twenty-four hour period. It is a derivative of the Equivalent Noise Level (Leq); being the same measure as Leq except that the noise levels which occur during the nighttime hours (2200 to 0700) are increased 10 decibeles over the actual noise levels. Leq, and therefore Ldn, is based upon an integrated measure (or computation) of the energy equivalent of the A-weighted sound pressure level. For a single, discrete noise event (e) such as the noise created by an aircraft flyover, the Leq(e) is the A-weighted counterpart of the Effective Perceived Noise Level EPNL(e) for that event.

Allowing 14 dB for the numerical difference between EPNL(e) and Leq(e), and realizing that in the measure of Ldn the nighttime <u>noise levels</u> are increased 10 dB, but in the measure of NEF the nighttime <u>noise exposure level</u> is increased by 10dB.

The approximate numerical equivalence for the same series of events is:

$$\text{Ldn} \approx \text{NEF} + 35$$

2. <u>One-Way Runway</u>

For a one-way runway, there will be only one flight path segment, therefore, j can be dropped from the equations. Thus,

$$\text{NEF(i)} = \text{EPNL(i)} + 10 \log [\text{Nd(i)} + 16.67\text{Nn(i)}] - 88$$

$$\text{NEF} = 10 \log \sum_i \text{ant } [\text{NEF(i)}/10]$$

3. <u>Single Type Aircraft</u>

For a single type of aircraft, i can be dropped from the equations. Thus,

$$\text{NEF} = \text{EPNL} + 10 \log [\text{Nd} + 16.67\text{Nn}] - 88$$

which can be rearranged as

$$\text{EPNL} - \text{NEF} = 88 - 10 \log [1 + 16.67 (\text{Nn}/\text{Nd})] - 10 \log (\text{nd})$$

and plotted as shown in Figure 8.