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UNITED STATES

ENVIRONMENTAL PROTECTION AGENCY

PROJECT REPORT

AIRCRAFT NOISE CERTIFICATION RULE FOR SUPERSONIC CIVIL AIRCRAFT

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SUMMARY

This report presents the supporting data for a proposed noise certification rule for supersonic civil aircraft.

The background information presented shows that supersonic transports are inherently noisier than subsonic jet transports, although the two current supersonic airplanes (Concorde and TU-144) targeted for airline service in the near future are not significantly noisier under the flight path than the four-engine narrow-bodied commercial jet transports now in world-wide operation. However, the supersonic aircraft noise is characterized by greater low-frequency content than the subsonic aircraft, which propagates within the audible frequency range to greater distances, and which causes greater vibration response of structures subjected to it.

The Analysis section considers certain idealized model airports and establishes the effects, on noise exposure of the airport neighborhood community, of the introduction of various rates of operation of supersonic airplanes into a subsonic airplane fleet. Results indicate that injection of a few flights per day of an SST would have noise effects ranging from trivial for a typical subsonic airplane fleet to substantial (about 5 dB increase in cumulative noise exposure) for a subsonic fleet retrofitted for noise control. As one possible expedient, one operation of a current DC-8 or B707 could be deleted for each SST operation introduced, with essentially no change in the neighborhood noise exposure (neglecting sideline effects.)

The Health, Welfare, and Economic Considerations section includes

an analysis which provides details on potential costs and possible actions to control noise exposure incident to introduction of SST flights. A methodology for determining noise impact is presented in an appendix and applied to an idealized model airport. The results illustrate the strong influence on noise impact that SST operations can have, particularly for communities that might be benefitting from reduced noise exposure due to operations of noise controlled aircraft. Various regulatory options for controlling the noise impact of SST aircraft are discussed in detail.

It is concluded that current designs of SST aircraft cannot comply with FAR 36 but that future designs can at least meet those requirements. In view of these conclusions as well as the other factors discussed, five of the various regulatory options are recommended for further consideration for the development of one or more rules.

The first rule would require that future supersonic airplanes (all SSTs after the Concorde and TU-144) meet the same noise standards required for subsonic airplanes (FAR 36) in effect on the date of type certificate application.

The second rule is designed to protect the public health and welfare by requiring an airline operator to seek FAA approval of proposed SST flights. In order to obtain this approval, the operator must submit a Noise Impact Assessment, showing that, by implementation of various options available to him, he will limit the increase in noise impact to that which would occur if an airplane that meets FAR 36 noise level requirements were to be used for the proposed operations.

The third rule would prescribe requirements for supersonic civil aircraft in two categories. Future supersonic airplane types would be required to comply with FAR 36 in effect on the date of design application, as in the first rule. Later production versions of current supersonic airplane types, i.e., those produced after Dec. 31, 1984, would be required to comply with the present provisions of FAR 36.

The fourth rule to be considered would be similar to the third, except that it would define later production airplanes of current supersonic types in such a way that all those airplanes produced after the ones now actually committed for construction would be required to conform to FAR 36.

The fifth rule as an alternate to the second, would seek to protect the public health and welfare by restricting landing and takeoff operations of supersonic airplanes to designated airports in the United States. The permission for SSTs to operate at those airports would be subject to approval by the airport operator and contingent upon operational restrictions, intended to limit the noise impact, agreed upon jointly by the FAA and the airport operator. Such restrictions might include the use of specified runways and noise abatement procedures, and restricted hours of operation.

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NOMENCLATURE

Abbreviation	Name
AC	Advisory Circular (FAA)
AGL	Above Ground Level. The height above the official elevation of the airport or air field (sometimes written AFL).
ANPRM	Advance Notice of Proposed Rule Making
ATC	Air Traffic Control
FAR	Federal Aviation Regulations
IFR	Instrument Flight Rules
ILS	Instrument Landing System
Mach Number	Ratio of speed of airplane to speed of sound
NIA	Noise Impact Assessment
NPRM	Notice of Proposed Rule Making
QN	Quiet Nacelle, i.e., nacelle treated with SAM
R/F	Refan - retrofit of jet engine providing a larger fan and treated nacelle
R/STOL	Reduced and/or Short (field) Takeoff and Landing
RTOL	Reduced (field) Takeoff and Landing
SAM	Sound Absorption Material (treatment for engine nacelle)
SST	Supersonic Transport
STOL	Short (field) Takeoff and Landing
VFR	Visual Flight Rules
V/STOL	Vertical and/or Short (field) Takeoff and Landing
VTOL	Vertical Takeoff and Landing

LIST OF SYMBOLS

Symbol	Unit	Description
A	acres or square miles	Area (within a given contour of cumulative noise level)
AL	dB or AdB	A-weighted Sound Pressure Level
ant	--	Antilogarithm (base 10)
ENI	people	Equivalent Noise Impact
EPNL	dB or EPNdB	Effective Perceived Noise Level
FI	--	Fractional Impact
Fn	lb.	Net thrust
HA	percent	Percentage of Population Expected to be Highly Annoyed
L	dB	The appropriate Leq or Ldn measure for local environmental noise
Lc	dB	The appropriate Leq or Ldn criterion level for the land use under consideration
Ldn	dB	Day-Night Noise Exposure Level
Leq	dB	Equivalent Noise Exposure Level
log	--	Logarithm to the base 10.
N	--	Number of aircraft operations
Nd	--	Number of day movements (0700 - 2200 hrs.)
NEF	dB	Noise Exposure Forecast
Nn	--	Number of night movements (2200 - 0700 hrs.)
P	people	Population exposed to specified Ldn

LIST OF SYMBOLS (cont'd)

Symbol	Unit	Description
PNL	dB or PNdB	Perceived Noise Level
RCI	percent	Relative Change in Impact
RI	percent	Ratio of Impact
W	lb.	Weight of Airplane
ΔENI	people	Change in Equivalent Noise Impact

1. INTRODUCTION AND PERSPECTIVES

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 are to 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.

The key findings of the "Levels Document" may be summarized as follows:

(1) The preferred measure for cumulative noise exposure is Leq, the energy average A-weighted sound level integrated over a 24-hour period, or Day-Night Level, Ldn. Ldn is essentially the same as Leq, except that the sounds occurring during night hours (2200 - 0700) are weighted by an adjustment factor of 10 dB to account for increased annoyance of noise during night hours.

(2) An Ldn of 55 dB has been identified as the noise exposure level which should not be exceeded in order to protect persons against annoyance, with an adequate margin of safety.

(3) An Leq of 70 dB has been identified as that noise exposure level which should not be exceeded in order to protect persons against permanent hearing impairment, with an adequate margin of safety.

Both of the foregoing levels are daily averages over long periods of time, rather than maximum allowables for single exposures.

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 air-carrier 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.

It should be understood that the eight proposed aircraft noise regulations represent a package which, in toto, is expected to bring about a substantial improvement in the noise environment due to aircraft. While any one regulation, by itself, will not solve the community noise problems due to aircraft, each one as a building block will result in appreciable improvement, and it is anticipated that all eight together will effectuate a marked reduction in the number of persons exposed to undesirably high levels of aircraft noise. This effect will be additive to the improvement expected over the next decade or so as the older, noisier aircraft in the U.S. aviation fleet are retired and replaced with newer, quieter types with larger passenger capacity.

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 where appropriate 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 Period (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 V/STOL 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 together as a system.

The foregoing discussion is relevant to the basic fact that aviation is a needed element of the national transportation system. If regulations intended to protect the public health and welfare imposed such a burden that the survival of the national aviation system were threatened, this would not be in the national interest. On the other hand, well-conceived regulations which optimally exploit the available alternatives, could protect the public health and welfare and, by improving the acceptability of airplanes, engender continuing development of the aviation system.

If it could be established that some particular design change or retrofit hardware for airplanes, or operating rule, could completely satisfy the requirements for protection (from airplane noise) to the public health and welfare, then that specific method should be used. It is unlikely, however, that any single option, within the legislative constraints, could completely satisfy the requirements for such protection. Consequently, a systems implementation, employing each noise control option available within its area of optimal application, should be considered as the most feasible method for accomplishing the desired objectives and equitably sharing the costs of noise control among all segments of the aviation community and that portion of the public that benefits from aviation.

The noise control regulations prescribed by the FAA for the aircraft manufacturers and operators are required 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 options, 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 and are 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 ultimately 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 unlimited 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 supersonic airplanes, regardless of category, to levels as low as is consistent with safe technological capability, and which:

(a) will be fully responsive to the guidelines of Reference 9 for protection to 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 is 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 at United States airports of civil aircraft capable of cruising supersonically and should:

(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 supersonic 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 options so that cost-effective noise reduction can be achieved.

4. BACKGROUND

Three regulations 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.

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

A. Previous Regulatory Actions on Noise Related to Supersonic Transport (SST) Aircraft

At this date, the only rule applicable to the sounds of SST aircraft is Reference 12 which should be adequate in protecting the public health and welfare from civil aircraft sonic boom. There is no comparable regulation applicable to the noise generated by SST aircraft during subsonic flight. That is the status today although the preamble to FAR 36 (issued approximately 5 years ago) stated that additional rule making concerning the noise type certification of suspersonic airplanes would be proposed at the earliest possible time.

On May 25, 1970, the Environmental Defense Fund (EDF) petitioned the FAA to promulgate "at the earliest feasible date" standards for noise type certification of supersonic aircraft. The FAA responded to this petition by issuing an Advance Notice of Proposed Rule Making (ANPRM 70-33) on August 4, 1970 (Reference 14). Interested persons were invited to participate in the rule making process by submitting data and comments by November 30, 1970.

Following is a summary of those comments from the FAA Docket # 10494 (Reference 15), which have a bearing on EPA's present proposals.

Need for a rule

There was unanimous agreement among industry and community interests that an effective rule for civil supersonic aircraft was necessary to avoid increase in community noise impact.

Form of the rule

Members of the aircraft and engine manufacturing industry indicated that, because of the basic differences in operational characteristics of supersonic aircraft vis-a-vis subsonic aircraft, any noise rule governing these aircraft should constitute a new Part of the FAR and not a modification to the current FAR Part 36.

Other respondents expressed the opinion that all civil supersonic aircraft should conform to the current FAR Part 36 rule either directly or with some appropriate modification that would consider the unique operational characteristics of these aircraft.

Noise Levels

Most of the responses indicated that supersonic aircraft noise levels should be no higher than those for subsonic aircraft as defined in Appendix C of FAR 36.

Representatives of the aircraft and engine manufacturing industry suggested two possible positions, viz:

(a) It is premature to establish levels since an inadequate data base was available;

(b) A noise limit should be established irrespective of gross weight, and this limit should consider the levels attained by the initial production version of the Concorde.

Measurement Points

The concept of 3 measurement points, (sideline, takeoff, and approach), was universally acceptable. However, the location of these points was a subject of controversy. Most of the responders suggested maintaining the same reference points as those identified for subsonic aircraft under FAR 36. Others stated that consideration should be given to re-locating the reference measuring points (particularly sideline) to account for the characteristic differences between supersonic and subsonic aircraft.

Trade-Off

Suggestions were offered that a more liberal trade-off allowance be permitted. FAR 36 for subsonic aircraft permits an exceedance of the noise limits no greater than 2dB at any one position with a maximum of 3dB total which must be offset by equal reductions at the remaining position(s). (For brevity, this is referred to as a 2/3 tradeoff.) For supersonic aircraft a trade-off of 3/5 (instead of 2/3) would permit greater flexibility in design and operational use, but would permit higher noise levels as well.

Each of these issues is addressed in the following sections of this report, along with other considerations of importance from the EPA viewpoint.

B. Comments on the First Draft of the EPA Project Report

This is the project report on SST noise prepared by the EPA which provides the basic input necessary for the preparation of a NPRM to be proposed by the EPA to the FAA for promulgation. The first draft was distributed for review and comment on 28 November 1973. Of 32 responses received, 28 contained specific comments on key issues. The major issues covered are summarized below. These issues are addressed in the revisions incorporated in the present report.

The five issues basic to all aircraft noise regulation and project reports are the following:

(a) Health and Welfare - Does the proposed regulation substantially protect public health and welfare, and does the project report adequately demonstrate it?

(b) Safety - Is the proposed regulation adequately protective of safety (at least does not degrade safety), and does the project report substantiate it?

(c) Technology - Is the proposed regulation technologically practicable and does the project report adequately address this matter?

(d) Economic Reasonableness - Is the proposed regulation economically reasonable, and does the project report show that it is?

(e) Appropriateness - Is the proposed regulation appropriate to the type of aircraft affected by the regulation?

A sixth and seventh may be added as well:

(f) Necessity - Is the proposed regulation necessary to protect the public health and welfare, and does the project report justify it?

(g) Energy aspects - Does the proposed regulation affect energy usage in a conservative manner - that is, either reduce, or at least not cause an undesirable increase in, energy usage requirements?

The comments received addressed five of these issues, as discussed briefly below. A sixth issue raised was concerned with the role of the airport operator in controlling the operations of airplanes from the airport. This point is covered under items (h) below.

(a) Health and Welfare Aspects:

Those who commented on this aspect suggested that the proposed limits were inadequately protective of public health and welfare, and felt that public health and welfare was not adequately addressed in the draft report.

The noise certification levels proposed in the first draft are considered too high to protect health and welfare by most commentators. The United States aircraft manufacturers, however, consider them realistic but indicate that achievement of FAR 36 levels is a goal for the 1980's time period. On the other hand, the Concorde manufacturers consider the proposed levels too stringent.

Suggested alternate approaches were as follows:

(1) Require all SST aircraft to comply with FAR 36 levels applicable to subsonic airplanes. This would effectively ban Concorde and TU-144 from operating at U.S. airports.

(2) Whilst retaining FAR 36 as the standard, allow a deviation, or variance, for Concorde and TU-144 for a definite - and pref-

erably brief - period of time. Alternatively, set an interim standard, less stringent than FAR 36, for a specified period.

(3) Limit SST operations to identified appropriate airports, utilizing specified runways and operational procedures as necessary to minimize noise intrusion.

(4) Set no standard at all and thereby avoid legitimizing the high noise levels associated with SST.

(b) Safety:

No commentators addressed the issue of safety.

(c) Technological Practicability:

As pointed out under the issue of Health and Welfare, the aircraft manufacturers' comments indicated doubts as to the technological practicability of achieving the proposed FAR 36 noise levels in an SST in the near future. U.S. aircraft manufacturers suggested that the proposed levels could be achieved in the 1980's, but the Concorde manufacturers suggested that achievement of those levels in the near future is not feasible.

(d) Economic Reasonableness:

Commentators on this aspect suggested that it was not within the province of EPA to consider economic viability of an airplane, and that emphasis on this factor was disproportionate to that on Public Health and Welfare.

(e) Appropriateness:

The question of appropriateness to the type was not raised as an issue.

(f) Necessity:

None of the respondents appeared to doubt the need for an SST noise regulation. The only question on this subject, as covered under the Health and Welfare issue, was whether it was wise to set a standard at all if the effect was to legitimize the high noise levels now associated with the SST.

(g) Energy/ Environmental Factors:

A number of commentators raised environmental questions, with particular emphasis on the amount of fuel consumed.

(h) Responsibility of Airport Operators:

The commentators on this point unanimously declared that the airport operator has neither the authority nor the expertise to dictate airplane operations, and implied that attempting to control SST noise by requiring airport operators to control the airplane operations shifted the burden of noise control from EPA/ FAA to the airport operators.

C. Significant Noise Related Design Features of SST Aircraft

(1) General

In the development of noise regulations for civil supersonic aircraft, the characteristic differences in configuration and propulsion requirements between subsonic and supersonic aircraft must be recognized and considered (References 16 and 17).

Many of the differences between the configurations result from the phenomenon of the drag associated with the formation of shock waves. This fundamental difference in the mechanisms of air flow at subsonic and supersonic speeds places severe limitations on the choice of both airframe configuration and powerplant which have consequent repercussions on the aircraft noise characteristics.

The air flowing past a body at subsonic speeds produces a drag force as a result of the friction between the air and the body's surface. This is shown as the skin friction drag component in Figure 1. In addition, a further pressure or "form" drag results from the disturbance of the airflow caused b;y the passage of the body. The greater the thickness relative to the length (or diameter/length ratio) of the body, the greater this form drag. However, it is only a small addition to the skin friction drag, and only increases slowly with body thickness over the range of shapes of practical interest.

At supersonic speeds the situation is very different. The skin friction drag is similar in magnitude to that for the subsonic case, but the form drag is now largely shock-wave drag, and its magnitude increases very rapidly with slenderness ratio. As a result, practical supersonic shapes have to be more slender than their subsonic counterparts if the drag is to be kept down to a level which does not undermine the aircraft's economic performance at supersonic speed.

This low slenderness ratio requirement is reflected in the type of powerplant that can be efficiently utilized for supersonic cruise aircraft.

For subsonic aircraft, one of the principal developments in reducing jet engine noise at the source has been the introduction of the turbofan engine, in which only a fraction of the air entering the engine intake goes through the combusion chamgers and turbine. The recent major reduction in noise in the new generation of engines for subsonic aircraft has been achieved largely by adopting bypass ratios in the region of (5 to 6)/1.

It is apparent that a much larger diameter nacelle is required to house the high bypass ratio turbofan than for the straight jet engine. At subsonic speeds, the increased drag due to the larger diameter turbofan engine is relatively small and its effect, as well as that of the increased engine weight, is more than compensated for by the substantial reduction in specific fuel consumption which is characteristic of these engines.

At supersonic flight speeds, the performance penalty associated with the significant increase in wave drag (as indicated in Figure 1), precludes the use of high bypass fan engines as an efficient and practical propulsion system for supersonic aircraft.

This sensitivity to drag also influences the design of the aircraft's lifting surface. As a result, the wing span of supersonic aircraft is generally smaller than that for comparably sized subsonic aircraft. For example, the 707/DC8 aircraft have a wing span of approximately 145 feet compared with about 85 feet for the Concorde/TU 144. This wing span reduction decreases the low speed lift/drag ratio of the aircraft, thereby requiring increased engine thrust capability at takeoff in order to provide adequate lift. The Concorde and TU-144 have engine thrust/gross weight ratios (FN/W) of about 0.39 compared with the thrust-to-weight ratio for the 707 and DC-8 subsonic aircraft of about 0.22 for equivalent takeoff distances.

This higher level of installed thrust is also required to accelerate the aircraft into the supersonic flight regime. Figure 2 shows graphically the rapid increase in drag in the transonic speed range due to high speed compressibility effects.

Another, and perhaps more important, reason for not using a high bypass ratio turbofan engine supersonically is that its thrust lapse rate with Mach number is much greater than that of a comparable turbojet engine, owing to the lower exhaust velocity of the former.

D. Concorde Noise Control Technology

Within the design constraints required for efficient supersonic flight, progress is being made in reducing the noise generated by civil supersonic aircraft types. The following discussion relates this progress to the technological state of the art at specific points in time. For this purpose, the technological capability existing at the time of the design and development of the Concorde and TU 144 on the one hand, and the U. S. SST on the other, provide two historical benchmark periods. Subsequent technology developments will provide the capability for further advancements in controlling the noise of civil supersonic aircraft of the future.

The Anglo-French Concorde SST development program was officially initiated in November 1962 with the signing of a bi-lateral agreement between the two countries. A detailed history of the program is given in References 16 and 17. The agreement established the sharing of design and development responsibilities for the British aircraft and engine manufacturers (BAC and Rolls-Royce) and for their French counterparts (SNIA and SNECMA).

By 1965, the basic aircraft characteristics had been finalized and prototype production was begun. Soon thereafter, an application for Type Certificate was submitted to the FAA, four years prior to the establishment of any official noise certification standard. However, community noise considerations were an inherent part of the Concorde development program. At the 14th ICAO Assembly held in Rome in 1962, the following resolution was adopted:

"THE ASSEMBLY RESOLVES:

(1) To urge all Governments that will be associated with the development of supersonic civil aircraft to ensure that before such aircraft are put into commercial service their airworthiness and operating characteristics are such that they will.....

(a) not create a noise exceeding the level then accepted for the operation of subsonic jet aircraft....."

It appears that the noise levels of the subsonic long range jets then in operation were adopted as a minimum target. Figures 3 thru 5 display the projected noise levels for the Concorde compared with the 4-engine medium-to-long haul subsonic aircraft in the 1965 operational fleet. The sideline noise as shown in Figures 3(a) and (b) compares favorably with the subsonic turbojets and low bypass turbofan when one considers the significantly higher thrust levels required for supersonic aircraft, as discussed earlier.

With the benefit of hindsight, it can be seen now that the noise levels of the subsonic jets of the 1965 fleet did not represent an appropriate target for an SST planned to become operational in the mid-1970's. The most reasonable interpretation of the 1962 resolution is that the noise target for the SST should be the noise level accepted for operation of subsonic jets at the time the SST goes into service. Although the developers of the Concorde and the TU 144 could not be expected to know what noise levels the FAA would prescribe for the subsonic jets of the mid-1970's, the growing dissatisfaction with noise in the early 1960's clearly suggested that the trend of acceptable aircraft noise levels would be substantially downward.

This in turn would imply that the target for the SST be significantly lower than the noise levels prevailing for the subsonic jets in 1965.

The Concorde takeoff noise (measured 3.5 miles from brake release) is shown in Figure 4. In Figure 4(a), noise is plotted as a function of aircraft gross weight (as is the case for FAR Part 36 certification). The Concorde is characteristically consistent with levels of noise produced by the 1965 jet fleet, with noise levels increasing as gross weight increases. However, in Figure 4(b), an apparent anomaly exists with respect to noise versus aircraft thrust-to-weight ratio. The trend for subsonic aircraft shows a significant decrease in perceived noise as the thrust-to-weight ratio increases. This is equivalent to providing excess power for climb (over that normally required) in order to gain altitude rapidly, thereby resulting in reduced levels of perceived noise under the flight path. The Concorde, however, does not follow this trend due to the supersonic aerodynamic requirements which lead to the high span loading and low aspect ratio that govern takeoff and landing performance. Despite the fact that the Concorde's thrust-to-weight ratio is significantly higher than that of the subsonics, the excess thrust available for climb may in fact not be enough to allow it to climb as fast as the subsonic aircraft. In other words, the increased thrust/weight ratio may not overcome the decreased lift/drag ratio. The combination of lower altitude and higher engine thrust (or exhaust velocity) would then lead to higher noise levels than might be expected due to the thrust-to-weight ratio parameter alone.

The approach noise for turbojet powered aircraft is generally lower than that for unsuppressed turbofans since the high frequency fan noise at reduced power setting is not present (Figure 5). The Concorde approach noise is consistent with the turbojet trend line which reflects the increased thrust required as a function of gross weight. It is also lower than the noise of low bypass fan powered transports of the 1965 era. However, the approach noise of these fan powered aircraft can be significantly reduced by the application of sound absorption material (SAM) in the engine inlet and the fan exhaust duct. This procedure effectively attenuates the high frequency fan noise. Similar treatment applied to the turbojet inlet would be effective for high frequency compressor noise but not for the low frequency exhaust noise which is not responsive to SAM treatment.

The noise levels of the preproduction Concorde 02, which were measured by the manufacturer at the FAR 36 measuring points, are listed in Table 1 (Reference 18). The tabulation provides comparative data on Effective Perceived Noise Level (EPNL) in units of EPNdB for the Anglo-French Concorde, the Russian TU-144, and typical subsonic turbojet airplanes (Reference 19). The latter are those in general use today and which have an anticipated life of at least 15 more years. Included in the tabulation are levels for subsonic aircraft that have been retrofitted with "quiet nacelles". It is seen that the SST noise levels at sideline are much higher than those for any other aircraft and at takeoff and approach are comparable to those for the non-retrofitted 707 and DC-8 aircraft.

E. Tupolev TU-144 Noise Control Technology

The USSR civil supersonic transport development program was also initiated in the early sixties. The TU-144 has the distinction of being the first civil SST aircraft to have flown and to have exceeded the speed of sound (Mach 1.0) (Reference 20). First flight occurred on the last day of 1968, approximately two months prior to the Concorde's first flight. Mach 1.0 was reached in June 1969. The Concorde accomplished this milestone in October 1969.

The target noise levels established for the TU-144 were similar to those of the Concorde, i.e., no greater than the noise of the 1965 fleet of long range subsonic civil jets. Estimated noise levels for the TU-144 are compared in Table 1 with those for the Concorde and typical subsonic turbojet airplanes. The comments made previously for the Concorde relative to the 707 and DC-8 are valid also for the TU-144.

In contrast to the turbojet propulsion system of the Concorde, the TU-144, at least in the early versions, utilizes four low bypass ratio turbofan engines (BPR 1.1) in the 44,000 pound thrust range as its power source. In addition to the turbofan concept, several other design features were incorporated to minimize the noise impact of the aircraft.

These include:

- Long intake ducts with sound absorption panels
- Sonic inlets to reduce forward propagation of compressor and fan noise

- High lift devices to provide improved takeoff climb at reduced thrust settings, and reduced thrust approaches.

Both the Concorde and TU-144 are expected to enter airline operational service by 1975. The USSR has not yet applied for an FAA type certificate.

F. United States SST Noise Control Technology

After many years of Government and Industry research and component development related to supersonic aircraft, the FAA, in 1963, issued a Request for Proposal for a civil supersonic transport design competition. The prior announcements of the Concorde and TU-144 development programs may have provided some of the stimulus for the FAA action. The feasibility studies and detail design competition continued through 1966 at which time the Boeing Company and the General Electric Company were selected to continue design refinement studies. Full scale development was initiated in 1968.

The development program contained noise specifications in terms of Perceived Noise Level (PNL) in units of PNdB which does not include corrections for tones and duration as does EPNL. The requirements were as follows (Reference 21):

- Sideline - 116 PNdB at 1500' from runway centerline
- Takeoff - 105 PNdB at 3.0 statute miles from brake release
- Approach - 109 PNdB at 1.0 statute mile runway threshold

These initial goals were later revised to correspond to the measurement concepts adopted in FAR 36, using effective perceived noise level (EPNL).

- Sideline - 120 EPNdB at 0.35 nautical mile from runway centerline
- Takeoff - 108 EPNdB at 3.5 nautical miles from brake release

• Approach - 108 EPNdB at 1.0 nautical mile from runway threshold.

The goal therefore was to conform to the subsonic FAR 36 requirements for takeoff and approach with a significant exceedance at the sideline measuring point. The vast majority of community noise problems at that time were associated with approach or takeoff flight operations; sideline noise effects were generally restricted to the airport property.

In early 1970, indications were that the effective perceived noise level at the sideline was expected to be 122 EPNdB without the use of an exhaust noise suppressor. A Supersonic Transport Community Noise Advisory Committee was established in July 1970. One of its objectives was to assess the available technology that migh be applied to effectively lower the SST noise. After several months of technical and economical feasibility reviews, the Committee concluded that technology can be developed to design an economically practical commercial SST aircraft/ engine configuration that could meet the FAR 36 requirements for large (600, 000 lbs. gross weight or more) subsonic aircraft.

Funding for continued development of the American SST was terminated in April 1971.

G. Advanced Noise Control Technology

Subsequent to the cancellation of further development effort on the United States SST aircraft program, the remaining DOT/FAA funds were directed to investigations into supersonic component technology needs (Reference 22). Under this program, Boeing has demonstrated in model tests an 18 dB noise reduction under static thrust conditions for high jet exhaust velocities. It should be kept in mind that flight noise reduction rarely matches the noise reductions obtained under static test conditions. Also, a specific noise reduction value is really meaningless unless the relevant exhaust flow and thrust performance changes are reported as well. Under this same program (Reference 22), jet noise suppressions up to 14 dB in perceived noise level (PNL) were obtained in tests of suppressor designs, at the cost of increased drag.

In addition, NASA has maintained a research effort to develop a supersonic technology data base for potential use in future military or civil supersonic aircraft, if and when the need should arise (Reference 23).

Some results of studies conducted by Pratt & Whitney Aircraft under contract with NASA Lewis Research Center, reported to the AIAA/SAE 9th Propulsion Conference (Reference 24) are also relevant. This reference shows that noise constraints have a major effect on the selection of the various engine and cycle parameters for supersonic transports; in addition, it concludes that there appear to be several potential propulsion systems capable of meeting the FAR 36 noise goals: the nonafterburning turbojet engine with a high level of jet suppression, the duct-heating turbofan engine with a low level of suppression, and some variable cycle engines.

Major concerns addressed in all of the SST programs are those of aircraft noise and chemical pollution. One of the key objectives is to reduce the sideline noise generated by supersonic transport aircraft. As discussed earlier, the unique propulsion requirements of these aircraft types tend to have the greatest influence on sideline noise. Flyover and approach noise can be alleviated to some extent by the application of optimized operational procedures, sound absorption materials, and appropriate inlet design.

Preliminary study results indicate that current technology (1973-75) propulsion systems may be capable of meeting the present FAR 36 noise levels. These would be applicable to an SST developed to enter operation in the 1980's. Aircraft weight, cost, and performance are affected by the choice of propulsion system utilized, but various options are available:

- Non-afterburning turbojet with exhaust suppressor
- Afterburning turbojet with exhaust suppressor
- Afterburning turbofan with or without exhaust suppressor
- Duct burning turbofan with or without exhaust suppressor

Utilizing 1980 technology in the form of engine and aircraft weight reductions plus improved suppressor technology, further reductions in noise levels (approximately FAR 36 levels minus 5 EPNdB) may be attainable for the conventional engines noted above. To achieve FAR 36 levels minus 10 or more will require the development and demonstration of new propulsion concepts such as dual-cycle engines, variable bypass engines, etc., as well as methods for controlling the aerodynamic air-frame noise. The development of new concepts can be accelerated by a better understanding of the basic principles of jet noise generation and suppression. The work in progress under an Air Force Contract (Reference 25), supported in part by the Department of Transportation, should be of considerable help toward this objective.

H. Noise Measurements of Concorde

The four Concorde airframe and engine developers, British Aircraft Corporation (BAC), Societe Nationale Industrielle Aerospatiale (SNIA), Rolls Royce Ltd (RR), and Societe Nationale d'Etude et de Construction de Moteurs d'Aviation (SNECMA), have conducted extensive noise testing and reported the results in References 16 and 17. Both of these references provide great detail on the Concorde Program; in particular, Reference 17 provides the latest predictions on noise and performance and a succinct summary of the developers' position. The references are factual and very informative but do not include all of the information that would be useful for the regulatory decision-making process.

In order to rectify the deficiency, both the EPA and the FAA conducted their own sets of noise tests on the Concorde 02 during several demonstration flights in the United States. The results, reported in References 26 and 27, indicate that certain aspects of the Concorde noise-related flight operations and the resultant noise signature characteristics, previously not delineated by the manufacturers, are important to the regulatory process and should be identified and evaluated. The relevant features of these references are presented in the following discussion.

Reference 26 describes noise measurements made of the Concorde 02 aircraft during operations at Dallas-Fort Worth and Dulles International Airports in September 1973. Data were acquired at 25 sites surrounding Dallas-Fort Worth and 15 sites surrounding Dulles. The results are reported in terms of various noise evaluation measures (A-Weighted Sound Level, Effective Perceived Noise Level, and others) and correlated with respect to distance and aircraft/engine operating parameters. Included are representative one-third octave band spectra for takeoff and approach operations at Dulles.

A prediction procedure is developed in Reference 26 based upon data measured at various distances and extrapolated to larger distances by conventional methods. The results of these semi-empirical predictions indicate that there is no reason to believe that the noise levels measured and reported by the Concorde developers cannot be achieved provided that certain noise abatement takeoff actions, which can be made standard operating procedures for that airplane, are fully utilized. However, noise abatement takeoff procedures were not used at Dulles and, as a consequence, the measured noise levels exceed the values claimed by the four Concorde manufacturers.

The test results of Reference 26 clearly indicate that the takeoff noise levels reported by the Concorde manufacturers were obtained under well controlled operating conditions; that is, noise abatement takeoff procedures were utilized to achieve the takeoff levels listed in Table 1. When these procedures are not used, the noise levels are substantially greater. In all fairness, however, it should be pointed out that this situation is true also for many of the subsonic aircraft. The noise levels for the subsonic airplanes reported in Table 1 are the FAR 36 values which are obtained under well controlled operating procedures, many with thrust cutback at takeoff, which procedure is generally not used in service.

In addition, the test results of Reference 26 show that the preponderance of the noise energy of the Concorde is concentrated in a lower frequency range than that of subsonic airplanes like the 707 and DC-8. This means that as the noise of the 707/DC-8 and Concorde airplanes propagates with distance, the levels of the subsonic types decrease at a greater rate than that of the Concorde. The reason is that low frequency sound energy is attenuated to a lesser extent by the atmosphere than is high frequency sound energy. Thus, if the Concorde and 707/DC-8 noise levels are approximately the same near the airport (say 3.5 nautical miles), the levels for the Concorde will be higher at greater distances. Also, low frequency sound energy is attenuated less by conventional building construction materials and will excite the natural vibration modes of most buildings more readily than high frequency sound energy. On the other hand, it should be pointed out, low frequency sound energy is less annoying to humans than high frequency sound energy, assuming the same energy levels for each.

Reference 27 describes noise and vibration testing pertaining to the Concorde 02 aircraft during operations at Fairbanks International Airport, Fairbanks, Alaska, in February 1974. Measurements were made at four sites for indoor and outdoor noise and indoor vibrations, the buildings being: (1) a motel, (2) a fire control tower, (3) an FAA office building, and (4) an FAA avionics equipment building. Data were obtained for a total of 24 operations of 737, 707, 720, and Concorde airplanes during takeoffs and landings. Seven of these operations were made by the Concorde and the remainder by the subsonic airplanes.

The results reported in Reference 27 indicate that the outdoor noise levels on the flight track of the Concorde were greater than those of the subsonic jets by nearly 6 dB on landing and nearly 9 dB on takeoff. The measured levels for all aircraft were normalized to 600 feet so the comparisons are valid for distance. However, there is no information regarding the thrust settings for any of the airplanes so the comparisons are not adequate regarding the operational procedures. In other words, if the tests were obtained under well controlled operating conditions (such as the FAR 36 requirements), the noise level differences probably would not be so large. Conceivably, in some cases, the subsonic airplane levels might exceed those of the Concorde at that distance (600 feet) at maximum thrust settings.

Regarding the differences in noise level indoors, the results reported in Reference 27 indicate that the indoor noise levels on the flight track of the Concorde were greater than those of the subsonic jets by more than 6 dB on landing and more than 11 dB on takeoff. The structures filtered the noise better for the subsonic jet aircraft than they did for the Concorde by about 0.5 dB for landing and about 2.5 dB for takeoff. The reason for the greater indoor noisiness of the Concorde is the greater transmissibility of low frequency sound through buildings. The buildings just do not filter the noise as well for low frequency sound as they do for high frequency sound.

Regarding the differences in structural vibration levels, the results reported in Reference 27 indicate that the levels are greater for

Concorde operations than those for the subsonic aircraft operations by about 15 dB on landing and about 9 dB on takeoff. The reason for the greater vibration response due to the Concorde is the greater intensity of low frequency noise generated by the Concorde compared to that generated by the subsonic aircraft.

In summary, the Dulles tests established that the noise generated by a fully loaded Concorde, when measured at the FAR 36 takeoff and landing measuring points, could equal the levels reported by the manufacturers. These levels are comparable to those for 707 and DC-8 type subsonic aircraft and can be achieved only if the Concorde is implementing noise abatement takeoff procedures. The Dulles and Fairbanks tests established that the Concorde can produce higher noise levels than represented by the manufacturers which also is true for the subsonic airplanes. The Dulles and Fairbanks tests established that the Concorde noise energy is concentrated in a lower frequency range than the noise energy for the 707 and DC-8 which leads to the following comparisons:

- the noise of the Concorde propagates at audible levels to greater distances;
- the noise of the Concorde penetrates conventional buildings more easily; and
- the noise of the Concorde excites the natural vibration modes of most buildings more readily.

A mitigating aspect, however, is that low frequency noise is less annoying to humans than high frequency noise, for the same energy levels. This means that an auditor located at 3.5 nautical miles from brake release might consider Concorde noise less obnoxious than 707 noise because of the high frequency contribution of the latter. However, as the auditor moves farther away from the airport, the high frequency noise component of the 707 will diminish to the point where it is no longer a factor in the auditor's judgement of the two noise sources. What remains then is the low frequency noise of both sources and the Concorde will be judged the louder of the two sources. But when this occurs, the level of the Concorde may be so reduced that it may not be a problem from an annoyance or any other health and welfare standpoint. However, there is an element of human response which could cause annoyance at levels below those associated with conventional sources of noise. It arises from identification of the source per se, and possible resulting hostility towards it.

5. ANALYSIS

A. Community Noise Environment

It is clear from the information presented herein that operation of the Concorde or the TU-144 at a U. S. airport would introduce a new and additional noise source comparable in level to the noisiest of the subsonic jets in the air carrier fleet. It therefore is instructive to attempt to define the existing noise environment prior to introduction of the new source as a basis for assessing the potential effect of the new source on the community noise exposure.

In order to provide generality and the ability to introduce variable conditions without excessive complexity or distraction by local detail, much of the analysis that follows will be based on a modeled situation -- that is, a model airport/community will be defined with the characteristics outlined below.

- One runway, assumed to be the one of major concern, will be considered.
- The composition of the fleet operating off the runway is assumed to consist of the following narrow-body airplanes powered by JT3D and JT8D low bypass turbofan engines:

JT3D		JT8D		
QTY	TYPE	QTY	TYPE	
33	707	72	727	
18	DC-8	16	737	
		34	DC-9	
51		122		173 Total

- Each airplane is assumed to land and take off in the same direction on the runway.
- Each airplane is assumed to produce Effective Perceived Noise Levels at the FAR 36 measuring points (see Figure 6) equal to the actual or estimated certificated noise levels for that airplane (Reference 19); this is tantamount to assuming takeoff and landing at maximum certificated weights, and operation in strict conformity to FAR 36 conditions.
- The Noise Exposure Forecast (NEF) and the Day Night Level (Ldn) points will be evaluated, for the baseline condition (unmodified air-caft) and for several defined retrofit modifications. All operations are assumed between the hours 0700-2200.
- Operations of the Concorde will be evaluated for three different rates of activity, and the NEF and Ldn contributions of those operations will be computed. The rates of activity refer to flights per day consisting of one landing and one takeoff per flight. The activity rates to be evaluated are: one, four, and eight flights per day.
- The latter rate might include the entry of supersonic airplanes by domestic airlines as well as foreign into their subsonic fleet activities.
- The incremental effect on noise exposures will be evaluated, in terms of incremental NEF and Ldn values and incremental areas exposed to given NEF and Ldn levels.

Noise Exposure Forecast (NEF) is a methodology for predicting (or measuring) a single number rating of the cumulative noise intruding into airport communities. The results of the computations are useful for planning purposes when the NEF levels at individual positions on the ground are combined into equal NEF contours and plotted on maps of the airport and its neighborhoods. The methodology for NEF, presented in Appendix A, was used to compute the values listed in Table 2. The NEF values pertain to the cumulative noise at a specific location on the ground and, through its relationship to day-night level (Ldn), can be related to health and welfare in accordance with Reference 9. The assumption that Ldn = NEF + 35 is sufficiently accurate for the relatively simple airport model used here where the purpose is to compare the cumulative noise effects of aircraft operations with and without the Concorde.

It should be emphasized here that the preferred measure for cumulative noise exposure is Ldn. The NEF values are used here in conjunction with Ldn because much of the currently available data and the computational procedures concerned with cumulative aircraft noise are provided in terms of NEF. For practical purposes, when discussing aircraft noise, the two measures are equivalent, with the adjustment factor of 35 added to NEF to yield Ldn, as indicated above.

To clarify the meaning of this measure of noise exposure, Day-Night Level, Ldn, is defined as the energy average A-weighted noise level integrated over a 24-hour period, with the noise levels occurring during nighttime hours weighted 10 dB higher to account for the greater annoyance of noise at night. The related measure, Leq, is identical to Ldn except that it does not add a correction factor for nighttime exposure. EPA, in the Levels Document, Reference 9, has identified the values of Ldn = 55 and Leq = 70 as noise exposure levels that should not be exceeded to protect the public health and welfare, with an adequate margin of safety, against annoyance and hearing impairment, respectively. These levels are not to be construed however, as standards, because they do not take into account considerations of technology and economics. They represent the values which are to be used to test the effectiveness of controls, or regulations from a health and welfare aspect.

B. Effects of SST Flights on Noise Exposure

The results of the noise exposure computations are summarized in Tables 2(a), and 2(b). Review of the computational results leads to the statements below, regarding the noise intrusion effects on introduction of SST flights into the hypothesized airport:

(1) Baseline - Unmodified Fleet of JT3D/JT8D Powered Airplanes

For this case, four SST flights per day produce a trivial increase in noise exposure at the approach (0.2dB) and takeoff (0.6dB) noise measuring points, and a perceptible increase (2.0dB) on noise exposure at the sideline noise measuring point. Since, for most airports, the main impact of sideline noise is within the airport boundaries, the overall effect of the SST flights may be described as slight. The increase in community area exposed to Ldn 75 probably is less than 10%.

Relative to the above values, three points are germane. The first point is that noise exposure levels (Ldn) result from estimates and generalizations of aircraft categories, mix of aircraft, runway utilizations, number of operations, flight paths, single event noise levels, and atmospheric conditions. And, considering these assumptions, predicted noise exposure levels for any given day can be considered to have an accuracy no better than plus or minus five decibels compared to actual levels that could be measured for that day. Ldn can be measured conveniently with available instrumentation; measurements over an extended period are necessary to provide a valid long-term average. The second point is that the computed (by the method of Appendix B) area exposed to a given value of Ldn is subject to an error of probably about 20%; the difference in area, therefore, is probably subject to same percentage error (e.g., 20% of 10%). The third point is that such small level or area increases do not represent a "quantum jump" in community noise exposure. For example, an increase of 1 dB to an area (or residence) previously exposed to Ldn of 74.1 dB will result in a level of Ldn 75.1 dB. The residence will experience only a 1 dB increase although it now would fall within the Ldn 75 contour area. Zones of noise exposure separated by noise exposure contours are useful for planning purposes, but it is erroneous to assume that contours represent sharp divisions between more or less critical zones.

One might argue, on the other hand, that increase in noise exposure is not the only valid way of assessing noise intrusion. The injection of a single event noise level significantly higher than the bulk of the single events that go to make up the noise exposure may be more disturbing or annoying to the person exposed than the small increment in cumulative measure of Ldn might suggest. Available scientific data are insufficient to provide any quantitative guide to this judgment. In the context of community noise due to airplanes, the best criteria available for judgment indicate that cumulative noise exposure is a more trustworthy and objective measure (References 8 and 9), unless the individual event is strikingly higher (say 10 dB or more) in noise level than surrounding events.

The point discussed in the previous paragraph is immaterial with respect to the baseline jet fleet, in any case, since the single event noise levels for the JT3D-powered 4-engine jets (DC-8 and 707) fall into the same range as the SST levels at the takeoff and approach measurement points. It becomes more significant in considering the other cases analyzed, wherein retrofit of "quiet nacelles" lowers the takeoff and approach noise levels of the JT3D-powered airplanes to 105 EPNdB or less. For these cases, the assumed SST single event levels will exceed the noisiest of the other events by upwards of 10 dB, which will impart a distinct audibility to those events.

(2) Modified Jet Fleet Conforming to FAR Part 36 Levels

If a retrofit regulation is promulgated in accordance with the FAA NPRM (Reference 28), the 1978 fleet would be expected to conform to the levels prescribed in FAR 36. In the noise environment generated by this fleet, the introduction of the SST (4 flights per day) would increase Ldn values at the sideline and approach measuring points slightly, i.e., about 1dB, and at the takeoff measuring point significantly, i.e., about 3dB. The corresponding increase of 64% in the area within the Ldn 75 contour is substantial, even taking into account the caveat, mentioned earlier, that this does not signify a step increase between more or less critical zones.

The above statement pertains to the situation where the 1978 fleet complied exactly with the noise level requirements of FAR 36. However, in practice, the retrofit hardware representing current and available technology would permit lower levels to be achieved.

(3) Modified Jet Fleet with "Quiet Nacelle" Treatment

In a community noise environment based on exposure to the jet fleet with "Quiet Nacelles", the introduction of the hypothesized operations of an SST would increase the noise exposure at the sideline and approach measuring points perceptibly, about 2 dB, and at the takeoff measuring point significantly, 3.8dB. Basically, since this presumed fleet would be slightly quieter than a fleet just conforming to FAR 36, the effect of the SST operations would be slightly more perceptible and annoying.

(4) Modified Jet Fleet with Refanned JT8D and Quiet-Nacelle JT3D

When injected into a community with noise exposure characteristic of the current jet fleet with refanned JT8D engines and quiet nacelles for the JT3Ds, the SST operations would be significantly apparent. The increases in Ldn of 5 dB at the sideline and 4.5 dB at the takeoff measuring point would be substantial, resulting in doubling of the area exposed to Ldn 75. The effect on the noise exposure at the approach measuring point (+1.8 dB) would be perceptible, but not necessarily significant.

(5) Typical JFK Airport Runway Fleet Mix

The four cases discussed earlier have been based on a hypothetical airport with operations of a hypothetical fleet. While this may not represent any one airport realistically, it probably yields a useful general picture for U.S. airports as a whole. A slightly more specific perspective may be gained by using a more realistic portrait of an actual airport. For this purpose, John F. Kennedy airport has been selected. The assumed fleet operations and noise contribution have been determined utilizing the following statistical data:

Total annual operations at JFK in 1972 for all commercial carrier airplanes, from Reference 29.

Relative usage of JFK runways, from Reference 30.

FAR certificated noise levels for the various airplanes, from Reference 19.

The noise exposure levels at the FAR 36 measuring points relative to JFK runway 13R/31L calculated for these conditions are listed in Table 2(b). The levels are somewhat higher than those computed for the hypothetical airport and fleet. Consequently, the injection of SST noise into this environment results in a barely perceptible increase in noise exposure at the sideline (0.9dB), and trivial increases at the other two measuring points (0.2 and 0.1 dB).

Indeed, it is pertinent to point out that, as regards takeoff and approach noise, the SST is approximately equivalent to a fully - loaded B707 or DC-8. Consequently, the effect of introducing an SST operation at an airport such as J.F. Kennedy, which has numerous operations by international airlines of heavily-loaded long-range subsonic jets, is about equivalent to adding another operation of a subsonic jet. Alternatively, if an SST operation were to replace a subsonic jet airplane operation, the noise exposure off the airport (i.e., neglecting sideline noise effects) would be practically unchanged.

Effects of other assumed combinations of subsonic and supersonic operations, including tradeoffs and costs involved to avoid increased community noise exposure, are discussed in Section 6, Health, Welfare, and Economic Considerations.

C. Regulatory Considerations for Concorde and TU-144

It is well known that there has been considerable controversy about a supersonic transport. One major product of this controversy was the cancellation of the United States development of a civil SST. One of the major reasons for this cancellation of the U. S. SST was the sonic boom problem. However, one of the other key objectionable features was considered to be the excessive community noise developed by the supersonic transport.

To avoid sonic boom occurrences in the U. S., it has been ruled that no supersonic overflights by civil aircraft will be allowed in the U. S. (Reference 12). Nevertheless, two supersonic transports are in development by other countries: (1) the Anglo-French Concorde, and (2) the Soviet Union's Tupolev TU-144. A small number of Concordes have been sold and are expected to go into commercial operation in the 1976 time period. Because of the relatively high noise levels of the Concorde, considerable opposition has been expressed to its entry into service in the U.S. The general feeling is that the injection of this new and potent noise source into an environment that is already non-acceptable for noise will signify a trend toward further degradation at a time when a major effort is under way to reduce the community noise exposure. One of the main purposes of this report is to explore this question and to establish:

(a) the probable effects of the Concorde on the community noise exposure, and

(b) whether, by suitable operation limitations, this effect can be restricted within acceptable bounds.

Ideally, of course, in the context of the EPA-assigned mission to improve the noise environment, it would appear desirable to preclude the introduction of a major new source of noise by excluding it from operation within this country. This is particularly so if, as is the case with the Concorde, it would introduce sound levels higher than those of the current fleet which many people already consider too high. It is a view also reinforced by high fuel consumption of the SST and related pollution effects. On the other hand, there are some who have philosophical and, to them, practical objections to the exclusion of an airplane such as the Concorde. These objections are discussed briefly in the succeeding paragraphs.

Exclusion of the Concorde from U.S. airports may tend to discourage technical development in civil supersonic aircraft technology. If such development were successful, it could lead to constructive exploitation of the advantages of civil supersonic flight while minimizing the disadvantages of noise, fuel consumption and pollution. If this kind of development is discouraged in the United States, it may lead to the loss of leadership in a potentially important technological and commercial area, to the detriment of our competitive position, balance of payments, etc. It is important, of course, that another kind of balance be considered also - the proper balance between the ostensible needs of commerce and industry and the need of the American people, as reflected in the National Environmental Protection Act, to protect the environment against accelerating degradation.

Those who oppose exclusion of the Concorde from operations in the United States also point out that such exclusion could have political repercussions. There are international aviation agreements to which the U.S. is a party and which must be taken into account. It is within the realm of conjecture that unilateral action taken by the U.S. government to exclude the Concorde from the U. S. could lead to reciprocal action against U.S. carrier operation of subsonic aircraft to other countries. Carried to its logical extreme, this type of action could create havoc in international air commerce.

Another significant factor that is taken into account by SST proponents is the enormous capital investment by the English, French and Russian governments in the development of SST aircraft. Several commentators have expressed the sentiment that the U.S. should feel no responsibility for salvaging an unwise investment, pointing out that the ICAO statement of 1962 clearly indicated that the drive toward quieter airplanes would have an effect on the acceptability of the Concorde at the time it was scheduled to go into service. Their view is that the U.S. should not accept the introduction of an airplane whose noise is patently a hazard to health and welfare. The proponents of the Concorde contend, on the other hand, that where the vehicle in question is not clearly a health hazard, the U.S. government might, because of international obligations, allow its introduction at least on a limited basis.

Finally, from an economics viewpoint, the SST proponents contend that it is not unreasonable to allow the supersonic transport the opportunity to demonstrate whether, with properly internalized costs, the supersonic transport can compete effectively in the marketplace. The phrase "properly internalized costs" is meant to indicate that the cost to the passenger should reflect all the actual costs, including those required to make the SST acceptable from a public health and welfare standpoint.

The view of Concorde proponents suggests consideration of a related matter -- possible growth of the Concorde. In order to be economically viable, all new aircraft must have a certain and defined growth potential. The reason for this is that new airframe and engine combinations are not nearly as efficient in terms of range, payload, operating costs, etc., as they can be after they have had the opportunity to be tested and evaluated in service. Generally, the most significant changes are made in the engine in terms of increased thrust while maintaining an adequate margin of safety. Increased thrust can be translated into increased flight range with the same payload, increased payload for the same range, or some combination of both.

Without growth potential of this sort, guaranteed by the manufacturers, new aircraft would have a very limited market at best, and most likely, no market at all. Figure 8, based upon information from References 17 and 18, shows the predicted relationship between sideline noise and takeoff noise for various values of Concorde maximum weight and percent thrust. In effect, Figure 8 represents an estimate of the effects of growth on sideline and takeoff noise. The intersection of the lines for 385,000 lb. maximum weight and 100 percent thrust (indicated by a circle) represents the preproduction model, Concorde 02, whose measured values are listed in Table 1.

The Concorde developers estimate at this time that the Concorde growth will not exceed the values bounded by the curves of Figure 8. For example, one extreme would be an increase in maximum weight to 405,000 pounds without an increase in thrust, resulting in a tradeoff reduction of about 1.5 EPNdB in sideline noise for an increase in takeoff noise of 4 EPNdB. Another extreme would be an increase in thrust of 10 percent with no increase in weight, resulting in a tradeoff reduction of 2 EPNdB in takeoff noise for an increase in sideline noise of nearly 3 EPNdB. Probably, the growth will not proceed along either of the extreme boundaries but more in the direction of no tradeoff where both sideline and takeoff noise increase at a rate of about one to one.

The majority of the information shown in Figure 8 pertains to the Concorde 02 preproduction model with the Olympus 593-602 engine. The first production model with the Olympus 593 engine at 400,000 pounds maximum weight is estimated to have about 3 percent more sea level static thrust, with reheat, than the preproduction model (38,000 pounds to 37,000 pounds). Figure 8 shows that the values for the sideline and takeoff noise levels estimated by the manufacturers (Reference 17) for the production Concorde are lower than, but within one decibel of, those that would be predicted for the Concorde 02.

D. Limiting Noise Exposure for Concorde and TU-144 by Operational Constraints

As a middle ground approach, and consistent with the suggestions of many commentators, it appears reasonable to consider allowing the Concorde and TU-144 to fly into and out of U. S. airports as an interim measure, providing the community noise exposure levels are not increased or the increase is negligible. A major factor in such an approach would be the imposition of strict operational constraints which could be used to limit the noise exposure due to the SST airplane operations.

It could be clearly indicated that such an arrangement was temporary, involving a waiver of requirements known to be desirable in order to allow the reasonable economic evaluation discussed earlier. In this context the waiver, for example, might be allowed for the first production lot of Concordes, which is approximately 20 airplanes. Subsequent production models would be required to meet successively lower levels, giving the manufacturers an opportunity to do the necessary development between production lots until either it has been demonstrated that the Concorde and TU-144 airplanes could meet levels that are required for subsonic transport airplanes or it turned out that it was not economically feasible to meet acceptable requirements with the supersonic transports.

The question of operational limitations requires some elaboration. The kind of constraints that may be envisaged includes such aspects as designating specific airports for SST operations, limiting the number of operations allowed per day at any one airport, designating the runways to be used for SST operations to minimize exposure of noise sensitive areas, limiting operations to the daytime, etc. These are the kind of constraints that might be included in an airport noise regulation; however, in the absence of an airport regulation, this type of limitation could be specifically included as part of the SST aircraft noise regulation in the form of an operating rule.

6. HEALTH, WELFARE, AND ECONOMIC CONSIDERATIONS

Fundamental to EPA's mandate, under the Noise Control Act of 1972, is the objective of attaining and maintaining a noise environment that is consistent with public health and welfare requirements. In striving for this objective, the agency is cognizant of FAA's requirement under Section 7 of the Act to take into account the availability of technology and cost of compliance in arriving at the balance of judgment as to the degree of quieting required.

Accordingly, in the EPA "Report" to Congress (References 1-7) on aircraft and airport noise, the costs were estimated of achieving several levels of cumulative noise environments employing the noise abatement alternatives of source control, operational procedures, and land use options.

Given these considerations, it is necessary to evaluate the influence of the introduction of supersonic airplane operations on the efficacy of the aviation noise control measure: i.e., what are the environmental impacts and how would these affect the overall aviation noise environment and the costs of achieving a specified environment.

Subsequent discussion will cover the following areas:

- The disbenefits of noise;
- The environment around an airport and impacts when SST is introduced under several sets of fleet source noise level conditions;
- The incremental costs of achievement of noise environment objectives with SST introduction;

- The operational constraints necessary to ensure that SST operations do not adversely affect the environment;
- Implications for SST fares under operational constraints.
- An assessment of the equivalent noise impact on the population surrounding an airport.

Other elements of the economic impact of introducing SST operations in the United States, such as the competitive effect on domestic airlines, or costs of equipping a fleet with SSTs, will not be considered here as they do not bear directly on the question of cost of controlling the noise impact of the supersonic airplanes.

A. The Disbenefits of Noise

In its report to Congress, 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 Levels Document (Reference 9) specifically identified two long-term average levels of cumulative noise exposure as those levels which should not be exceeded in order to protect the public health and welfare with an adequate margin of safety:

- A Day-Night Level (Ldn) no greater than 55 dB, to protect against annoyance (including interference with speech communication).
- An Equivalent Noise Level (Leq) no greater than 70 dB, to protect against significant adverse effects on hearing.

The potential of indirect effects of noise is also admitted, but there does not exist sufficient evidence to quantify them 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 their 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 adverse effects of noise are:

- The relative attractiveness of real estate is degraded;

- The delivery of public services is disturbed, e.g., interruptions of educational instruction;
- Interpersonal relationships are aggravated;
- Continual or repetitive annoyance is manifested as tension and stress;
- On the job performance, i.e., productivity, is diminished.

These results demonstrate the insidious nature of noise in 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 yet well-defined. For example, there is no accurate quantification of the relative reduction in costs that would accrue in removing one person from an Ldn 80 environment vis-a-vis removing two persons from an Ldn 70 environment. That is, sufficient research to quantify the cost benefits of noise reduction has not been performed to date. Consequently, as in many environmental situations, not having quantitative estimates of the benefits of noise reduction precludes analysis of the amount of noise environment reduction that is justified on a cost-benefit basis; therefore, the subsequent analyses will use a cost - effectiveness analytic framework.

A cost-effectiveness analysis can, however, yield very persuasive information on the merits of the noise control options. To begin with, it is necessary to consider the reduction in noise levels, the reductions in land areas exposed to specific noise levels, and the population removed from these noise level zones. In addition, it is possible, by using the methodology described in Appendix C, to make a Noise Impact Assessment (NIA) which expresses the change in human response expected from the people exposed to specific levels of environmental noise. When the above are correlated with the costs of the noise control options, the resulting cost-effectiveness analysis is very powerful.

It should be kept in mind that the introduction of an SST to major U.S. airports will not expose persons to a high level of noise who have not previously been so exposed. Rather the situation is one where someone exposed to a high noise level, with the introduction of an SST, may be exposed to an even higher noise level or a comparable level that may sound different.

B. Methods of Reducing Cumulative Noise Levels

Achievement of any desired Day-Night Level (Ldn) can be realized by combinations of reducing source noise emissions and protecting noise-sensitive receivers.

Reduction of current aviation source noise emissions can be accomplished by retrofitting the commercial aircraft fleet using source noise abatement technology, implementing noise abatement takeoff and landing procedures and exercising airport operational control such as preferential runways, restriction on flight operations, etc. Protection of noise-sensitive receivers can be accomplished through the soundproofing of residential and other sensitive structures or through the purchase of land and subsequent relocation of existing incompatible land uses.

Actions to reduce the noise levels by existing aircrafts' source abatement and operational options may not totally eliminate noise impacts at a given location. 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 costs of same may be found in Reference 5.

In this report, the "cost" of achieving any given Ldn 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 are the incremental costs of preventing degradation of the community noise environment around an airport if an SST type aircraft were allowed to operate into and out of such an airport?"

By the 1978-80 time period fleet noise levels are expected to be relatively lower than those of today's fleets because not as many, if any, straight jet aircraft will be operating in the fleet and the low bypass ratio fan jet aircraft are expected to be retrofitted. The capacity represented by the retired aircraft will have been replaced by the less noisy high bypass ratio fan jet aircraft. Lower fleet noise levels translate into reductions in the areas within Ldn contours around airports which in turn imply smaller 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 decrease because they are the vintage aircraft in the current fleet. These general trends are incorporated in the subsequent analysis. However, one must remember that we are dealing with individual airports and their costs of achieving specified levels of cumulative noise exposure. This is so because the SST can operate effectively only at the larger metropolitan airports. These are the very airports which are currently the most severely impacted.

C. Mixed Operations of Supersonic and Subsonic Jet Aircraft

Section 5 utilized a simple model hypothesizing a single runway airport to calculate noise exposures (Ldn) at the three FAR 36 measuring points for three subsonic fleet configurations. Subsequently, for each fleet configuration, the effects of introducing three different rates of daily operations of an SST were determined in terms of incremental increases in the Ldn values and the percentage increases in land area corresponding to the increased noise exposure. These percentage increases can be simply converted into net incremental land areas beyond the airport boundaries in which populations may be exposed to the identified noise exposures.

These areas were estimated by a simple geometric analysis, using as a starting point the equivalent single-airplane average EPNL at the 3.5 nautical mile takeoff measuring point determined from the calculated NEF at that point for the baseline fleet. By use of the data in Reference 31 on EPNL vs slant range, it was possible to plot a contour from which the enclosed areas, both on and off the hypothetical airport, were calculated. From these values, the corresponding enclosed gross areas for the Ldn 65, 70 and 75 contours were determined by use of the relationship,

$$Ldn(1) - Ldn(0) = 15 \log(A / A0)$$

developed in the appendix. The net areas were established by subtracting the estimated on-airport areas from the calculated gross areas, with one minor exception. For the Ldn 65 contour, the on-airport area subtracted was 1.5 square miles, which was assumed to be the relevant area of the airport. Shown in Tables 3 (a) and (b) are the net impact areas for each aircraft noise level situation and the incremental impact area increases resulting from introducing 1, 4, and 8 SST flights per day. One should note from Table 3 (a) that as time passes and the source noise options become available, and are implemented, the net noise exposure impact area decreases. In addition, it should be noted from Table 3 (b) that the SST incremental impact areas increase as the rest of the fleet becomes quieter.

D. Costs of Compatible Land Use Induced by SST Noise

Introducing SST operations at the hypothesized airport increases the noise impact area for each fleet noise control option. Accordingly, a larger population around this airport would be exposed to higher noise levels than those that would exist if the SST flights were not allowed to occur.

This incremental increase in population exposed is estimated by assuming the following population densities within Ldn contours:

- Ldn 75 = 2000 people/square mile
- Ldn 70 = 2500 people/square mile
- Ldn 65 = 5000 people/square mile

These densities are typical for East Coast metropolitan airports which are candidates for the SST activity, References 32 and 33. The noise impacted populations for the conditions of baseline and the two retrofit options relative to the three noise exposure levels are given in Table 3 (c).

It should be noted that these density values are applied to the areas within the baseline contours. As the areas within a given contour shrink because the fleet becomes less noisy, population densities are assumed not to change; consequently the density values applied in the computation are those associated with the baseline areas. Simply multiplying incremental Ldn areas by the respective population densities is assumed to yield the additional number of people exposed to an increased noise environment.

These SST noise - induced population impacts will result in greater costs of achieving a desired cumulative noise level. An estimate of such induced costs can be developed by recognizing that the increases in noise that this incremental population will be exposed to are not dramatic, e.g., on the order of a few decibels over their previous environment in most cases. Referring to the unit cost curve for compatible land use control of Reference 5, a one decibel increase in the Ldn 75 range will require an additional one thousand dollars per person for compatible land use control techniques. A one decibel increase in the Ldn 70 range will require an additional 500 dollars per person. For each person exposed to the Ldn 65 range, the induced cost is estimated to be three hundred dollars per dB increase. Multiplying these unit costs by the incremental populations yields the increased costs of noise compatible land use. Shown in Tables 3 (d) and (e) are the increased population and cost impacts of having the SST activity at the hypothetical airport. It can be seen that as the subsonic commercial fleet becomes less noisy, the population (except for Ldn 65) and cost impacts increase.

There is an apparent anomaly in the population increase figures for the Ldn 65 areas. That is, the increase in impacted population within the Ldn 65 area due to the SST operations becomes smaller instead of larger as the subsonic fleet becomes quieter. The reason for this resides in the assumption, noted earlier, that the baseline distribution of population remains constant. As the fleet becomes quieter, the Ldn 65 area shrinks so that it eventually lies within the area that was previously an Ldn 70 area, with an assumed population density of 2500 instead of 5000 people per square mile. Consequently, the increase in area due to the SST operations introduced into the quieted-fleet situation occurs within area of lower assumed population density, which results in a smaller computed increase of impacted population, when compared to the baseline fleet situation, despite the larger increase in impacted area.

In perspective, it merits pointing out that the results presented in Tables 3 (a) thru (e) are based on theoretical approximate calculations regarding a hypothetical airport. Consequently, they should be considered as generally indicating the magnitude of the noise problem presented by the introduction of the SST operations, rather than as literal estimates of the actual costs that might be incurred. In this context, the results reveal that introduction of one flight per day of the SST at a fairly busy airport with today's subsonic fleet (prior to retrofit) represents a minor problem in noise intrusion; whereas in the same environment eight SST flights per day represent a significant problem. The reason for the striking difference in effect between the two levels of SST operation is that the increase in Ldn acts as a multiplier squared in computing the dollar cost. First, the area affected (and consequently, the number of people affected) as discussed earlier, is directly related to the change in Ldn in dB; second, the number of people affected is multiplied by the number of dB change in Ldn, as well as by the average cost per person, in arriving at the total cost.

Interestingly enough, the introduction of a single SST flight per day in the quiet fleet situation (QN 3D and R/F 8D) appears to cause less of a problem in terms of the cost approach than eight SST flights in the baseline fleet situation (about $1.1 million vs $5.81 million for the three Ldn zones) although it results in a slightly greater increase in Ldn (1.6 vs 1.2 dB). The reason for this is the much larger affected area (and number of people) involved in the case of the baseline fleet. However, the flaw in the use solely of cumulative levels to evaluate such situations is highlighted, since in fact the SST may be more noticeable.

Finally, it can be seen that the noise intrusion problem, in terms of equivalent "cost", becomes a major one as additional flights of the SST are introduced in the quiet fleet situations.

This confirms the result one would expect intuitively as multiple operations of a new and louder noise source are injected into an environment that has been improved by the application of noise control options such as retrofit to the air-carrier fleet. Since an appreciable portion of the fleet is expected to be quieter by the time an SST goes into service in 1976, as cited above, one may well expect that SST operations on a regular basis would be more noticeable then than they would be at present.

Economic rules of efficiency and equity require that the creator of this increased noise environment should pay for the efforts required to reduce these induced public health and welfare disbenefits. Therefore, according to such rules, the airlines wishing to introduce SST flights would be required to pay the induced costs of land use control, or other corrective action (e.g., noise insulation, compensation, etc.). These costs are a negative input into that airline's investment decision.

E. Operational Constraints to Eliminate the Impact of SST Noise

There is an operational approach which can eliminate the induced cumulative noise compatible land use costs estimated in the previous section. This approach is to eliminate other noisy aircraft flights such that the impact areas do not change. For the baseline case, only one JT3D flight would have to be eliminated for each SST flight introduced. Substantially higher numbers of flights would have to be eliminated if the quiet nacelle retrofit and the refan retrofit were implemented into the fleet.

Again, economic efficiency rules dictate that these eliminated flights must come from the activities of the airline that is offering the SST. For this case, then, it follows that the lost revenues from the eliminated flights must be reflected in the fare structure for the SST. The airport operator should also be expected to recover the landing fee revenues from these curtailed flights by charging an appropriate landing fee for the SST. Essentially, trying to recover the revenues from three curtailed flights or more will add substantially and disproportionately to the fares that would have to be charged per seat on the SST. Cost of such SST service at these higher fare levels could result in an extreme curtailment of demand.

In summary, introducing SST activity at its present noise emission levels at an airport will either induce additional noise exposure for populations surrounding the airport, or require the reduction in flights of comparably noisy aircraft. Whichever action is taken, the respective environmental correction costs may result in an increased fare structure which would be of concern to the operator. These aspects must be taken into consideration as well as those relating to the heavy energy (fuel) consumption of the current supersonic airplane as compared with subsonic aircraft.

F. <u>Options Considered for Rulemaking to Control Noise Impact of Current SSTs</u>

In considering a possible regulation to protect the public health and welfare from the noise that would be caused by landing and takeoff operations of supersonic airplanes at U.S. airports, several key factors should be taken into account.

(1) The current SSTs are inherently noisy by virtue of their design features, and there is no known technology now available that will permit significant reduction of their noise without severely compromising their operational capabilities.

(2) As a result of several factors, there is considerable uncertainty as to the ability of the SST to operate sucessfully on a revenue-producing basis in competition with subsonic jet aircraft. This leads to the supposition that only a small number of current-design SSTs actually will be produced and be in service. In turn, this implies that SSTs are likely to represent a minor threat to the environment, in terms of the incremental cumulative noise imposed on airport neighboring communities.

(3) Because of the large investment in both dollars and prestige, made by the governments supporting development of the SSTs, the United States government may be reluctant to take overt action that might be construed as being directly responsible for the failure of the current SST programs. The apparently modest benefits in environmental protection that might be gained by imposing onerous restrictions on the SST easily could be outweighed by the effect of such restrictions

on our international relations. This would be especially true if the current SST programs became admitted failures and the failures were attributed to the restrictions imposed by the United States.

(4) Aside from the foregoing considerations, it should be recognized that the most reliable criteria available regarding human response to environmental noise are those related to cumulative noise exposure, as outlined in references 5 and 6. Consequently, in considering the environmental impact of current SST operations, the government must turn to cumulative noise as the criterion by which to judge that impact.

Ideally, the best place to control noise is at the source; this principle is applied in the noise level requirements of FAR Part 36. It is also implicit in the Noise Certification requirements for supersonic airplanes now under consideration by the International Civil Aviation Organization. Since, however, it is not feasible to control the source noise of current early production SSTs to Part 36 levels, it may be advisable to adopt regulatory procedures that will control the noise impact caused by introduction of current SST operations.

In view of the noise characteristics of current SST aircraft, including the impracticability of noise-abating retrofit in the present state of the art, selection of a suitable method for controlling the noise impact is not a simple matter. Various regulatory options for accomplishing this control have been considered. They are outlined in the paragraphs that follow, with pros and cons summarized.

1. Outright ban: Conceptually, the simplest and most effective

way to control current SST noise is to prohibit their operations in the United States. From the viewpoint of equity, however, the question arises as to whether this harsh restriction is warranted in the light of the possibly modest degree of benefit to be achieved by such restriction.

Pro

- There is no doubt that such a rule would be completely protective of the environment, in terms of the possible effects of the SST.
- The rule is simple, with no confusion and no uncertainty.
- If it were promulgated promptly, the rule would provide early notice to prospective operators and the manufacturers of the current SSTs that there would be no market for such SST operations in the United States.

Con

- Since the current SSTs are about as noisy as the current 707 and DC-8 subsonic airplanes without retrofit, and since it is presumed by many that relatively few current SSTs will be placed into operation, the restriction seems unduly harsh, and therefore unfair, when viewed against the degree of environmental hazard posed by the SST.
- Promulgation of such a rule could have undesirable effects on the existing reciprocal aeronautical arrangements between the United States Government and the governments of France, England, and the Soviet Union.

- The rule might be considered unfair particularly because the current SSTs might be able to operate at certain airports with negligible noise impact because of the absence of noise-sensitive areas in the general vicinity of takeoff and landing paths.

2. Imposition of Part 36 Requirements: Requiring that the SST conform to the source noise level requirements of Appendix C of Part 36 is conceptually a logical and sensible rule, since it would require of SSTs exactly what Part 36 requires of subsonic airplanes. However, such a rule for early production of current SSTs would not be considered appropriate, as there is no known technology to permit current SSTs to comply with the noise level requirements of Part 36 in an economically reasonable manner.

Pro

- The rule is simple in concept, consistent with existing rules (for subsonic aircraft) and easy to enforce.
- It would protect the environment against SST noise to the same extent that Part 36 does against subsonic airplane noise.

Con

- The rule is inappropriate to current SSTs since as stated above, there is no known current technology for these airplanes to enable them to meet Part 36 noise level requirements.
- It therefore would be tantamount to a ban on current SSTs, subject to similar objections as an outright ban.

3. Allow SST Operation at Designated Airports with Restrictions: This option, which has a number of different possible forms, essen-

tially would designate certain U.S. airports at which the current SSTs would be allowed to operate, subject to certain restrictions designed to minimize its effects on the noise environment. These restrictions would include one or more of the following:

(a) Limited number of takeoffs and landings.

(b) Takeoffs and landings restricted to designated noise abatement runways to avoid noise-sensitive areas.

(c) Restrictions on the time of day in which operations are allowed - e.g., curfews.

(d) Use of special noise abatement procedures for both takeoff and landing, including procedures automatically programmed on the airplane in-flight computer, with pilot takeover occurring only for reasons of safety.

In view of the limited number of current SSTs that are expected to be in operation, the following restrictions also may be considered in order to permit the operation of those airplanes in the United States without adversely affecting public health and welfare:

(a) Restricted number of daily SST operations country-wide;

(b) Restricted number of daily SST operations on an airport-by-airport basis;

(c) Restricted number of airports approved for SST operations.

The above restrictions would provide assurance of a limited number of SST operations approved by the Federal government.

<u>Pro</u>

- Adoption of a rule based on the foregoing principle would avoid an outright ban of the SST, allowing a limited number of operations.

- It would limit the number of localities exposed to SST noise.
- If properly implemented, it would also limit the noise impact in the communities neighboring to the designated airports.

Con

- The availability of airports suitable for application of this rule has not been adequately substantiated; in particular, the designated airports not only must have the right arrangement of non-noise-sensitive areas under the runway flight paths, they also must be in locations that provide adequate and convenient access to the large metropolitan centers that would serve as the point of origin or destination for most SST passengers.
- The selection of airports to be designated for SST operations may be considered arbitrary and unfair by some SST operators.
- On the other hand, the residents exposed to the noise impact (actual or potential) in the vicinity of the designated airports may consider the selection discriminatory against them.
- In spite of careful selection of designated airports and runways, there probably would be increased noise impact due to the SST operations, since very few airports are free of neighboring noise-sensitive areas. For this reason, and because the benefits of noise abatement procedures for takeoff and landing are limited in degree, adoption of this type of rule might allow inadequately controlled increases of SST noise im-

pacts; hence, such a rule might be considered inadequately protective of the environment.

4. Impose Restrictions on SST Operator at SST Airports

This option, although similar to the previous one in many respects, differs conceptually from it in that there would be no attempt to designate the airports at which SSTs would be allowed to operate. Instead, it would allow the market forces to determine the airports at which SST operations would be introduced. However, once it was established that SST operations were to be conducted at an airport, then a rule restricting the noise impact would go into effect. In one form of such a rule the SST operator would be constrained to take the action necessary (which may include tradeoff of subsonic airplane operations) to limit the increase in noise impact caused by the SST operations to that which would be caused by an airplane that meets the noise level requirements of Appendix C of Part 36 of the Federal Aviation Regulations.

Even though the retrofit of current SST airplanes is not practicable at this time, control of the incremental effect of these airplanes on the cumulative noise exposure can be achieved to some extent by noise abatement takeoff and landing procedures, and exercising airport operational control such as preferential runways and night curfews. There is also another method of operational control that might be taken to permit the introduction of the current Concorde or TU-144 supersonic airplanes while at the same time controlling the noise impact for those airports. Under this method an operator would eliminate one or more flights of his noisier subsonic turbojet engine-powered airplanes at an airport to compensate for the increase in noise generated by each SST flight that he introduces at that airport. For example, in regard to the current subsonic fleet perhaps only one B707/DC8 flight would have to be eliminated at most airports by an operator to compensate for each Concorde flight he introduced. The operator would of course have to eliminate a larger number of B707/DC8 flights if Quiet Nacelles, Quiet Engine, or Refan retrofit were installed in his subsonic fleet operating into the airport at which the SST flights are introduced.

This "tradeoff" method of noise control would be less attractive at airports that have sideline noise problems. Fortunately, the geometry of most United States airports includes sufficient land areas adjacent to their runways that the higher sideline levels of the Current SSTs compared to the subsonic types would not preclude tradeoff. On the other hand, if tradeoff were used, suitable regulatory constraints should be applied to avoid abuse. For example, if such a rule were in force, eliminating operations of subsonic airplanes to compensate for the introduction of SSTs and subsequently restoring those same operations would be considered as a circumvention of the rule and contrary to the tradeoff purpose. Similarly, the introduction of noisy subsonic operations in anticipation of the rule and the subsequent removal of those operations to effect a tradeoff, would also be considered a circumvention of the rule and contrary to the tradeoff purpose. Regulatory constraints to prevent such abuses would include the following provisions:

(1) A requirement that all subsonic airplane operations introduced after the introduction of SST operations must be with airplanes capable of compliance with the noise level requirements of Appendix C of Part 36.

(2) A requirement that all subsonic airplane operations proposed for tradeoff must have been in service at least six months prior to introduction of SST operations.

The foregoing constraints, intended to prevent circumvention of the noise control features of the tradeoff option, might be considered discriminatory against the SST operator, for the following reason. If the SST should create new traffic demand, or if the withdrawal of the subsonic operation should leave an unsatisfied subsonic traffic demand, the SST operator could reinstate the subsonic flight only with an airplane that meets the noise level requirements of Part 36. A non-SST operator who wished to institute a new operation could do so with an airplane that does not meet those requirements, if it is an existing airplane. Of course, any newly-produced subsonic airplane introduced into operation must meet the FAR 36 noise level requirements.

While it is true that the trade-off option with constraints as proposed herein would be discriminatory in the sense described above, such discrimination might be considered appropriate, as it would be based on the fact that the SST is a newly-produced airplane with noise levels substantially above the standards of Part 36, whereas all newly-produced subsonic aircraft are required to meet those standards. Since the SST noise cannot be controlled adequately at the source, such a rule would attempt to control the noise impact and to permit SST operations by allowing the alternative actions listed above.

A regulation for current SSTs as outlined in the foregoing, well may be controversial. On the one hand, it may be considered inadequately protective of the environment. On the other hand, it may be considered arbitrarily harsh and discriminatory with respect to the SST manufacturers and operators, in that it imposes penalties, in the form of restrictions, on SST operators, which are incommensurate with the degree of harm that may be imposed by the projected SST operations.

It becomes clear, however, that although such a rule may limit the additional noise exposure that may be caused by an SST operator, it would provide no control over added noise exposure that may result from noisy subsonic operations introduced by a non-SST operator to accommodate increased traffic. As a consequence, such a rule may be criticized as offering no control over cumulative noise while still imposing restrictive limitations on SST operators.

In response to that criticism, it should be pointed out that such a rule is designed only to limit the increase in noise exposure, or impact, caused by introduction of current SST operations. Control of additional noise impact due to increased traffic represents a completely different problem, which could be resolved with other suitable aircraft/airport noise regulatory actions. In the absence of the other noise regulations, however, a workable SST noise rule could perform its intended function of controlling the increase in cumulative environmental noise caused by introduction of current SST operations.

The pro and con arguments implicit in the foregoing discussion are summarized below.

Pro

- While avoiding a ban on current SSTs, this type of rule would protect the public health and welfare by providing a mechanism to limit the increase in noise impact due to current SST operations.
- It would avoid arbitrary restrictions on the use of airports for SST operations, allowing market forces to establish which airports would be suitable for such operations.

Con

- This type of rule does not attack the SST noise problem at the source, instead using an indirect measure (noise impact) as the criterion for control.
- The rule may be considered discriminatory against SST operators, imposing restrictions on them which are not imposed on non-SST operators.

5. Impose Restrictions on All Operators at SST Airports

A variation of this option which may overcome at least some of its objectionable features would be a rule, applying only to airports with SST operations, that would require all new flight operations at such airports to comply with the foregoing limitation on the noise impact increase.

Pro

- Adoption of such a rule would avoid a ban of the SST, yet would control the noise impact that otherwise would be caused by introduction of SST operations.

- By requiring new flights of all operators (not only SST operators) to control the noise impact to that of an airplane meeting Part 36 noise level limits, it would eliminate the objection that the rule was discriminatory against the SST operator.
- Since the characteristics that make an airport a suitable candidate for SST operations are those likely to generate considerable subsonic airplane traffic as well, the SST airports would tend to have the largest noise-affected areas. Hence, the control of noise impact increase provided by such a rule would take place at the airports most in need of such control.
- Because the rule would apply at relatively few airports - those suitable for SST operations - it probably would not have a severe economic impact on any airline. The noise impact requirement in many cases could be met by shifting quiet airplanes from some other route or airport assignments, rather than requiring retrofit of a noisy one. It will be recalled that Part 36 now requires that new subsonic airplanes, which may have to be purchased to meet the increased traffic demand, would have to meet the noise level requirements of Appendix C of that Part.

<u>Con</u>

- One objection that may be raised to this type of rule is that it evades a direct attack on the "real" problem, which is SST noise exposure; thereby it penalizes airlines that operate only subsonic airplanes, as well as SST operators. Regarding the first point, it has already been stated that the cumulative noise exposure is the basis for the best criteria avialable on the effects of noise. As for the second point, the rule has no effect on a subsonic operator whose airplanes meet Part 36 noise levels. It may be considered discriminatory against those operators with noisy low-bypass, narrow-bodied jets; although the rule is aimed primarily at SST noise, the side effect of controlling noise due to unretrofitted 707 and DC-8 airplanes (by no means an imaginary problem) at the airports most in need of noise control would appear to be beneficial rather than otherwise. However, such operators may contend that the rule was capricious, in that it requires such an operator to take the prescribed action based on a circumstance beyond his control, namely, the introduction of SST operations by another operator.

- Another possible objection is that this approach ostensibly does not take into consideration the greater low-frequency content of SST noise as compared to subsonic airplane noise. As indicated in the earlier discussion, it is not entirely clear that this characteristic of SST noise will necessarily make it more annoying. In any event, if scientific information becomes available that make it possible to quantify the effects of such low-frequency noise in terms of noise impact, such criteria may be applied in implementation of the rule.

6. <u>Escalating Restrictions on SST Source Noise:</u> Another option considered would aim at minimizing the noise impact of supersonic transports without imposing operational restrictions upon their use. This option would require that the various current SST airplanes manufactured after the initial production meet the following successively lower noise standards:

(a) First 20 airplanes - Noise limits at currently projected levels, or best efforts;

(b) Second 20 airplanes - Noise limits 5 dB below first production;

(c) Third 20 airplanes - Noise limits 10 dB below first production; and

(d) All subsequent airplanes - Meet the noise level requirements of Appendix C of Part 36.

This approach provides one interesting aspect. If the conservative views regarding the economic success of the current SSTs turn out to be correct and no more than twenty such airplanes are places into service, an automatic limit is placed on the environmental degradation without any restrictions being placed on the SST.

If, on the other hand, the current SSTs were to turn out more successful economically, than many now envisage, a series of escalating restrictions on the noise output of the SST would help to limit the overall environmental impact.

<u>Pro</u>

- This type of rule would avoid an outright ban or other arbitrary constraints on the SST.

- It would provide the SST manufacturers with the incentive, and to some extent the time, to embark on a intensive research and development activity to advance the state of the art and develop new and improved techniques and hardware for reducing the noise emissions of current SST aircraft and propulsion systems.
- As implied above, it would provide automatic triggering of new standards in an escalating series for the SST, reducing the allowable noise emissions if more than the limited number of twenty were to be placed into service.

Con

- Even introduction of the first 20 SSTs into operation without restriction would impose increased noise on the environment, although admittedly the increase would be limited in extent. If additional SSTs were placed in operation, there would be additional increases of environmental noise beyond that which would occur with new subsonic airplanes, which must conform to Part 36 noise level requirements. Consequently, unacceptable increases in environmental noise could occur.
- In the light of present knowledge of supersonic aircraft noise control, it appears unlikely that significant reduction of the noise emissions of current SSTs could be accomplished without extensive, and expensive, redesign. Consequently, this type of rule might be considered as effectively imposing a limit of twenty on the number of SSTs produced.

7. No Regulation: There are a number of commentators, not necessarily advocates of the supersonic transport, who suggest that no regulatory action at all should be taken with respect to the noise of current supersonic airplanes, notwithstanding the noise impact that may result from their operations.

Pro

- Airline operations of current supersonic transports may not be viable, in terms of economics or fuel consumption. Consequently, it is hypothesized, the number operating into U.S. airports may be so small as to be no significant hazard to the environment.
- The viability of the current supersonic transport program is believed by some to be so fragile that the imposition of any noise controls might result in its demise. Therefore, restrictions for noise control should not be imposed in order to allow the program to survive, regardless of the possible noise impact.

Con

- This approach is based on the conjecture that the SST program will be of such limited success that no more than twenty current SSTs ever will be in service. Although this may be the prevailing opinion, such a conjectural outcome is by no means assured. It would appear to be only prudent to recognize the possibility that many more than twenty current SSTs will operate, and to provide suitable regulations to protect the environment in the event of such a contingency.

- In any event, even twenty or fewer current SSTs landing at and taking off from a small number of airports, or the same airport, can represent a significant noise impact in the environs of those airports. Therefore, suitable regulations are required to protect the public against the encroachment of such noise.

8. Airport Noise Regulation: The last option considered is to delay the adoption of a current SST regulation until an airport noise regulation has been adopted. Such a regulation would provide the ground rules and procedures for cooperative decisions and actions by local communities, employing land use controls, and airport management, with the collaborative support of the FAA with its powers of operational control, to establish mutually acceptable levels of noise impact and to control numbers, types and operations of the aircraft at each airport in order to achieve the designated acceptable levels of noise.

If such an airport regulation were adopted, restrictions similar to those listed in Option 3 could then be established, appropriate to each airport, applying to all aircraft operators, thus obviating any further need for the regulatory controls on noise impact, applying specifically to current SST operators, that would be incorporated in a regulation of that type. Pending the development and promulgation of such a regulation, it appears that some standard is needed for the protection of the public health and welfare from the noise of supersonic aircraft, and that some regulation embodying the concepts discussed herein, imperfect though it may be, should be adopted.

G. Noise Impact Assessment

Up to this point, SST noise was evaluated by assuming a model airport and fleet mix and calculating the noise exposure (Ldn) resulting from the introduction of several rates of SST operations. Estimations were made for the noise exposure areas, population exposed, and costs of protecting the people by compatible land use control.

Another way of evaluating the noise effects on communities due to the introduction of SST operations at an airport is by making a Noise Impact Assessment (NIA) according to the methodology presented in Appendix C.*

The underlying concept for Noise Impact Assessment is to express the change in human response expected from the people exposed to the environmental noise being considered. Three steps are involved:

definition of "before" noise environment,

definition of "after" noise environment, and

definition of the relationship between the noise environments, and the degree of its "impact" on the population in terms of expected human response relative to specified criteria levels.

Noise criteria levels for various land uses or occupied spaces are given in Table 4. It is assumed that these levels, if not exceeded, would provide entirely acceptable acoustical environments (i.e, they represent zero noise impact). These levels are specified for outdoors although the use of most of these spaces is usually indoors. The noise

*This methodology was developed by Working Group No. 69, Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), National Academy of Sciences, National Research Council.

reduction for typical building construction has been used to arrive at outdoor noise levels which would provide acceptable indoor environments.

The Noise Impact Assessment procedure has been applied to the data listed earlier in this Section which quantified by Ldn methodology the noise effects of introducing SST operations. The tabulation given in Table 5 shows the values of Equivalent Noise Impact (ENIB and ENIA) before and after introduction of SST operations at the rates of 1, 4, and 8 takeoff and landing operations per day under the three different assumed subsonic fleet configurations. Also shown are the results for Change in Equivalent Noise Impact (ENI), Relative Change in Impact (RCI), and Ratio of Impact (RI).

It should be pointed out that the ENI values computed here are those due to Day-Night Levels (Ldn) of 65 dB and greater; the data on which these computations were based included noise exposure values no lower than Ldn 65.

From a review of the tabulated results, a number of conclusions can be drawn, generally similar to those adduced earlier from the Ldn analysis.

(1) The powerful effect of retrofit of the subsonic airplanes on the aircraft environmental noise impact is readily apparent from these data. The ENI caused by the subsonic fleet is reduced to about 14% of the original value by Quiet Nacelles (3D and 8D) and to about 10% by combined Quiet Nacelles and Refan.

(2) Introduction of one to eight SST operations per day into the

baseline fleet produces a significant increase in the Relative Change in Impact; from 4.4 to 29.6 percent, respectively. However, the increase is much more striking for the retrofitted fleets. For the Quiet Nacelle fleet (QN-3D and 8D), one to eight SST operations per day increases the RCI from 21.5 to 185.3 percent. And for the fleet consisting of Quiet Nacelles and Refan, the RCI for one to eight SST operations per day increases from 31.6 to 255.0 percent. The above figures illustrate the strong influence on noise impact that SST operations can have, particularly for communities that might be benefitting from reduced noise exposure due to operations of noise controlled aircraft.

7. CONCLUSIONS

Whereas the Concorde and TU-144 aircraft designs, and therefore their noise characteristics, were set in the early 60's, future generations of civil supersonic aircraft are not restricted by the technology of the 1950's and 60's. The aircraft and engine manufacturers are keenly cognizant of the public outcry against aircraft noise. Future designs will have to conform to reduced noise requirements if they are to be commercially acceptable at existing and future airports. Noise standards need to be identified now so that the industry is aware of what is expected of these advanced aircraft in future years.

As pointed out in Reference 5, there is an approximate 8-10 year delay between the identification of technology availability and the operational application of that technology. Therefore, new aircraft utilizing current technology would not see operational service before 1982-85.

Consequently, the first generation SSTs (Concorde and TU-144) will inject new noise sources into the air transport systems that are approximately equivalent in noisiness to the narrow-bodied 4-engine subsonic transports under the flight path and noisier at the sidelines on takeoff. The Concorde noise is characterized by a greater content of low-frequency noise energy than its subsonic counterparts. This characteristic may make the Concorde noise somewhat more objectionable, as the predominant low frequency noise propagates with lower attenuation due to atmospheric absorption, thereby maintaining a higher sound pressure level over longer distances (and larger population areas) than does the higher-frequency noise of the subsonic jets. Furthermore, this low frequency sound excites more structural vibration of buildings (which in turn may cause objectionable rattling noises in building interiors) than does the high frequency sound. On the other hand, it is generally recognized that the lower frequency sounds do not contribute as much to annoyance as do higher frequency sounds, which may at least partially balance out the negative aspects of long-distance propagation and vibration excitation.

With the introduction of the Concorde and TU-144 into international airline service in the 1975 time period, a stimulus may be provided for growth versions of these aircraft as well as incentives for new aircraft developments. In order to prevent the possible future escalation of noise from this type of aircraft, it is appropriate at this time to promulgate a noise regulation which will provide design goals for future civil supersonic aircraft. It is emphasized that all operations over the United States land areas are constrained to be at subsonic speeds in accordance with FAR Part 91.55 (Reference 12). Hence sonic boom is not an issue.

Sideline noise has been identified as the most demanding design requirement for supersonic aircraft. However, the preamble of FAR 36, for subsonic aircraft, acknowledged the need for consideration of aircraft type in the establishment of the sideline measuring point (0.35 nautical mile for 4-engine aircraft). Despite this fact, sideline noise has not been a significant community problem at most airports since the majority of the objectionable noise has been confined within the airport property. As was indicated in Section 4, increases in the engine thrust-to-weight ratio for a given type of aircraft reduce the noise impact under the takeoff flight path. However, for a given size of vehicle the sideline noise is thus increased due to the additional thrust required. This characteristic provides an opportunity for trade-off considerations which might effect some reduction in community noise impact. Figure 8 indicates this relationship for the Concorde aircraft at various gross weights and thrust settings. The data indicates that a 5% increase in installed engine thrust would decrease takeoff noise 1 dB while increasing sideline noise by not greater than 1.5 dB.

From all of the data available, including that of the cancelled U.S supersonic transport program, it appears that future designs of civil supersonic aircraft can at least meet the noise provisions of FAR 36 as presently defined for subsonic aircraft.

Advanced propulsion developments may provide still further reductions in the generated noise but these concepts have yet to be demonstrated. Furthermore, the contribution of aerodynamic noise and core engine noise to the total aircraft noise signature needs to be understood and evaluated in order to determine the maximum noise reduction potential available with optimized engine and airframe design.

Future SST aircraft will be subject to other design constraints in addition to noise control before they can be considered as viable systems. Energy concerns will be reflected by their fuel consumption characteristics, and engine emission standards will provide additional ecological constraints. Noise, emissions and fuel consumption characteristics are directly interrelated and therefore need to be considered concomitantly.

In order to allow an opportunity for the first generation supersonic transports to demonstrate their viability, it appears reasonable to allow at least some of these airplanes to exceed the FAR 36 subsonic airplane noise limits provided that the increase in community noise pact would be insignificant or adequately controlled. Present technology does not practicably allow reducing the source noise emissions from current SSTs. Other actions must be considered, primarily operational constraints. Among the possible actions that might be taken are the following:

(1) Use preferred airports and runways which help avoid noise-sensitive areas.

(2) Use noise abatement takeoff and approach procedures to the maximum extent commensurate with safe operating procedures.

(3) Revise schedules to eliminate one or more night flights of subsonic airplanes. This could be advantageous if feasible, because of the 10 dB weighting of nighttime noise events in the Ldn contour.

(4) Apply retrofit technology specifically to (or replace with new airplanes) one or more of the noisy subsonic aircraft operating at the airport to be impacted by SST flights, to achieve a balancing reduction in Ldn.

(5) Trade off flights of other noisy subsonic aircraft in order to

limit the effect on noise impact. For example, one flight of a DC-8 or 707 is almost equivalent in Ldn effect to one flight of a current SST, if there is little or no noise-sensitive area at the sidelines, and thus an airline could substitue an SST flight for a DC-8 or 707.

8. RECOMMENDATIONS

Among the wide range of regulatory options previously considered for controlling the noise of supersonic civil airplanes, the following five are recommended for further consideration.

A. Future SST Aircraft

A rule should be considered for promulgation which requires supersonic transport airplanes to comply with the same noise standards applied to subsonic transport aircraft at the date of type design application. The rule should be applicable to all type design applications made after 6 August 1970 (except for those airplane types that have been flown before 31 December 1974). This date represents the publication of ANPRM 70-33 (Reference 14) serving notice that the FAA is considering rule making to establish noise standards for the type certification of civil supersonic aircraft. This date is early enough to preclude commitment of significant economic resources to development programs for new airplanes which might otherwise be initiated without adequate consideration for environmental noise effects.

B. Current SST Aircraft

A rule should be considered for promulgation which requires that operators of current types of SST aircraft (Concorde and TU-144) must include a Noise Impact Assessment (NIA) with their application to land and take off in the United States. The NIA should show that the increase in noise impact caused by the operations of current SSTs will be no greater than that which would be caused by the same number of operations of an airplane that meets the noise level requirements of FAR 36. Also, the EIS should include the following information:

- The particular airports and runways to be utilized.
- The noise abatement takeoff and approach procedures and other restrictions that will be employed to minimize noise impact.
- The number of operations (and times) per day at each airport.
- The number of operations and types of subsonic airplanes to be replaced by SST operations.

The rule should, in addition to the factors of safety, economic reasonableness, and technological practicability, be considerate of the following:

- The design requirements of supersonic aircraft are unique.
- The Concorde and TU-144 aircraft exist and substantial resources were expended by the manufacturers in noise control research and development.
- The types and locations of airports from which airlines will choose to operate SST aircraft are limited because of economic considerations (payload, range, etc.).

In other words, most air-carrier airports are not candidates for SST operations. Also some airports because of size or proximity to non-residential areas (e.g., water) may be able to permit Concorde and TU-144 operations with negligible or no effect on the population.

It should be noted that, as the subsonic fleet becomes less noisy due to replacement of the narrow body four-engine airplane with quieter wide-body airplanes and/or implementation of retrofit rules for noise control, the noise impact of the SST may have to be re-evaluated.

C. Future SST Aircraft and Later Production Versions of Current SST Aircraft

A rule should be considered for promulgation which would pertain to supersonic civil airplanes in two categories: future SSTs and later production versions of current SSTs.

For future supersonic airplanes, that is, airplanes for which the date of application for a type certificate is after August 6, 1970, (the date of publication of ANPRM 70-33), except for those airplane types that have been flown before December 31, 1974, the regulation should require that the airplane conform to the FAR 36 standards in effect on the date of application.

For later production versions of current SST airplanes which are now in process of fabrication and production, the regulation should require that the supersonic airplanes comply with the FAR 36 standards in effect as of December 1, 1969, i.e., present FAR 36 levels. The cut-off date in the regulation should be defined in terms of airplanes that will have had no flight time before December 31, 1984. This date was selected because it reflects the existing planned program of the Concorde developers to have built and delivered 30 Concordes by 1985.

D. <u>Future SST Aircraft and Later Production Versions of Current SST Aircraft (Alternate Regulatory Approach)</u>

A rule should be considered for promulgation, similar to the one outlined above, which would pertain to supersonic civil airplanes in the two categories of future SSTs and later production versions of current SSTs.

As recommended above, future supersonic airplanes would be required to conform to the FAR 36 standards in effect on the date of application for type certificate.

Also, as recommended above, later production versions of current SST airplanes would be required to conform to the FAR 36 standards in effect as of December 1, 1969. However, "later production versions of current SST aircraft" would be defined in such a manner as to include all aircraft upon which substantive productive effort will not have commenced by the date on which the regulation is proposed. To provide a definite frame of reference, "substantive productive effort commenced" can be defined to signify that parts have been fabricated or delivered or are on order in aggregate equivalent in total value to a specified percentage (e.g., 5 percent or more) of the selling price of the airplane.

The intent of the regulation would be to ensure that no more supersonic airplanes than those now actually committed for production (rather than those expected to be manufactured by 1985) would be allowed to operate at United States airports with source noise emissions exceeding those permitted by FAR 36 standards.

E. Current SST Aircraft (Alternate Regulatory Approach)

A rule should be considered for promulgation which allows current types of SST aircraft to engage in landing and takeoff operations only at airports designated by the FAA Administrator as being suitable for SST operations. The rule would require that, in order for an SST to operate at the airport, the operator of the airport, at his option, must agree to its designation as an SST airport, and the airplane must conform to specified restrictions regarding runway use, noise abatement prodcedures, hours of operation, etc., mutually determined by the FAA and the airport operator. The criteria for designation of an airport as being suitable for SST operations would be based on the factors outlined below, plus others that may evolve as a result of public review and comment. The major factors to be considered would include, besides the basic ones of safety, economic reasonableness and practicability:

- Appropriate route patterns and traffic, and potential demand for SST service.
- Effects of SST landing and takeoff operations on the noise impact in the neighboring communities, taking into account the noise characteristics of the SST and the expected frequency of SST operations.

The recommendation for such a regulation could be combined with a proposed regulation for future SSTs, as outlined in Sections 8A and 8C herein.

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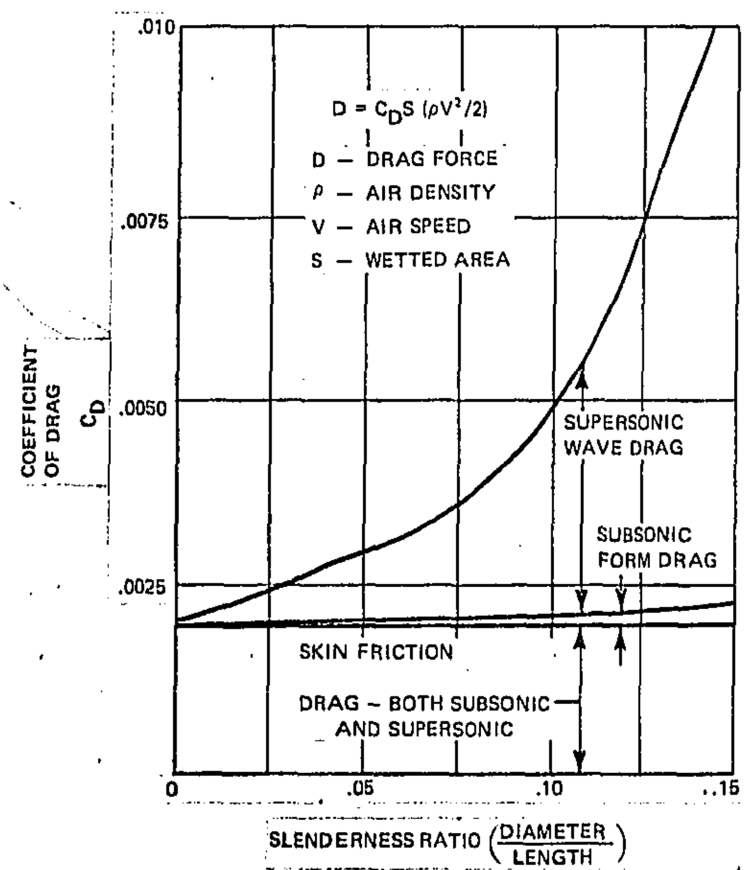


FIGURE 1. SUBSONIC AND SUPERSONIC FLOW DRAG.

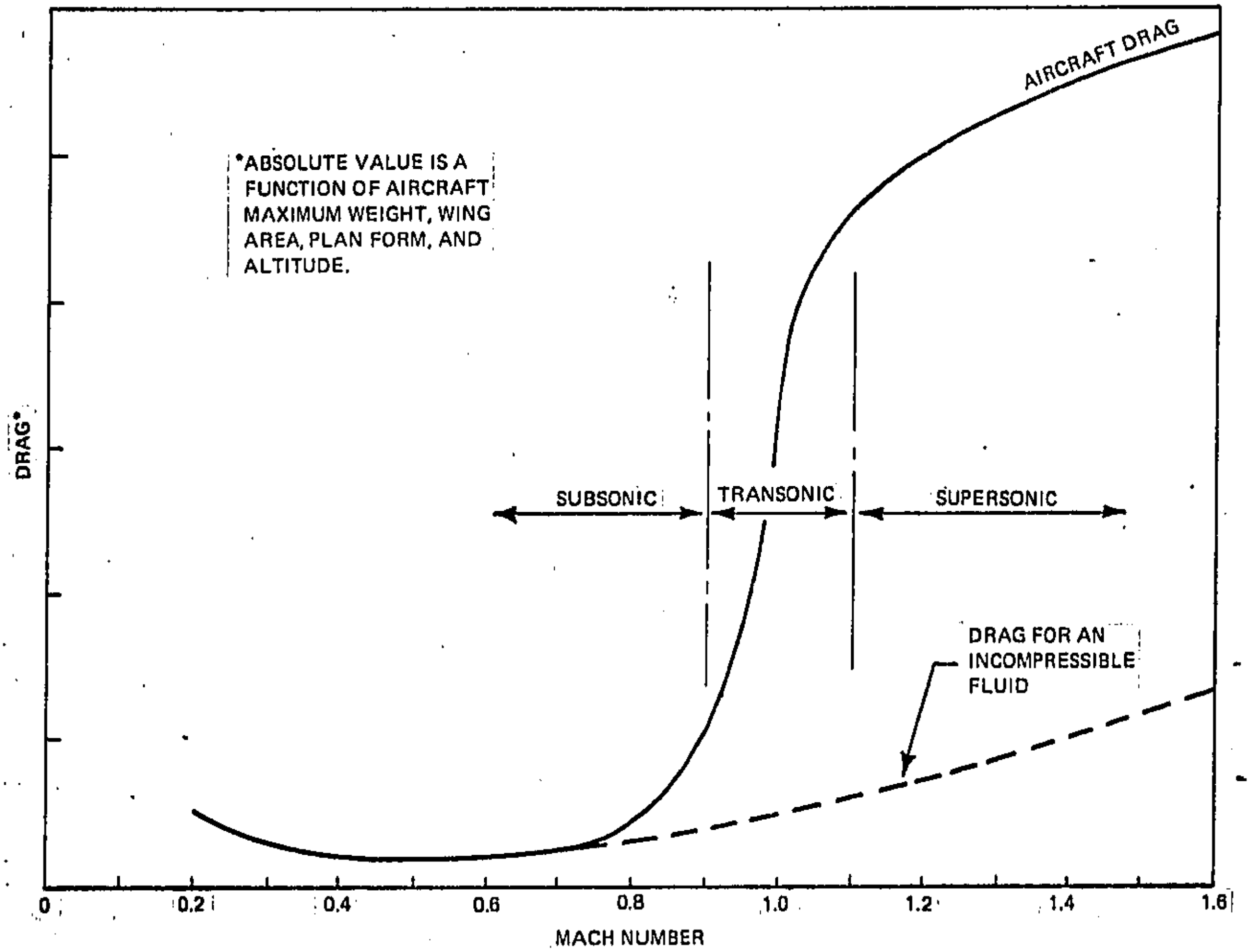
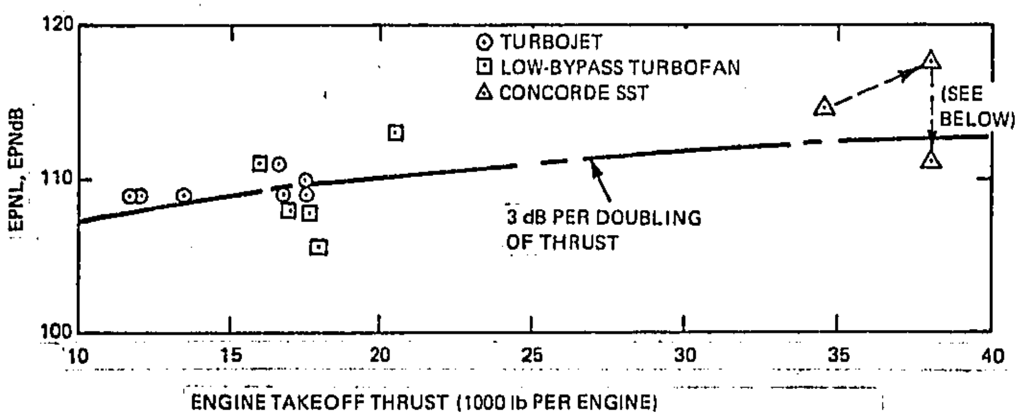
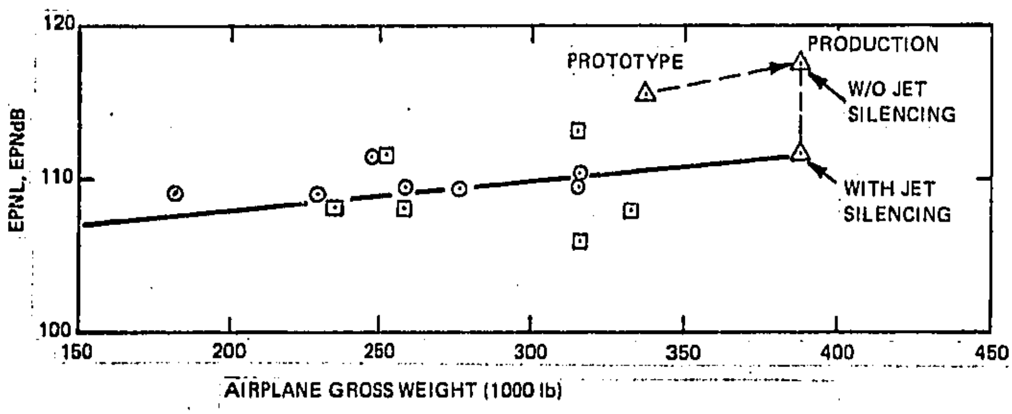


FIGURE 2. AIRCRAFT DRAG CHARACTERISTICS VS. LEVEL FLIGHT MACH NUMBER.



(b) EFFECTIVE PERCEIVED NOISE LEVEL vs. ENGINE TAKEOFF THRUST



(a) EFFECTIVE PERCEIVED NOISE LEVEL vs. AIRPLANE WEIGHT

FIGURE 3. COMMERCIAL JET TRANSPORTS - SIDELINE NOISE.
(4-ENGINE AIRPLANES - 1965 FLEET).

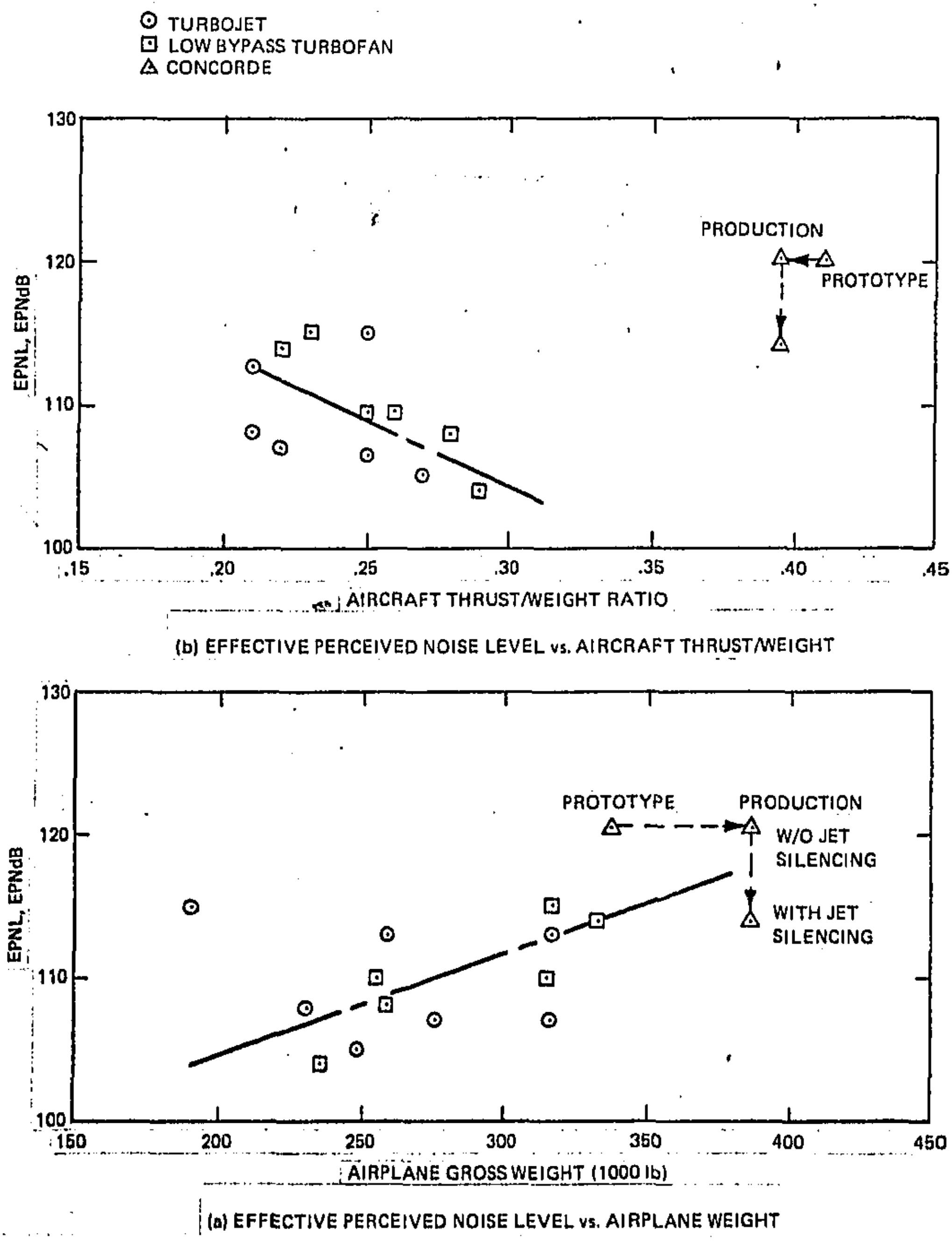


FIGURE 4. COMMERCIAL JET TRANSPORTS - TAKEOFF NOISE.
(4-ENGINE AIRPLANES - 1965 FLEET).

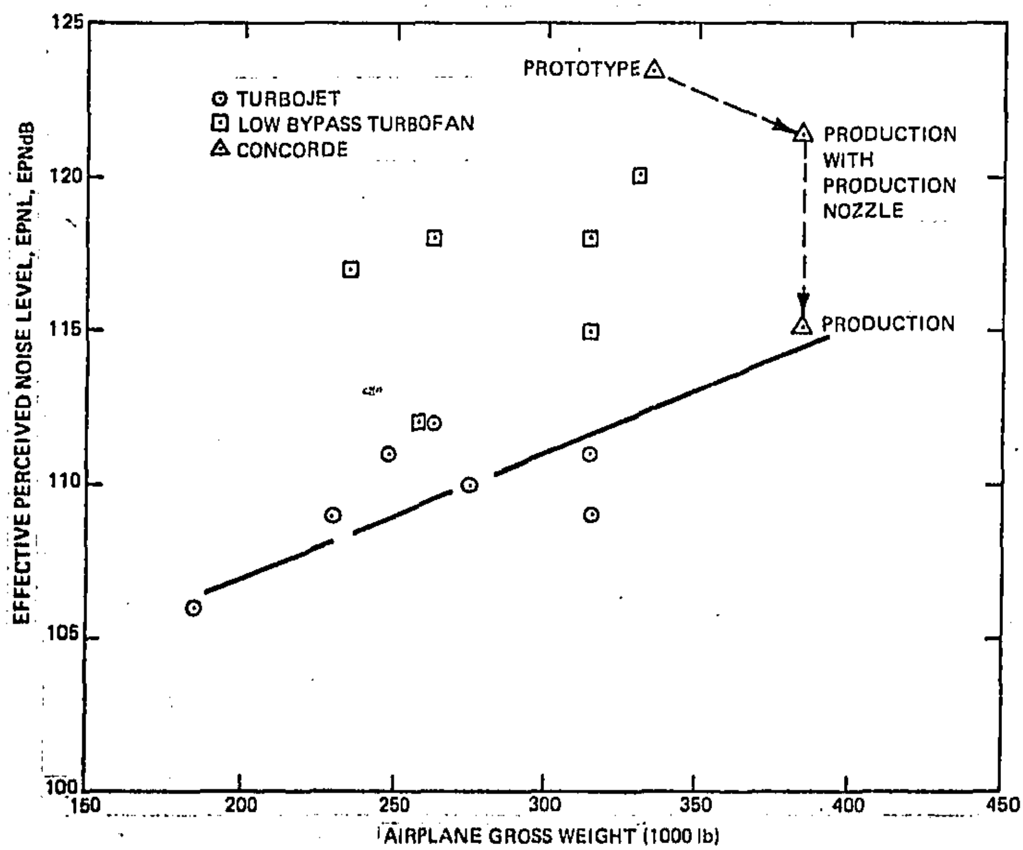


FIGURE 5. COMMERCIAL JET TRANSPORTS - APPROACH NOISE.
(4-ENGINE AIRPLANES - 1965 FLEET).

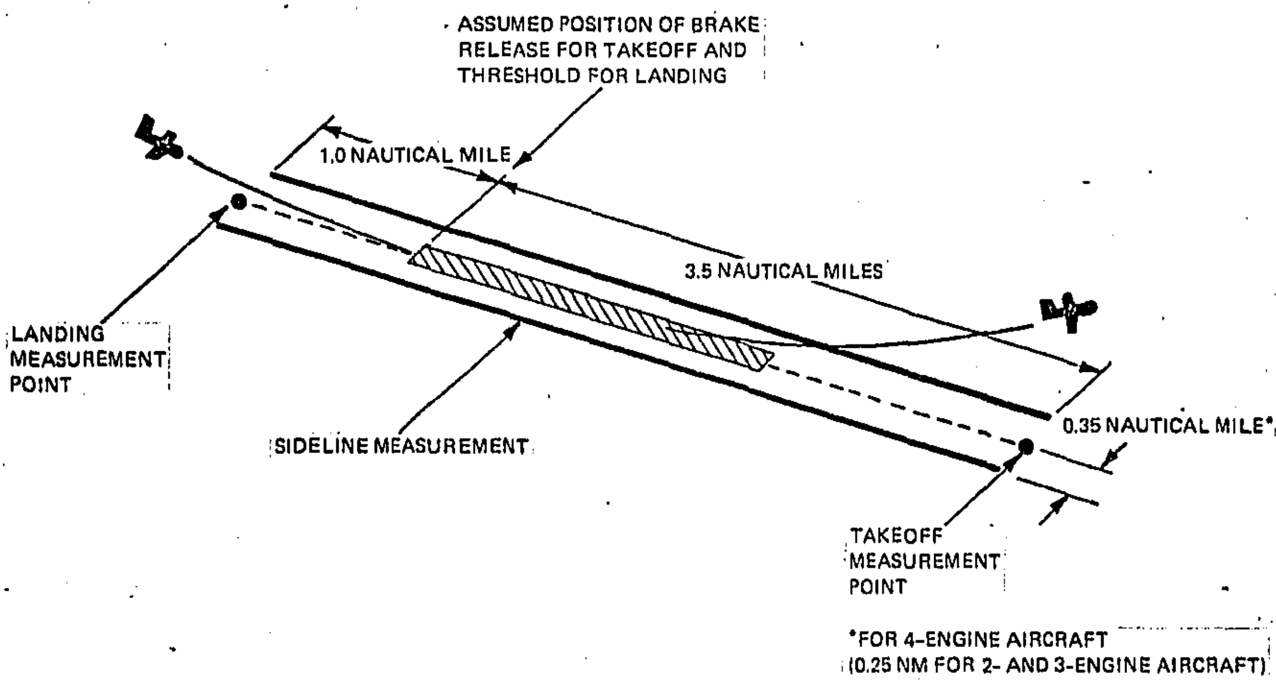


FIGURE 6. FAR 36 NOISE CERTIFICATION MEASURING POINTS.

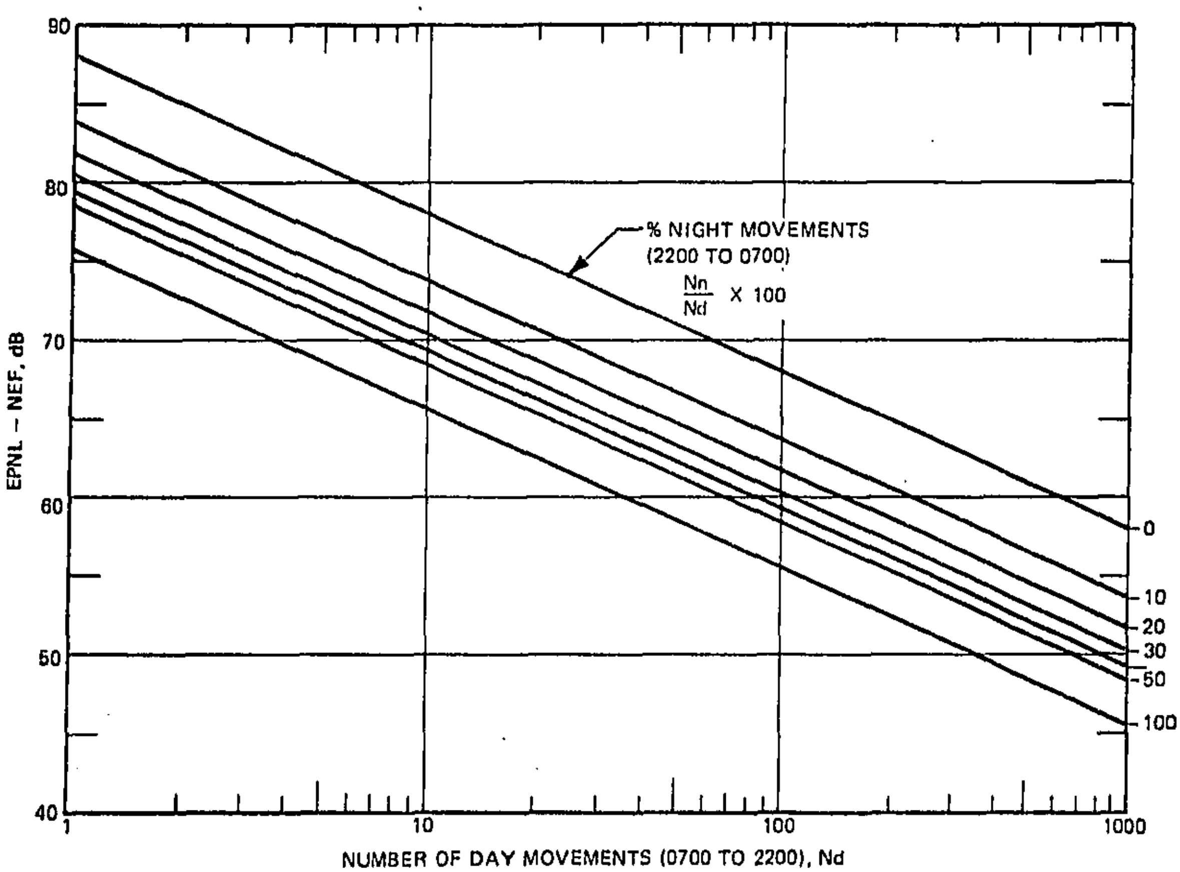


FIGURE 7. EPNL AND NEF RELATED TO NUMBER OF MOVEMENTS FOR A SINGLE AIRCRAFT.

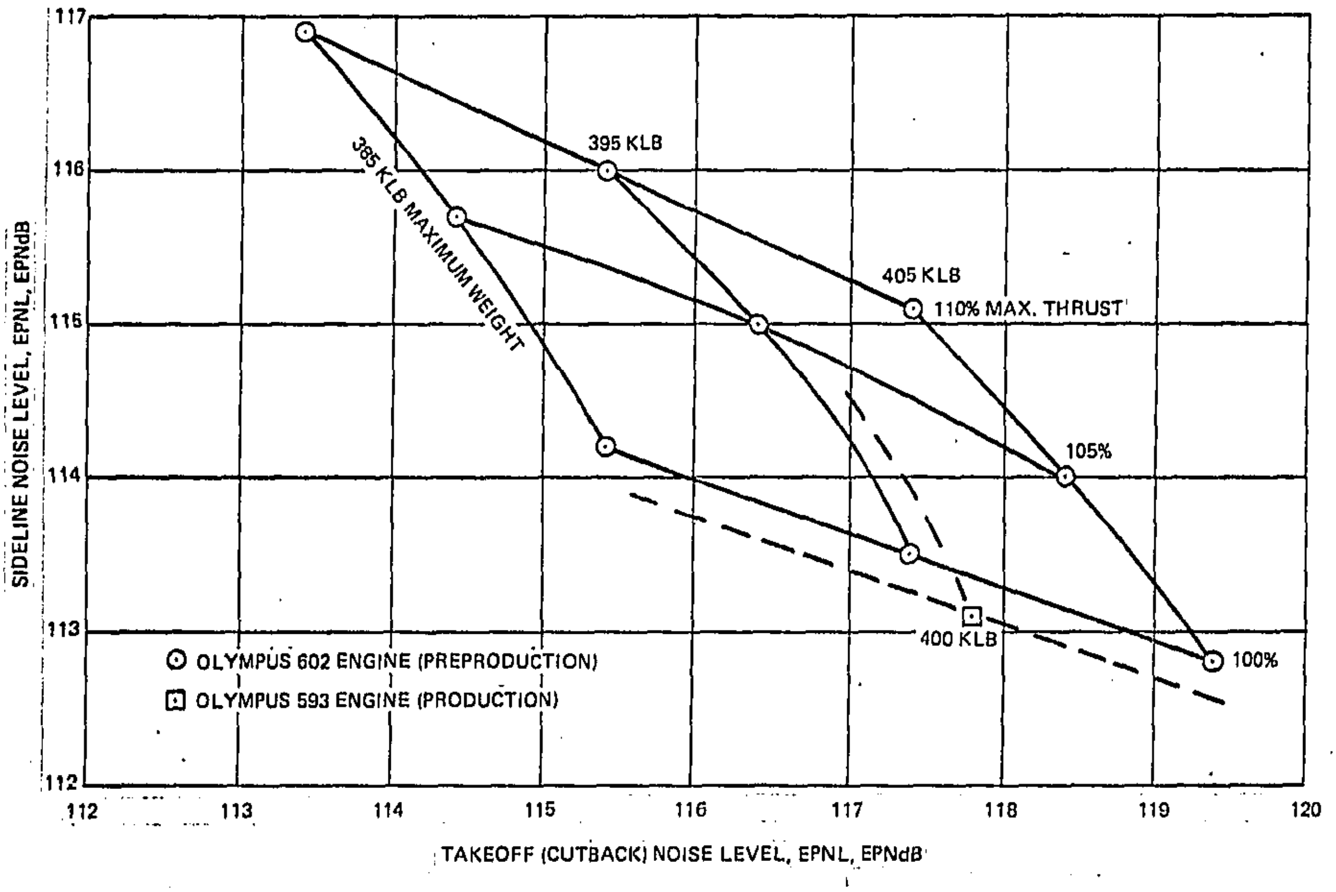


FIGURE 8. PREDICTED NOISE LEVELS FOR GROWTH OF CONCORDE.

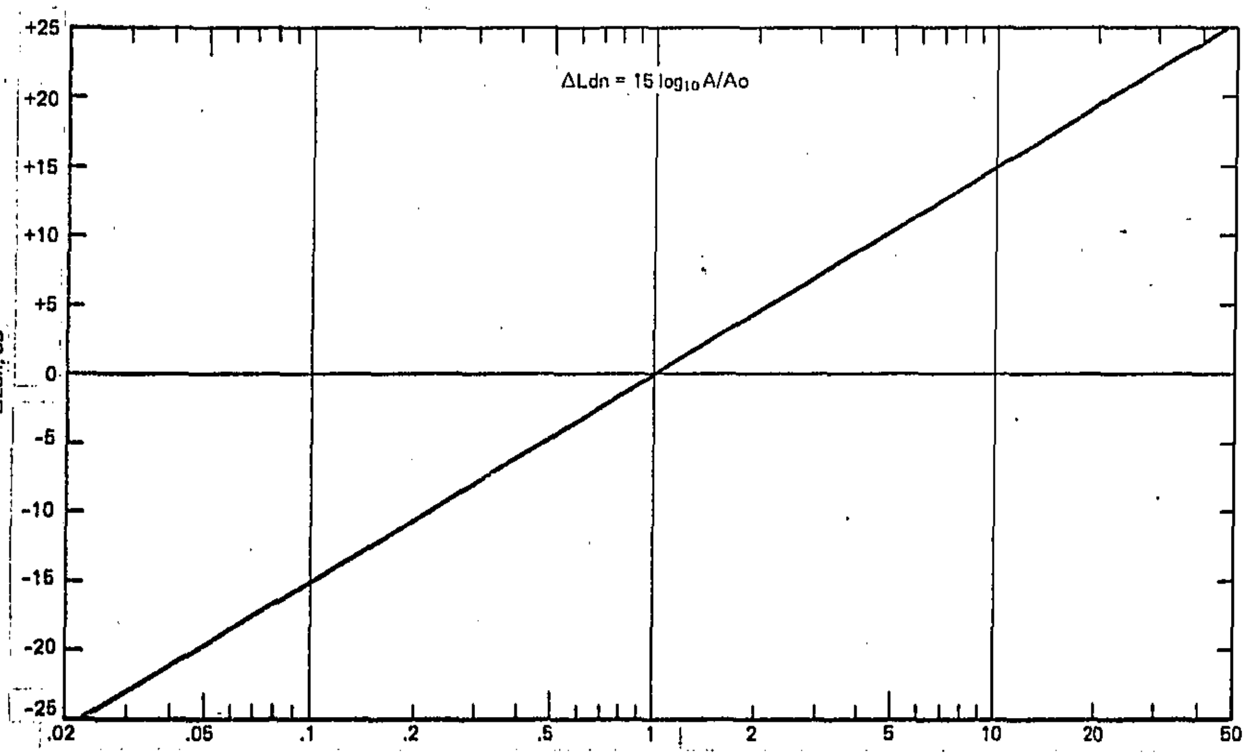


FIGURE 9. RELATION BETWEEN ΔLdn AND AREA WITHIN Ldn CONTOUR.

AIRPLANE			FAR 36		CONFIGURATION NOISE LEVELS @ FAR 36 MEAS. PTS., EPNdB		
ENGINE	TYPE	WEIGHT KLBS	MEAS. POINT	NOISE LEVEL REQ'T EPNdB	BASELINE OR STANDARD	QN - 3D QN - 8D	QN - 3D R/F - 8D
JT3D	BOEING 707	333.6	S/L	106.3	102.1	99.2	99.2
			T/O	103.8	113.0	102.2	102.2
			APP	106.3	116.8	102.2	102.2
	DOUGLAS DC-8	325.0	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	172.5	S/L	104.4	99.9	99.9	91.7
			T/O	99.0	100.0	97.5	93.1
			APP	104.4	108.1	100.0	101.0
	BOEING 737	103.5	S/L	102.9	101.1	101.1	85.7
			T/O	95.3	91.7	91.7	82.5
			APP	102.9	108.9	101.6	100.8
	DOUGLAS DC - 9	108.0	S/L	103.0	101.1	101.5	92.0
			T/O	95.6	97.0	94.5	85.0
			APP	103.0	108.0	99.0	98.0
OLYMPUS 593/602	CONCORDE 02	385.0	S/L	106.7	114.2	N.A.	N.A.
			T/O	104.8	115.4		
			APP	106.7	114.5		
OLYMPUS 593	CONCORDE PRODUCTION	400.0	S/L	106.8	113.1	N.A.	N.A.
			T/O	105.1	117.8		
			APP	106.8	114.9		
NK 144	TU - 144	396.0	S/L	106.8	114.0	N.A.	N.A.
			T/O	105.0	110.0		
			APP	106.8	110.0		

TABLE 1. NOISE LEVELS FOR SUBSONIC AND SUPERSONIC TRANSPORTS.

SUBSONIC FLEET CONFIGURATION	FAR 36 MEAS. POINT	SUBSONIC FLEET NEF dB	SUBSONIC FLEET Ldn dB	OPS. PER DAY	SST NEF dB	SST Ldn dB	TOTAL NEF dB	TOTAL Ldn dB	EFFECT OF SST Δ NEF & Δ Ldn dB	EFFECT OF SST Δ AREA 0/0
BASELINE OR STANDARD	S/L	35.5	70.5	1	27.1	62.1	36.1	71.1	+0.6	+10
	T/O	43.2	78.2		29.1	64.1	43.4	78.4	+0.2	+ 3
	APP	47.2	82.2		27.1	62.1	47.2	82.2	0	0
QN - 3D QN - 8D	S/L	34.6	69.6		27.1	62.1	35.3	70.3	+0.7	+11
	T/O	33.7	68.7		29.1	64.1	35.0	70.0	+1.3	+23
	APP	35.5	70.5		27.1	62.1	36.1	71.1	+0.6	+10
QN - 3D R/F- 8D	S/L	29.7	64.7		27.1	62.1	31.6	66.6	+1.9	+34
	T/O	32.5	67.5		29.1	64.1	34.1	69.1	+1.6	+28
	APP	35.9	70.9		27.1	62.1	36.4	71.4	+0.5	+ 8
BASELINE OR STANDARD	S/L	35.5	70.5	4	33.1	68.1	37.5	72.5	+2.0	+36
	T/O	43.2	78.2		35.1	70.1	43.8	78.8	+0.6	+10
	APP	47.2	82.2		33.1	68.1	47.4	82.4	+0.2	+ 3
QN - 3D QN - 8D	S/L	34.6	69.6		33.1	68.1	36.9	71.9	+2.3	+43
	T/O	33.7	68.7		35.1	70.1	37.5	72.5	+3.8	+79
	APP	35.5	70.5		33.1	68.1	37.5	72.5	+2.0	+36
QN - 3D R/F- 8D	S/L	29.7	64.7		33.1	68.1	34.7	69.7	+5.0	+116
	T/O	32.5	67.5		35.1	70.1	37.0	72.0	+4.5	+100
	APP	35.9	70.9		33.1	68.1	37.7	72.7	+1.8	+32
BASELINE OR STANDARD	S/L	35.5	70.5	8	36.1	71.1	38.8	73.8	+3.3	+66
	T/O	43.2	78.2		38.1	73.1	44.4	79.4	+1.2	+20
	APP	47.2	82.2		36.1	71.1	47.5	82.5	+0.3	+ 5
QN - 3D QN - 8D	S/L	34.6	69.6		36.1	71.1	38.4	73.4	+3.8	+79
	T/O	33.7	68.7		38.1	73.1	39.5	74.5	+5.8	+144
	APP	35.5	70.5		36.1	71.1	38.8	73.8	+3.3	+66
QN - 3D R/F- 8D	S/L	29.7	64.7		36.1	71.1	37.0	72.0	+7.3	+207
	T/O	32.5	67.5		38.1	73.1	39.2	74.2	+6.7	+180
	APP	35.9	70.9		36.1	71.1	39.0	74.0	+3.1	+61

TABLE 2. EFFECT OF SST OPERATIONS ON NOISE EXPOSURE.
(a) HYPOTHETICAL AIRPORT - SINGLE RUNWAY.

SUBSONIC FLEET CONFIGURATION	FAR 36 MEAS. POINT	SUBSONIC FLEET		SST			TOTAL		EFFECT OF SST	
		NEF dB	Ldn dB	OPS PER DAY	NEF dB	Ldn dB	NEF dB	Ldn dB	ΔNEF & ΔLdn dB	Δ AREA 0/0
	S/L	39.3	74.3		27.1	62.1	39.6	74.6	+0.3	+ 5
	T/O	49.2	84.2	1	29.1	64.1	49.2	84.2	0	0
BASELINE	APP	51.3	86.3		27.1	62.1	51.3	86.3	0	0
	S/L	39.3	74.3		33.1	68.1	40.2	75.2	+0.9	+15
OR	T/O	49.2	84.2	4	35.1	70.1	49.4	84.4	+0.2	+ 3
	APP	51.3	86.3		33.1	68.1	51.4	86.4	+0.1	+ 2
STANDARD	S/L	39.3	74.3		36.1	71.1	41.0	76.0	+1.7	+30
	T/O	49.2	84.2	8	38.1	73.1	49.5	84.5	+0.3	+ 5
	APP	51.3	86.3		36.1	71.1	51.4	86.4	+0.1	+ 2

TABLE 2. EFFECT OF SST OPERATIONS ON NOISE EXPOSURE
(b) JFK AIRPORT - RUNWAY 13R/31L

SUBSONIC FLEET CONFIGURATION	NOISE EXPOSURE AREA, SQUARE MILES					
	GROSS			NET		
	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
BASELINE OR STANDARD	10.69	4.95	2.30	9.19	4.32	1.38
QN - 3D QN - 8D	2.49	1.15	0.54	2.09	1.01	0.32
QN - 3D R/F - 8D	2.07	0.96	0.45	1.74	0.84	0.27

TABLE 3. TAKEOFF OPERATIONS OF SUBSONIC AND SUPERSONIC TRANSPORTS AT HYPOTHETICAL AIRPORT.
(a) NOISE EXPOSURE AREAS DUE TO SUBSONIC FLEET.

SUBSONIC FLEET CONFIGURATION	NOISE EXPOSURE AREA, SQUARE MILES								
	1 SST FLIGHT PER DAY			4 SST FLIGHTS PER DAY			8 SST FLIGHTS PER DAY		
	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
BASELINE OR STANDARD	0.32	0.13	0.04	1.04	0.42	0.13	2.14	0.86	0.28
QN-3D QN-8D	0.48	0.23	0.07	1.67	0.81	0.26	3.01	1.45	0.46
QN-3D R/F-8D	0.49	0.24	0.08	1.74	0.84	0.27	3.13	1.51	0.49

TABLE 3. TAKEOFF OPERATIONS OF SUBSONIC AND SUPERSONIC TRANSPORTS AT HYPOTHETICAL AIRPORT.
(b) INCREASE IN NOISE EXPOSURE AREAS DUE TO SST.

SUBSONIC FLEET CONFIGURATION	POPULATION					
	DENSITY, PEOPLE PER SQUARE MILE			IMPACT, PEOPLE		
	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
BASELINE OR STANDARD	5,000	2,500	2,000	34,460	10,110	2,760
QN - 3D QN - 8D	SEE NOTE			4,535	2,020	640
QN - 3D R/F - 8D				3,660	1,680	540

NOTE: POPULATION DENSITY WITHIN GIVEN CONTOUR AREA IS BASED ON BASELINE VALUES. FOR EXAMPLE, FOR THE QN AND R/F FLEET, THE NET AREA WITHIN Ldn 70 SHRINKS FROM 4.32 TO 0.84 SQUARE MILES WHICH IS TOTALLY WITHIN THE BASELINE Ldn 75 AREA. CONSEQUENTLY, THE POPULATION DENSITY IS CONSIDERED TO BE 2,000 PEOPLE PER SQUARE MILE WHICH IS THE VALUE ASSOCIATED WITH THE BASELINE Ldn 75 AREA.

TABLE 3. TAKEOFF OPERATIONS OF SUBSONIC AND SUPERSONIC TRANSPORTS AT HYPOTHETICAL AIRPORT.
(c) POPULATION IMPACTED BY NOISE DUE TO SUBSONIC FLEET.

SUBSONIC FLEET CONFIGURATION	INCREASE IN POPULATION, PEOPLE								
	1 SST FLIGHT PER DAY			4 SST FLIGHTS PER DAY			8 SST FLIGHTS PER DAY		
	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
BASELINE OR STANDARD	1,600	325	80	5,200	1,050	260	10,700	2,150	560
QN - 3D QN - 8D	960	460	140	4,175	1,620	520	8,900	2,900	920
QN - 3D R/F - 8D	980	480	160	3,480	1,680	540	8,450	3,020	980

TABLE 3. TAKEOFF OPERATIONS OF SUBSONIC AND SUPERSONIC TRANSPORTS AT HYPOTHETICAL AIRPORT.
(d) INCREASE IN POPULATION IMPACTED BY NOISE DUE TO SST.

SUBSONIC FLEET CONFIGURATION	INCREASE IN COST, DOLLARS								
	1 SST FLIGHT PER DAY			4 SST FLIGHTS PER DAY			8 SST FLIGHTS PER DAY		
	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75	NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
BASELINE OR STANDARD	96	33	16	937	315	156	3,852	1,290	672
QN - 3D QN - 8D	374	299	182	4,761	3,078	1,976	15,486	8,410	5,336
QN - 3D R/F - 8D	470	384	256	4,698	3,780	2,430	16,984	10,117	6,566

UNIT COST, $ PER PERSON PER dB		
NEF 30 Ldn 65	NEF 35 Ldn 70	NEF 40 Ldn 75
300	500	1,000

TABLE 3. TAKEOFF OPERATIONS OF SUBSONIC AND SUPERSONIC TRANSPORTS AT HYPOTHETICAL AIRPORT.
(e) INCREASE IN COST FOR NOISE COMPATIBLE LAND USE CONTROL DUE TO SST.

Observer Category	Land Use	Outdoor/Indoor Noise Reduction		Noise Level Criteria	
		Level dB**	Windows	Ldn dB	Leq dB
1	Residential	15	Open	55	--
2	Hospital	15	Open	55	--
3	Motel and Hotel	15	Open	60	--
4	School Buildings and Outdoor Teaching Areas	15	Open	--	60
5	Church	25	Closed	--	60
6	Office Buildings	25	Closed	--	70
7	Theater	35	Closed	--	70
8	Playgrounds and Active Sports	NA	NA	--	70
9	Parks	NA	NA	--	60
10	Special Purpose Outdoor Areas	NA	NA	--	*

* Intruding noise shall not exceed existing Leq minus 5 dB.
** Where knowledge of structure indicates a difference in noise reduction from these values, the criterion level may be altered accordingly.

TABLE 4. CRITERIA FOR NOISE IMPACT ANALYSIS OF SENSITIVE LAND AREAS

Subsonic Fleet Config.	No. of SST OPS Per Day	ENIB (Without SST) People	ENIA (With SST) People	ΔENI People	RCI %	RI %
Baseline or Std.	1	25,100	26,211	+1,111	+ 4.4	104.4
QN - 3D QN - 8D	1	3,580	4,348	+ 768	+ 21.5	121.5
QN - 3D R/F- 8D	1	2,511	3,304	+ 793	+ 31.6	131.6
Baseline or Std.	4	25,100	28,710	+3,610	+ 14.4	114.4
QN - 3D QN - 8D	4	3,580	6,790	+3,210	+ 89.7	189.7
QN - 3D R/F- 8D	4	2,511	5,309	+2,798	+111.4	211.4
Baseline or Std.	8	25,100	32,535	+7,435	+ 29.6	129.6
QN - 3D QN - 8D	8	3,580	10,213	+6,633	+185.3	285.3
QN - 3D R/F- 8D	8	2,511	8,915	+6,404	+255.0	355.0

TABLE 5. INCREASE IN NOISE IMPACT AT A HYPOTHETICAL AIRPORT DUE TO THE ADDITION OF SST OPERATIONS

APPENDIX A

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:

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

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

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 decibels 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 noise levels are increased 10 dB, but in the measure of NEF the nighttime noise exposure level is increased by 10dB, the approximate numerical equivalence for the same series of events is:

$$Ldn \approx NEF + 35$$

2. One-Way Runway

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

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

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

3. Single Type Aircraft

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

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

which can be rearranged as

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

and plotted as shown in Figure 7.

4, Use of Curve

Figure 7 gives the relationship between EPNL, NEF, and number of movements for a single airplane operating to or from a single runway. However, Figure 7 can be used in a more general manner. If The EPNL's and number of movements (Nd and Nn) are known for a variety of aircraft types referred to a specific location, then the cumulative NEF, at that location, is simply the sum of the individual NEF's taken from Figure 8. That is,

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

This procedure would hold regardless of the number of runways involved.

APPENDIX B

COMPUTATION OF NOISE EXPOSURE EFFECTS OF SST OPERATIONS

1. REFERENCE FLEET - NOISE EXPOSURE FORECASTS

The reference fleet of airplanes described in Section 5 is defined based on the information presented in Reference 20. Table 7, adapted from Table 6 of that report, shows the composition of the reference fleet, the Effective Perceived Noise Levels (EPNL) at the FAR 36 measuring points, and the NEF values for the fleet at those measuring points for the various assumed conditions:

(a) Baseline - based on current certificated values of Effective Perceived Noise Level (EPNL);

(b) "FAR 36" - based on premise that all airplanes meet the EPNL requirements of FAR Part 36;

(c) "QN-3D+8D" - based on premise that the airplanes powered by JT3D + JT8D engines are retrofitted with "quiet nacelles";

(d) "QN-3D, R/F-8D" - based on premise that the JT3D-powered airplanes are retrofitted with quiet nacelles and the JT3D-powered airplanes with refanned engines.

2. COMPUTATION OF INCREMENTAL AREAS WITHIN NEF 30 AND NEF 40 CONTOURS.

In sections 5 and 6 of this report, the effects of community noise exposure of the introduction of SST operations are quantified in two different, but related, measures. The primary measure is computed as a change in Day-Night Level (Ldn) or Noise Exposure Forecast (NEF) in decibels. (The NEF/Ldn methodology is outlined in Appendix A.) The derived measure is increase in area enclosed within the contours of Ldn 65 (NEF 30) and Ldn 75 (NEF 40). The basis for this computation is summarized herein.

The basic equation used is the following:

$$\Delta \text{Ldn} = \Delta(\text{NEF}) = 15 \log A/Ao, \quad (1)$$

where Ao is the reference area enclosedd within the original Ldn (NEF) contour,

and A is the area enclosed within the contour modified by introduction of the additional airplane operations. The line representing this equation is plotted in Figure 10, which may be used to estimate the change in exposed area due to a change in NEF value measured at a specified point. It will be noted that this relationship applies to either positive or negative changes in Ldn or NEF. For example, an Ldn increase of 4.5 dB will result in an increase in the area within the Ldn 65 (or 75) contour by a factor of 2 (that is, A/Ao = 2); correspondingly, a decrease in Ldn of 4.5 dB will result in a decrease by a factor of 2 in the enclosed area (that is, A/Ao = 0.5).

Equation (1) is not an exact equation, based on theoretical considerations. It is a reasonably good approximation, based largely on results of computation of NEF and EPNL contours, shown in various sources. For example, Reference 22 describes a model for predicting noise exposures around airports. Based on considerable computational data, this model may be summarized by the following equations:

$$\text{NEF 30 area} = .86 \times 10\ [10 \log N + 24 - 30] \tag{2}$$

$$\text{NEF 30 area} = .98 \times 10\ [10 \log N - 16] \tag{3}$$

where N is the number of daily operations
and area is in square miles
Equation (2) may be re-written as

$$\log(\text{NEF 30 area}) = .0655 + [10 \log N - 6] \tag{4}$$

$$\text{or } 15 \log(\text{NEF 30 area}) = C + 10 \log N \tag{5}$$

Since NEF is directly related to 10 logN (as seen in Appendix A) this is equivalent to

$$15 \log Ao = C + (\text{NEF})o \tag{6}$$

and for a change in NEF, $\Delta \text{NEF} = (\text{NEF}) - (\text{NEF})o$

one obtains $15 \log A_1/Ao = \quad \text{NEF}$, which is identical to Equation (1). an analysis was run on a series of calculations of EPNL contours and enclosed areas reported in Reference 26.

In the referenced report, the contours of EPNL 100, 95, 90 and 85 dB were computed and the areas enclosed within the contours measured. The EPNL contours for three different airplanes (707, 727, and DC-9) were computed using experimentaly derived curves of EPNL versus slant range (References 27 - 29).

Based on the data form these reports, the ratios A/Ao were computed for EPNL = 5 dB, 10 dB, and 15 dB. The results are listed in Table 8. The mean values of A/Ao obtained for those three values of ΔEPNL, both from the FAA data (References 26 - 29) and from Equation (1), were as shown below:

EPNL	A/Ao [computed from FAA data]	A/Ao [based on Equ. (1)]
5 dB	2.33 ± 0.4	2.14
10 dB	5.28 ± 1.25	4.64
15 dB	10.8 ± 2.89	10.0

These results indicate that Equation (1) provides an adequate approximation (within about 10%) to the predicted areas enclosed within the EPNL contours ranging from 85 to 100 dB.

APPENDIX C

NOISE IMPACT METHODOLOGY

1. Discussion

The Noise Control Act of 1972 defines environmental noise as "the intensity, duration, and the character of sounds from all sources". The EPA has chosen the equivalent A-weighted sound pressure level (Leq) as its basic measure for environmental noise (References 1, 4, 8, and 9). There are two time intervals of interest in the use of Leq for noise impact assessment. The smallest interval of interest is one hour usually considered the "design hour" of a day. The primary interval of interest for residential land uses is a twenty four hour period, with a weighting applied to nighttime noise levels to account for the increased sensitivity with the decrease in background noise at night. This twenty-four-hour weighted equivalent level is denoted the Day-Night Level (Ldn).

The underlying concept for noise impact assessment is to express the change in human response expected from the people exposed to the environmental noise exposure being considered. Three steps are involved: (a) definition of initial acoustical environment; (b) definition of final acoustical environment; (c) definition of the relationship between the specified noise environment and the degree of its "impact" in terms of its expected human response.

The first two components of the assessment are entirely site or system specific, relating to either estimates or measurement of the environmental noise before and after the action being considered. The same approach is used, conceptually, for the examination of a house near one proposed road, the entire highway system, or the totality of the nation's airports. The methodology for estimating the noise environment will vary widely with the scope and type of problem, but the concept remains the same.

In contrast to the widely varying methodologies that may be used for estimating the noise environment in each case, the relationships to human response can be quantified by a single methodology for each site or noise producing system considered in terms of the number of people in occupied places exposed to noise of a specified magnitude. This does not mean that individuals exhibit the same susceptibility to noise; they do not. Even groups of people may vary in response depending on previous exposure, age, socio-economic status, political cohesiveness and other social variables. In the aggregate, however, for residential locations the average response of groups of people is quite stably related to cumulative noise exposure as expressed in a measure such as the average yearly Ldn. The response considered is the general adverse reaction of people to noise which consists of a combination of such factors as speech interference, sleep interference, desire for a tranquil environment, and the ability to use telephones, radio, or TV satisfactorily. The measure of this response is related to the percentage of people in a population that would be expected to indicate a high annoyance to living in a noise environment of a specified level of exposure.

A generalized expression for the percentage of a population expected to be highly annoyed (% HA) when exposed to a specified environmental noise level is:

$$\% \text{ HA} = 2(\text{Ldn} - 50)$$

The data from which this expression was derived also show that, even for situations where, for example, 20% of the people would be expected to be highly annoyed by their noise environment, the majority of the population is not at all annoyed.

2. Criteria for Noise Impact

The above considerations permit the specification of numerical values for noise levels in spaces devoted to various types of uses which, if not exceeded, would provide entirely acceptable acoustical environments. Thus, if those values are not exceeded, it could be assumed that there would be no impact from environmental noise.

Specific noise criteria level values for those land uses or occupied spaces generally encountered in noise impact assessments are provided in Table 4. Each of the levels provided in the table is specified as an outdoor noise level, even though the use of many of the spaces is usually indoors. The noise reduction for typical building construction has been used to arrive at an outdoor noise level that would provide an acceptable indoor environment, since in any general environmental impact study it is only an outdoor noise level that can be predicted in any practical application. Also, it has been assumed in the table that industrial and commercial applications are zero impacted at any environmental noise level.

3. Fractional Impact

Using the criteria levels of Table 4 as definition of zero impact, a method is needed for defining impact if these criteria noise levels are exceeded. In both the cases of annoyance response and speech interference, the range of noise levels between totally acceptable conditions and totally unacceptable conditions is approximately 20 decibels. For annoyance this is an Ldn range of 55 to 75; for speech this corresponds to the articulation index range from 1.0 to slightly less than 0.4. The percent of noise impact at a location can thus be defined as ranging from zero, when the local noise level is at or below the relevant criterion level, to 100% when the local noise level exceeds this criterion level by 20 decibels.

For any location, the percent exceedance of the noise level above the criterion level is defined as the Fractional Impact (FI), expressed as:

$$FI = 0.05\,(L - Lc) \qquad \text{for } L > Lc$$

$$FI = 0 \qquad \text{for } L \leq Lc$$

Where L is the appropriate Leq measure for the local environmental noise (i.e., either Ldn or Leq) and Lc is the appropriate criterion level from Table 4 for the land use under consideration. Note that FI can exceed unity, if L exceeds Lc by more than 20 dB.

The possibility of hearing loss, however, will start becoming a factor for a Ldn greater than approximately 75 dB. The quantification, therefore, of the impact for levels above 75 dB becomes less obvious. In spite of this the fractional impact is continued to be calculated according to the formula even for levels above 75 dB. Constraints on the interpretation of the total impact and the characterization of adverse impact are designed to give appropriate weight to the hearing loss considerations.

4. Total Impact

In order to introduce the number of people affected by each level of environmental noise into the analysis, it is assumed that a trade-off can be made between the intensity and the extensity of noise impact. That is, an assumption that a moderate exceedance of criterion levels for a large group of people would be expected to be of greater impact than a large exceedance of criterion levels for a small number of people. A way of defining the impact is to determine the number of persons (Pi) of the total population under consideration (P) who have various exceedances (Li - Lc) of the criterion levels. This determination should be performed using (Li - Lc) increments of 5 decibels or less. Thus the Equivalent Noise Impact (ENI) of a specific noise environment for a population P can be expressed as:

$$ENI = \sum_i (FIi)(Pi)$$

This descriptor (ENI) might be considered as the "equivalent population" 100% impacted by noise. For residential uses, it can be defined as the equivalent number of persons exposed to a Ldn of 75 dB. It provides an estimate as to the magnitude of the impact and serves as the basis of other measures which are useful for comparing impact of different noise sources and regulations or combinations of these with each other. Such comparisons assume the same area or population base.

The Change in Equivalent Noise Impact is defined as:

$$\Delta ENI = ENIA - ENIB$$

Where ENIB and ENIA are the "before" and "after" population exposed to some noise condition. This measure is useful for comparing the effects of various actions with each other. These comparisons are valid even though the areas or population bases differ.

Another useful measure is the Relative Change in Impact (RCI). This characterizes the change in impact due to some action by looking at the "before" and "after" noise conditions. The measure (expressed in percent) is defined as:

$$RCI = 100 \; (\Delta ENI \; / \; ENIB)$$

This measure, to be meaningful, must be used for the same area or population base.

Another measure which is useful for regulatory purposes is the Ratio of Impact (RI) expressed in percent as follows:

$$RI = 100 \; (ENIA \; / \; ENIB)$$

To be meaningful, this value should be computed using the same population. Ideally, the total national population affected by the noise in question should be used for the population base.