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An Assessment of Commuter Aircraft Noise Impact

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1 ABSTRACT

This report examines several approaches to understanding "the commuter aircraft noise problem." The commuter aircraft noise problem in the sense addressed in this report is the belief that some aspect(s) of community response to noise produced by commuter aircraft operations may not be fully assessed by conventional environmental noise metrics and methods. The report offers alternate perspectives and approaches for understanding this issue. The report also develops a set of diagnostic screening questions; describes commuter aircraft noise situations at several airports; and makes recommendations for increasing understanding of the practical consequences of greater heterogeneity in the air transport fleet serving larger airports.

2 INTRODUCTION

2.1 PROBLEM STATEMENT

Although it is not clear that consequential nationwide community response problems due to commuter aircraft noise exposure currently exist, the term "commuter aircraft noise problem" is used throughout this report to refer to the generic belief that some aspect(s) of community response to commuter aircraft noise emissions are not fully or properly accounted for by conventional environmental noise metrics, dosage-response relationships and interpretive criteria. Since this view is a somewhat nebulous one, it is helpful for the sake of exposition to state it as an explicit strawman proposition. In colloquial terms, the issue examined in this report is that

> "Even though commuter aircraft are quieter than large jet airliners, their operations appear to annoy people to a greater degree than would be expected on the basis of standard predictive methods."

For the sake of discussion in this report, this strawman is accepted at face value, even though its current tenability at any particular airport remains to be demonstrated.

2.2 BACKGROUND

For economic and other reasons, commuter aircraft operations have increased greatly both in numbers and as proportions of total operations at many U.S. airports in the last several years. The 2138 aircraft operated by 124 domestic regional carriers in 1995 transported 57.2 million passengers (Shifrin, 1996). Commuter aircraft flew nearly 13 billion revenue passenger miles in 1995, averaging 2179 hours of utilization per aircraft at a load factor of nearly 50%. Table 1 shows national trends in commuter aircraft activity since 1984 (FAA, 1995; Shifrin, 1996). The number of annual enplanements on commuter flights nationwide has grown at a compound rate of about 9% over the last decade, during which time commuter airlines have flown increasingly larger aircraft longer distances. The average passenger trip length in 1995 was 223 miles, while the average number of seats per aircraft was 24.6.

Little of this growth in commuter operations was foreseen either prior to the deregulation of the late 1970s or in subsequent FAR Part 150 studies at many airports. FAA expects enplanements on commercial aircraft to increase by 3.7% per year for at least the next decade. If enplanements on commuter aircraft continue to grow at rates similar to those sustained over the last decade, then it is clear that an increasing proportion of domestic passengers will be transported on commuter aircraft in the future.

Although the composition of the commuter aircraft fleet has changed considerably in the last decade and will continue to do so in the future, the noise emissions of smaller commuter aircraft remain lower in level than those of larger airliners, particularly on departure. At most large regional and hub airports, commuter operations already constitute a quarter or more of all operations. This trend has increased the heterogeneity of fleets at major airports, and raised questions about the appropriateness of environmental assessment methods developed during the pre-deregulation era, when the bulk of scheduled service was provided by a fairly homogeneous fleet of large jet transports.

Table 1 Growth of domestic commuter aircraft operations since 1984

YEAR	ENPLANED PASSENGERS (MILLIONS)	AVERAGE BLOCK LENGTH (MILES)	AVERAGE SEATS PER AIRCRAFT	AVERAGE LOAD FACTOR (PERCENT)
1984	21.0	161	19.1	46.2
1985	21.9	162	19.4	44.3
1986	23.3	167	20.2	45.0
1987	28.0	161	19.7	46.0
1988	30.1	172	19.2	46.6
1989	32.1	179	20.4	47.8
1990	37.2	184	20.8	47.1
1991	38.7	186	21.5	46.8
1992	42.7	197	22.9	48.1
1993	46.7	203	23.0	48.7
1994	53.6	211	23.7	50.4
1995	57.2	223	24.6	49.9

In the short term, the growth in numbers of passengers transported by commuter aircraft has constituted a positive trend from the perspective of integrated noise exposure in airport neighborhoods. In units of integrated noise exposure, increases in numbers of commuter operations are generally offset by decreases in sound exposure level of individual overflights, particularly on departure. This is the case even when commuter operations do not reduce enplanements on larger jet aircraft, but instead increase total operations. Increases in numbers of commuter flights have thus far had only minor effects on total areas enclosed by airports' DNL contours.

Figure 1, adapted from Fidell, Horonjeff, Mills, Baldwin, Teffeteller, and Pearsons (1985), illustrates the bimodal distribution of maximum A-weighted sound levels in a neighborhood near an airport serving a fleet of both propeller-driven and jet aircraft. A few dozen Stage II jets are responsible for the higher mode, while several hundred propeller-driven general aviation aircraft are responsible for the lower mode. Fidell *et al.* (1985) note that the relatively few jet operations would control the aircraft-produced DNL to within 1 dB in this neighborhood, even if as many as 4,000 propeller aircraft operations per day contributed to the lower mode.

Growth in numbers and percentages of commuter aircraft operations may nonetheless pose problems for airport communities, airport proprietors and others. As commuter airlines extend service to greater numbers of destinations at increasing stage lengths, and as they compete with larger equipment for passengers, problems of exacerbated community response to aircraft noise in general (*i.e.*, not merely reactions to commuter operations) may arise in airport neighborhoods. Other

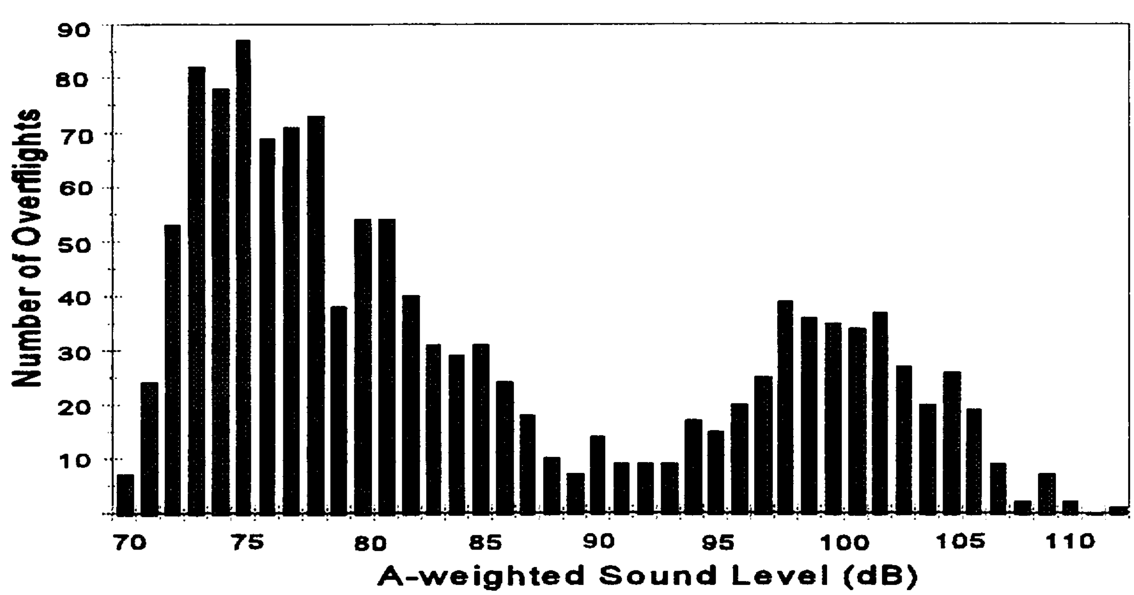


Figure 1 Illustration of bimodal distribution of maximum A-weighted aircraft noise levels in a neighborhood near an airport supporting both propeller-driven and jet aircraft.

potential problems include commitment of runway and taxiway capacity without a commensurate increase in passenger enplanements (and hence, diminished revenue from passenger facility charges, commercial space rentals, concession fees, and other sources of airport funds), and disproportionate increases in air traffic control workload. These other problems may be of particular concern to airports that are already operating at or near runway and gate capacities.

Commuter aircraft have competed most effectively over the last decade with larger jet transports in markets for which larger equipment does not offer notably shorter block times, and in which greater flight frequencies can compensate for somewhat longer block times and less comfortable equipment. (It should be noted, however, that the larger partners of the 43 code sharing commuter airlines often make final decisions about equipment and route allocation for other reasons as well.) Commuter operations have also profited from the natural decline in rail and bus service. As commuter airlines continue to build market share, increase load factors, offer service to more distant city pairs, develop point-to-point networks in addition to providing feed traffic at hubs, and operate in a more stringent regulatory environment, they will operate larger aircraft, including multi-engine turbofan aircraft.

These trends have already blurred the once-clear distinction between commuter and other airline operations. Swearingen Metroliners, Beechcraft 1900D, Jetstream 31 and similar smaller commuter aircraft are being retired from revenue service at some larger hub airports, and are being replaced with larger aircraft such as Bombardier's 50 seat Regional Jet, Aerospatiale/Aeritalia ATR-72, and Fokker F70 and F100 jets. Additional 70-100 seat turboprop and turbofan powered aircraft (*e.g.*, the Dash 8-400, Boeing 737-600 and -700 models, and MD-95) are likely to join the "commuter" and "regional" short haul fleets within a few years.

In its public hearings, the Federal Interagency Committee on Aircraft Noise (FICAN) has begun to hear from community representatives reporting annoyance due to commuter aircraft noise that is seemingly disproportionate to the integrated noise exposure produced by such operations. It is far from clear, however, that such complaints are directly attributable to any unique aspect of commuter aircraft noise emissions and operations. Increasing numbers of commuter aircraft operations at airports also affect the frequency of overflight noise intrusions, the heterogeneity of spectral content of aircraft overflight noise, the variance of the distribution of SEL values of aircraft overflights in a given neighborhood, the character of ground runup noise, and sometimes the geographic distribution of overflown communities with respect to long established jet flight tracks and runway ends. Any of these factors alone or in combination could contribute to aggravated community response to commuter aircraft operations.

2.3 ORGANIZATION OF REPORT

Chapter 3 contains background information in several areas related to commuter aircraft operation. Chapter 4 summarizes perspectives of several airports and communities regarding commuter aircraft noise impacts, and develops a set of diagnostic screening questions. Chapter 5 examines several plausible explanations for the commuter aircraft noise problem. A Glossary is provided for the benefit of readers unfamiliar with some of the terminology of regulatory acoustics. Two Appendices contain additional technical detail.

3 NATURE OF COMMUTER OPERATIONS

3.1 TERMS AND DEFINITIONS

Scheduled passenger-carrying operations in airplanes with 30 or fewer passenger seats or of 7,500 pounds or less in payload capacity are currently conducted under FAR Part 135. Such aircraft operations have traditionally been considered as "commuter" airline operations. A proposed revision of regulations of March, 1995 (Notice 95-5; 60 CFR 16230) imposes certain additional requirements on providers of scheduled passenger service in all aircraft with 10 to 30 seats, and on all operators of turbojet airplanes regardless of seating configuration. These new regulatory requirements resemble those applicable to Part 121 certified carriers (major long-haul airlines).

Per 14CFR Part 91 *et al.*, FAA currently considers "commuter" airline operations to be scheduled, passenger-carrying flights conducted under FAR Part 135 in airplanes with a passenger-seating capacity of 30 or fewer seats. The Department of Transportation defines "commuter category airplanes" and "commuter" operations more broadly than FAA, using the term "commuter" to include all scheduled passenger-carrying operations conducted in airplanes with a passenger-seating capacity of 20 to 60. FAA avoids use of the term "regional," widely used by the airline industry to indicate scheduled passenger-carrying flights and airplanes in short haul service. For reasons noted in the following subsections, the term "commuter" is used in its broadest sense in this report, including that of "regional" and even larger aircraft.

3.2 OPERATIONAL TRENDS AND FLEET MIX

The marked increases of recent years in commuter aircraft operations at airports nationwide have several origins, beginning with the deregulation of the late 1970s. As the national air transportation network evolved from city pair toward hub-and-spoke topology, an expanding niche was created for aircraft with lower direct operating costs over short block times than large turbofan powered aircraft. Factors as diverse as marketing trends (*e.g.*, airline code-sharing in flight reservation systems), competitive pressures for flight frequencies, aircrew labor costs, and technological improvements in the speed and comfort of smaller transport aircraft, have all fostered these trends. Although these trends will almost certainly continue in the future, their quantitative effects on numbers and proportions of commuter operations at particular airports have proven difficult to forecast. Factors such as the relative proportions of transfer, origination, and destination traffic at an airport, as well as types and schedules of service offered by competing airlines, the airport's geographic relationship to other population centers and competing airports, and the size and population density of an airport's hinterland, all affect the economics of fleet operation.

3.3 DIVERSITY OF AIRCRAFT AND POWERPLANTS IN COMMUTER SERVICE

Table 2 compares characteristics of the two dozen-odd aircraft types flying in scheduled commuter service in the United States. The table omits a number of fixed wing aircraft that currently conduct less than 1% of U.S. commuter aircraft operations,[1] even though they may be in common service elsewhere. Table 2 also omits rotary wing, amphibian, business jets and certain other aircraft types in air taxi service. The table, although not intended to be comprehensive, indicates the considerable range in size and capacity of aircraft in commuter service. Aircraft in "commuter" and short haul ("regional") service range in passenger capacity from 2 to 74, and in weight (with which engine power and hence noise emissions scale directly) from about 7,000 to 60,000 pounds. Figure 2 shows the numbers and proportions of commuter aircraft that account for the bulk of current operations.

The number of turboprop engines powering this diverse fleet is considerably smaller than the number of aircraft models in commuter and regional service. As noted by Galloway and Wilby (1980), variants of Pratt and Whitney (Canada) PT-6, AiResearch TPE331, Rolls-Royce Dart, and Allison 501 engines are among the most common turboprop engines. These engines have been fitted with such a variety of gearboxes (driving two- to six-bladed, constant or variable pitch propellers of varying shape, length, and tip speed) that the noise emissions of different commuter aircraft equipped with the same engines can differ markedly from one another.

Propellers are generally the predominant source of turboprop aircraft noise. Propeller rotation speeds vary from about 1000 to 2000 rpm across commuter aircraft models, while helical tip Mach numbers vary from less than 0.6 to more than 0.8. This wide range of propeller rpm and tip speeds leads to substantial differences in spectral distributions of tones and broadband energy

[1] Based on August, 1995 OAG information.

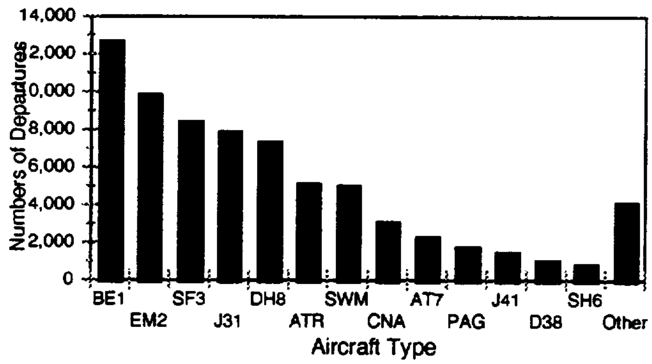
within aircraft types as a function of operating conditions, and among different commuter aircraft models.

Table 2 Summary of aircraft types accounting for the bulk of scheduled commuter service in the United States. (Derived from information compiled by Frawley and Thorn, 1995. All specifications are approximate, as variant powerplants and seating arrangements are common among different production batches and sales.)

AIRCRAFT	POWERPLANT / PROPULSION	PASSENGER CAPACITY	GROSS WEIGHT (Pounds)	COMMENTS
Piper (PA-31, PA-42, *etc.*)	Variety of piston and turboprop engines, including two 260kW Lycoming and two 460kW P&W PT6A in PA-31 models alone	2-10	up to 7,800	Piper models account for 2.5% of U.S. scheduled commuter operations, plus considerable air taxi and corporate service; ranges up to 1290 mi
Beechcraft 1900	Two 820kW or 955kW P&W CPT6A turboprops, four-bladed constant speed propellers	19	16,950	More than 200 built, 1900D model manufactured since 1991; 1570 mi range, 288 kt cruise speed with 10 passengers. With smaller models (King Air, B99), accounts for almost 20% of all U.S. commuter operations
Cessna	One or two piston engines or turboprop	4-14	up to 8,750	Up to 1400+ mi range
Pilatus Britten-Norman BN-2A/B Islander BN-2T Turbine Islander	Two piston engines or turboprop	8	6,600	1000+ mi range
Fairchild (Swearingen) Metro/Merlin	Two 700kW (Metro) or two 495kW (Merlin) Garrett AiResearch TPE331 turboprops driving three-bladed constant speed propellers	6-19	16,500	Metro II, III and 23 models evolved from 1960s Merlin design; about 1000 in service, accounting for more than 7% of U.S. commuter operations. 1900+ mi range
British Aerospace (Jetstream) 31/41	Two 700kW (J31)/ 1230kW (J41) Garrett TPE331 turboprops turning four- or five-bladed constant speed propellers	19 - 27	15,322 (J31) 24,000 (J41)	Derivatives of late 1960's Handley Page design, accounting for about 13% of U.S. commuter operations. 650-1150 mi range
Government Aircraft Factories N22B/N24A Nomad	Two turboprop	12-16	9,400	730 mi range

AIRCRAFT	POWERPLANT / PROPULSION	PASSENGER CAPACITY	GROSS WEIGHT (Pounds)	COMMENTS
DeHavilland DHC-6 and 7	Two 431 or 460 kW P&W PT6 (DHC-6); four 835kW (DHC-7) P&W PT6 turboprops turning four-bladed constant speed propellers	20 (DHC-6) 54 (DHC-7)	12,500 (DHC-6) 47,000 (DHC-7)	Very successful family (more than 1000 sales) dating to mid-1960s; account for almost 12% of U.S. commuter operations. Range up to 1100+ nautical miles with full passenger loads in revenue service
Embraer EMB-110 (Bandeirante)	Two 560 kW P&W PT6A turboprops turning three- bladed constant speed propellers	18-21	13,010	1000+ mi range
Dornier 228	Two 535kW Garrett AiResearch TPE331-5 turboprops driving four- bladed constant speed propellers	15-19	14,110	1320 mi range
Embraer EMB-120 (Brasillia)	Two 1340kW P&W118 turboprops turning four- bladed constant speed propellers	24-30	26,433	About 300 Brasilia models account for about 14% of U.S. commuter operations. Brasilia entered service in 1985. 800+ mi range; 30,000+ ft ceiling
Shorts 330	Two 875kW P&W PT6A turboprops	30	22,900	900+ mi range
Dornier 328	Two 1380kW P7W119B turboprops, driving six- bladed constant speed propellers	30-39	30,071	840 mi range
Saab SF 340	Two 1295 or 1305kW General Electric CT7-5 or -9 turboprops, turning four-bladed constant speed propellers	33-37	29,000	Design from late 1970s collaboration of SAAB and Fairchild; nearly 400 now in service. Accounts for almost 12% of U.S. commuter operations; 2145 mi range
Shorts 360	Two 990kW P&WPT6 turboprops driving five- bladed constant speed propellers	36-39	27,100	600+ mi range
DeHavilland DHC-8 (Dash 8) (All Series)	Two 1490kW, 1605kW, 1775kW, or 1865kW P&W 121-123 turboprops turning four- bladed constant speed propellers	36-56	36,300-43,000	820-2050 mi range

AIRCRAFT	POWERPLANT / PROPULSION	PASSENGER CAPACITY	GROSS WEIGHT (Pounds)	COMMENTS
Fokker F27 Friendship/Fairchild F-27	Two 1730kW Rolls-Royce Dart Mk 536-7R turboprops, driving four- bladed constant speed propellers	44-60	45,500	1440 mi range
British Aerospace (Hawker Siddeley) 748	Two 1700kW Rolls-Royce Mk 534, 535 or 552 turboprops, driving four-bladed constant speed propellers	48-51	27,400-46,500	1600+ mi range
Convair (All Series)	Two piston radial engines driving three-bladed constant speed propellers (CV240, 340, and 440); two 2800kW-3430kW turboprops (CV540, 580, 600, 640 and CV5800)	40-76	49,700-63,000	1600-2500+ mi range
Aerospatiale/Alenia ATR-42	Two 1340kW P&W120 turboprops, driving four-bladed constant speed propellers (ATR 42-300); 1455kW turboprops (ATR 42-320); two PW127Es driving six-bladed standard propellers (ATR42-500)	42-46	22,647-36,817	Continental Express is first US customer for ATR42-500, latest addition to Aero International Regional (AIR), with expected delivery of 8 aircraft between May and November 1996, and option to purchase 12 more; 2700+ mi range
Aerospatiale/Alenia ATR72	Two 1610 or 1850kW P&W124 or 127 turboprops, turning four- bladed propellers	64-74	47,400	Developed as a stretched version of ATR 42, entered into service in 1989. ATR42 and 72 models fly about 10% of U.S. commuter operations. 1200+ mi range in revenue service with full passenger loads



	WEEKLY DEPARTURES	
Beechcraft 1900	12,679	17.8%
Embraer EMB-129 Brasilia	9,867	13.9%
Saab SF 340	8,409	11.8%
British Aerospace Jetstream 31	7,927	11.2%
De Havilland DHC-8	7,332	10.3%
Aerospatiale/Alenia (all series)	5,128	7.2%
Fairchild Metro/Merlin	5,009	7.1%
Cessna	3,112	4.4%
Aerospatiale/Alenia ATR72	2,297	3.2%
Piper	1,787	2.5%
British Aerospace Jetstream 41	1,496	2.1%
Dornier 328	1,039	1.5%
Shorts 360	836	1.2%
Other (combined commuter aircraft types individually less than 1% of total departures)	4,123	5.8%

Figure 2 Commuter aircraft departures by aircraft type to all destinations from 238 U.S. airports (OAG, August 1995).

Figures 3, 4, and 5, adapted from Figures 1, 2 and 3 in Galloway and Wilby (1980), illustrate the variety of spectra of various engine/propeller combinations. A regression equation developed by Galloway and Wilby that predicts EPNL values for commuter aircraft with a standard error of 3.2 dB is as follows:

$$L_{EPN} = 10\log_{10}(NP) + 47.82\log_{10}M_h + 21.2\log_{10}\frac{V}{h} + 81.8$$

N = number of engines
P = average horsepower per engine
M_h = helical tip Mach number
V = true airspeed in knots
h = altitude in feet

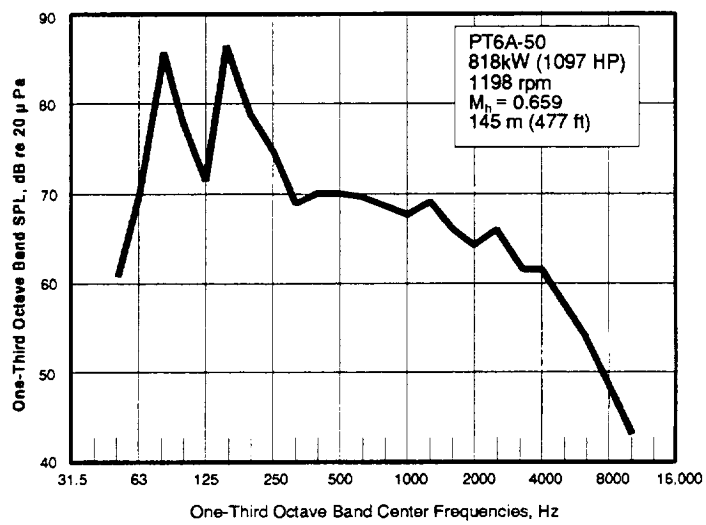


Figure 3 One-third octave band sound pressure levels for Dash-7 at time of PNLTM (takeoff power) (Galloway and Wilby, 1980).

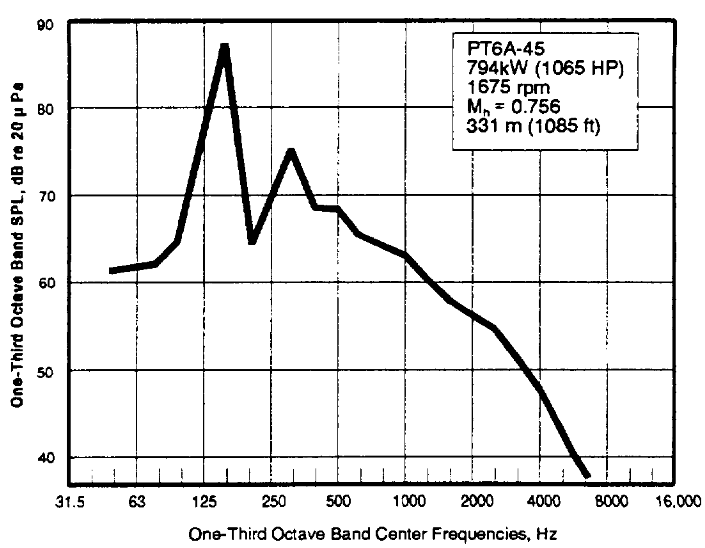


Figure 4 One-third octave band sound pressure levels for SD330 at time of PNLTM (takeoff power) (Galloway and Wilby, 1980).

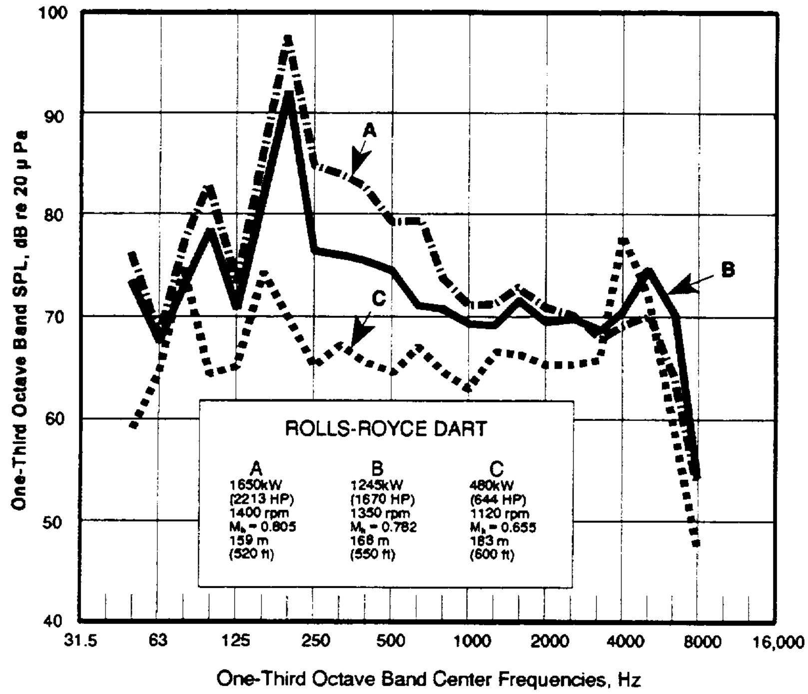


Figure 5 One-third octave band sound pressure levels for Hawker Siddeley 748 at time of PNLTM (various powers) (Galloway and Wilby, 1980).

3.4 RANGE OF SEL FOOTPRINT AREAS OF COMMUTER AIRCRAFT

Version 5.0 of FAA's Integrated Noise Model (INM) was exercised to determine the land areas within aircraft SEL noise contours produced by single approaches and single departures of the salient commuter aircraft included in Figure 2 and a few commercial jet transports. The aircraft included in this study are summarized in Table 3. The Beechcraft 1900 and Fairchild Metro/Merlin were not available in INM. Aircraft substitutions for British Aerospace Jet Stream 31, Aerospatiale ATR-42 and ATR-72, Embraer 120, and Fokker-27 were available in INM. The maximum gross takeoff weights of the turboprops and of the larger jets were 12,500-46,500 and 95,000-240,000 pounds, respectively.

Land areas in square statute miles were calculated within 5 dB intervals of SEL ranging from 55 dB to 85 dB. Table 4 compares land areas within SEL contour intervals produced by a single approach of each of the 10 aircraft. The land areas within the SEL contour intervals for the various aircraft are distributed similarly. Two of the propeller planes (Dash-6 and Shorts 330) expose nearly

Table 3 Aircraft types for which SEL contours for single approaches and departures were compared

Aircraft Type	Aircraft Substitution in INM	Aircraft Stage (per INM)	Aircraft Type (per INM)
DeHavilland DHC-6	British Aerospace Jet Stream 31	--	turboprop
DeHavilland DHC-7	--	3	turboprop
DeHavilland DHC-8	Aerospatiale ATR-42	3	turboprop
Shorts 330	--	3	turboprop
Saab SF340	Embraer 120	3	turboprop
British Aerospace HS748	Fokker-27, Aerospatiale ATR-72	2	turboprop
B757	--	3	commercial jet
Fokker-100	--	3	commercial jet
MD81	--	3	commercial jet
B727-200	--	1	commercial jet

as much land area within the 70 dB≤SEL≤75 dB and lower contour intervals on approach as the B727-200.

Table 5 compares land areas within SEL contour intervals produced by single departures of each of the 10 aircraft. Land areas within the 65 dB≤SEL≤ 70 dB contour interval for departures range from 6.5 square miles (for the Dash-7) to 81 square miles (for the B727-200).

The relationship between the land area within SEL contour intervals on approach and departure for the ten aircraft is illustrated in Figures 6, 7 and 8. Data points lying above the diagonal indicate greater land area within noise contours on departure than on approach. Points lying on or near the diagonal indicate similar amounts of land area within noise contours on departure and approach. Points lying below the diagonal indicate greater land area within noise contours on approach than on departure. Figures 6, 7 and 8 show this information for the 55 dB≤SEL≤ 60 dB, 65 dB≤SEL≤ 70 dB, and 75 dB≤SEL≤ 80 dB contour intervals, respectively. The land area within all contours on departure was greater than that on approach for all 10 aircraft. The land area produced by departures and approaches by the 727 far exceeded the land areas of all other aircraft operations.

Table 4 Land areas (in square miles) within 5 dB intervals of SEL of a single approach

Aircraft	55≤ SEL≤ 60 dB	60≤ SEL≤ 65 dB	65≤ SEL≤ 70 dB	70≤ SEL≤ 75 dB	75≤ SEL≤ 80 dB	80≤ SEL≤ 85 dB	SEL ≥ 85 dB
DHC6	34.1	27.3	23.7	13.5	5.7	2.2	1.1
DHC7	7.6	3.9	1.6	0.8	0.2	0.1	0
DHC8	1.9	1.4	0.8	0.3	0.1	0.1	0
SD330	36.1	28.0	22.9	9.1	2.9	0.7	0.3
SF340	27.6	24.2	12.5	4.5	1.6	0.5	0.2
HS748	20.1	12.4	6.9	3.7	2.0	1.2	1.3
B757	26.9	22.7	15.1	8.2	4.1	2.2	1.4
MD81	25.8	22.0	12.0	5.7	2.9	1.5	0.7
F-100	28.0	20.4	10.4	5.0	2.4	1.3	0.7
B727	37.6	29.9	25.0	18.5	11.7	7.4	5.8

Table 5 Land areas (in square miles) within 5 dB intervals of SEL of a single departure

Aircraft	55≤ SEL≤ 60 dB	60≤ SEL≤ 65 dB	65≤ SEL≤ 70 dB	70≤ SEL≤ 75 dB	75≤ SEL≤ 80 dB	80≤ SEL≤ 85 dB	SEL≥ 85 dB
DHC6	44.8	35.0	28.5	16.1	5.5	1.7	0.6
DHC7	38.6	17.1	6.5	2.1	0.9	0.4	0.2
DHC8	81.4	48.9	15.2	3.6	1.0	0.4	0.2
SD330	64.4	50.3	43.0	13.1	3.4	1.3	1.2
SF340	38.9	30.2	25.6	9.4	2.2	1.0	1.0
HS748	91.8	73.1	64.7	47.3	15.0	4.3	2.4
B757	38.4	29.8	21.0	9.0	4.0	1.8	1.7
MD81	60.7	45.6	35.8	29.5	21.5	8.9	6.3
F-100	75.3	50.6	41.0	21.8	8.9	3.6	2.5
B727	151.6	106 .0	81.0	65.0	56.0	40.0	31.0

Unlike the other commuter aircraft included in this study, land area within the 55 dB≤SEL≤ 60 dB contour on departure for the Dash-8 and HS748 aircraft were comparable in size to the land areas of the jet transports (as shown in Figure 6). The Dash-8 generated up to 40 times more land area within the 55 dB≤SEL≤ 60 dB contour interval on departure than on approach. The ratio of land area within the 55 dB≤SEL≤ 60 dB contour interval on departure and approach for the Dash-7 and the HS748 was about 5:1, for the 727 was 4:1, and for the MD81 and the F-100 was about 2:1. Ratios of land area within this contour for the other commuter aircraft were about 1:1.

Land areas within the 65 dB≤SEL≤ 70 dB contour interval on departure for the HS748 and the SD330 were comparable in size to the jet transports (as shown in Figure 7). Ratios of land area within the 65 dB≤ SEL≤ 70 dB contour interval on departure and approach were 15:1 for the Dash-8 and 9:1 for the HS748. Ratios for the other aircraft were similar to that observed within the 55 dB≤ SEL ≤ 60 dB contour interval.

Land areas within the 75 dB≤ SEL≤ 80 dB contour interval on departure for the HS748 were again comparable in size to the jet transports (as shown in Figure 8). All of the commuter aircraft other than the HS748 produced SEL contours encompassing very similar land areas within this contour on approach and departure. Ratios of land area on departure and approach within the 75 dB≤ SEL ≤ 80 dB contour interval for the HS748, the Dash-8, and the MD81 were 7:1, whereas ratios for the Dash-7, F-100, and 727 were about 4:1.

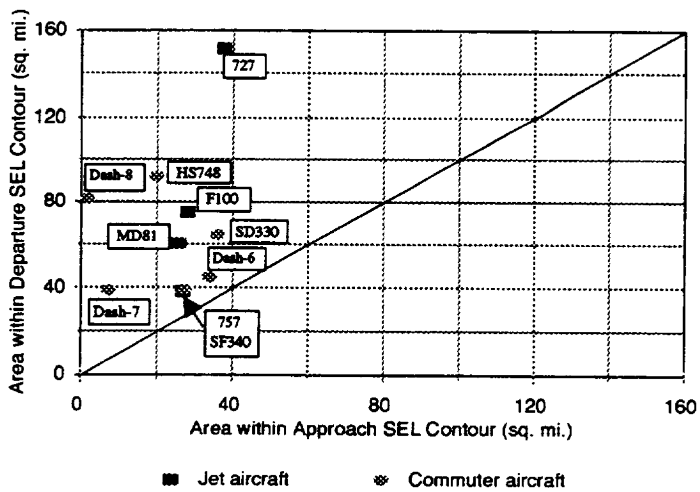


Figure 6 Comparison of land area within 55 dB≤SEL≤ 60 dB noise contour on departure and approach for 10 aircraft.

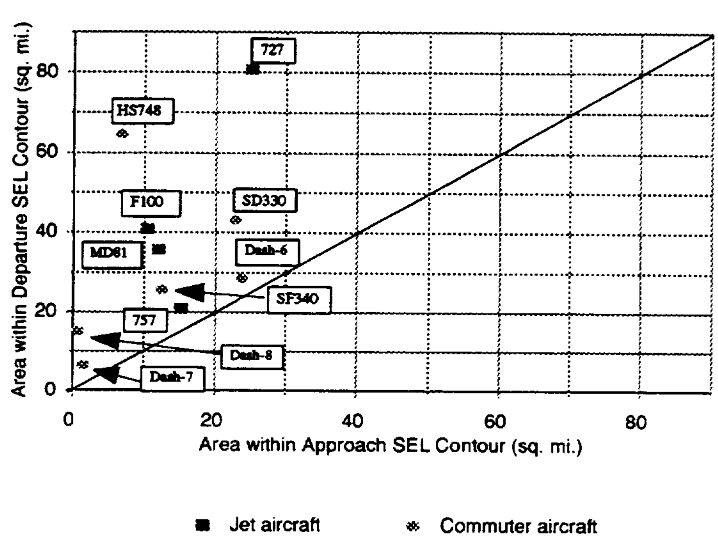


Figure 7 Comparison of land area within 65 dB≤SEL≤70 dB noise contour on departure and approach for 10 aircraft.

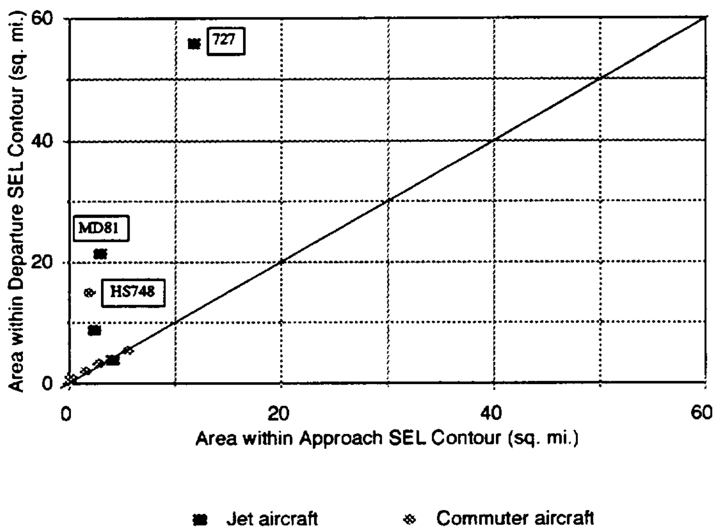


Figure 8 Comparison of land area within 75 dB≤ SEL≤ 80 dB noise contour on departure and approach for 10 aircraft.

3.5 SUMMARY OF POTENTIAL CONSEQUENCES OF INCREASED COMMUTER FLIGHT OPERATIONS

Table 6 summarizes factors affecting the acoustic effects of increases in commuter aircraft operations at airports and their potential consequences for community response. Non-acoustic factors such as those noted by Fields (1993) may be responsible in some circumstances for adverse community response to commuter aircraft operations as well. These include type-specific fear of crashes, attitudes of misfeasance and malfeasance toward airport proprietors and commuter operators, concerns about the necessity for increased airport use and the likelihood of future airport expansion.

Table 6 Relationship between aspects of increased commuter aircraft operations and possible effects on community response.

ASPECT OF INCREASED COMMUTER OPERATIONS	POTENTIAL EFFECTS OF INCREASED COMMUTER OPERATIONS IN AIRPORT NEIGHBORHOODS
Nature of propulsion noise	Increased variability in character and identifiability of aircraft overflight and ground runup noise at airports with predominantly jet fleets
Flight frequency	Greater numbers and temporal density of overflights, correspondingly fewer intermediate periods free of audible aircraft noise
Individual overflight duration	Increases in time that aircraft overflights are audible and total noise duration
Time above threshold	May increase total time above lower threshold values
Single event levels	Mean overflight levels for fleet as a whole may decline
Integrated noise levels	Minor effect on departure levels; greater effect possible on approach levels, particularly as Stage II aircraft are phased out and commuter aircraft increase in size and number
Flight paths	Potential increases in newly exposed populations (dependent on runway orientation and utilization, surrounding land uses, and approach and departure routings)
Ground runups	Potential changes in character and increased duration of taxiway queuing noise
Time of operations	Adverse response to bunching of flight times possible at hub airports

4 AIRPORT AND COMMUNITY PERSPECTIVES ON "THE COMMUTER NOISE PROBLEM"

Discussions about local experiences with commuter aircraft noise were held with airport, airline, and community personnel involved in planning, development, operations and noise assessment at a range of airports. The proportion of commuter operations at the selected airports encompassed the range (from about 25% to about 60%) observed at most large airports. The following subsections summarize these discussions. Details of commuter operations at each airport may be found in Appendix A.

4.1 RECOGNITION OF PROBLEM

None of the airport personnel interviewed believed that commuter aircraft operations created community response problems as great as those associated with operations of larger jet aircraft. The basis of this belief was informal in most cases, however, and was based primarily on the rarity of specific mentions of commuter aircraft in noise complaints. By itself, however, complaint experience does not provide a firm basis for reaching conclusions about potential commuter aircraft noise problems for a variety of reasons:

- Many complaints are difficult to associate with individual aircraft operations, both by the complainant and by airport representatives;
- Times of occurrence of noise events producing complaints are often uncertain;
- Many complainants are unaware of the types of aircraft about which they complain;
- Flight track matching is sometimes uncertain or impossible on a *post hoc* basis;
- Many complaints (*e.g.*, "aircraft off course/too low") do not specifically concern noise exposure; and
- Small numbers of individuals often account for large percentages of total complaints.

All of the airport personnel interviewed appreciated the relative insensitivity of DNL contours to noise exposure created by commuter aircraft operations at airports with mixed jet and commuter activity. Since most interpreted community response issues in strict accordance with FAA land use compatibility guidelines, few had independently considered the possibility that commuter aircraft operations might contribute in other ways to airport noise problems.

4.2 SEGREGATION OF COMMUTER AND JET TRAFFIC

Airports varied widely in air traffic control practices with respect to the treatment of commuter aircraft. Some airports constrained commuter operations to particular runways and flight tracks to enhance runway capacity, while others made no effort to maintain separate jet and commuter approach and departure traffic streams. All airport personnel interviewed indicated that in practice, flight tracks of commuter aircraft were much more variable than those of jets. Variability in aircraft flight tracks in general and in commuter flight tracks in particular was generally believed to increase under VFR conditions and as air traffic controller workload and airport capacity increased.

4.3 RELATIVE LEVELS OF COMMUTER AND JET AIRCRAFT OVERFLIGHTS

Several airport personnel observed that in actual operating experience, noise levels created by commuter aircraft did not differ greatly from those of the quieter Stage III aircraft in certain flight regimes. As described in Appendix A, Section A.3.6, at least one airport noted that commuter aircraft were routinely among the noisier events at some noise monitoring points. Both of these observations tend to suggest that at airports lacking significant numbers of Stage II operations, the "commuter noise problem" may not differ from the standard aircraft noise problem in some neighborhoods. This in turn suggests that the "commuter noise problem" might become more salient as the deadline for phasing out Stage II operations approaches in the year 2000.

4.4 DIAGNOSTIC SCREENING PROCEDURE

Factors that may favor development of adverse community response to commuter aircraft noise that may seem disproportionate to its integrated exposure at a particular airport include the following:

- Fleet composed primarily of Stage III jet aircraft
- Residential neighborhoods exposed primarily to approach operations
- Residential development to the side of the extended centerline of the runway from which most large transport aircraft operate, near departure taxiway queues, or near ends of runways used primarily for commuter operations
- Recent introduction or increase in commuter aircraft operations

Figure 9 is a schematic of a set of questions that may aid in identifying potential commuter aircraft noise problems at specific airports. A brief discussion of the decision points is provided below.

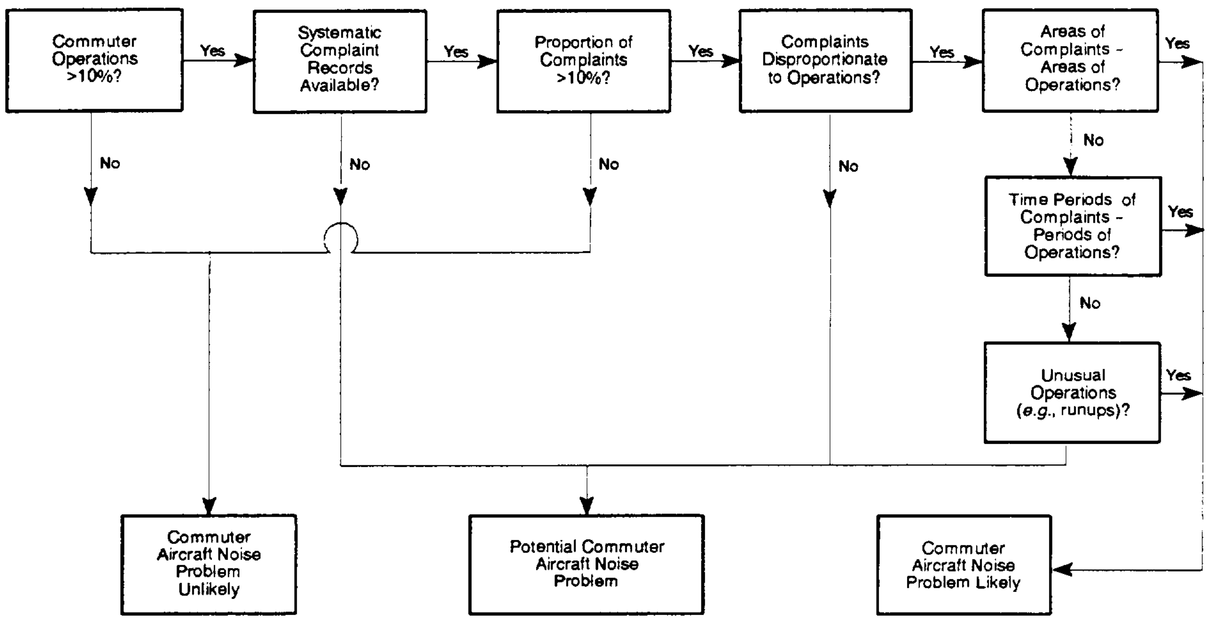


Figure 9 Commuter aircraft noise problem diagnostic issues.

4.4.1 Have commuter aircraft operations at the airport constituted at least 10% of total operations at the airport over the past year?

An airport cannot as a matter of definition have a "commuter aircraft noise" problem of the disproportionate sort addressed in this report if it lacks jet operations. However, a commuter aircraft noise problem at an airport with predominantly jet operations is unlikely to be recognizable as such until commuter operations exceed at least 10% of total airport operations.

4.4.2 Has the airport proprietor maintained detailed, systematic, and retrievable records of complaints, flight tracks, and numbers and types of aircraft operations for at least a year?

Although commuter aircraft operations may contribute disproportionately to an airport's noise problem, there may be no reliable means to detect it from archival information unless such information is systematically maintained. A social survey to assess the prevalence of annoyance with commuter aircraft overflights may be required to produce an empirical diagnosis in such cases.

4.4.3 Does the proportion of complaints about commuter aircraft operations exceed the proportion of commuter aircraft operations at the airport over the last year?

If the proportion of complaints about commuter operations exceeds the proportion of commuter operations in areas overflown by such aircraft, a commuter aircraft noise problem in the sense addressed in this report is likely.

4.4.3.1 Do the geographic areas of complaint roughly correspond to specific geographic areas of commuter operations?

A commuter aircraft problem within a small, circumscribed area may go unnoticed, particularly at a large airport with multiple runways.

4.4.3.2 Do the time periods of complaints roughly correspond to specific time periods of commuter operations?

Cyclic bunching of commuter operations providing synchronized feed traffic to longer haul jet operations may create problems at airports dominated by single major carriers.

4.4.3.3 Have atypical types of commuter operations (e.g., runups) or numbers of commuter operations occurred over the past year?

A transitory problem related to historically atypical or recently increased flight frequency may occur, irrespective of noise level.

5 POTENTIAL EXPLANATIONS FOR "THE COMMUTER AIRCRAFT NOISE PROBLEM"

Several hypotheses may be identified that might in principle account for commuter aircraft noise problems. One class of hypotheses focuses on the annoyance of individual overflights, without concern for long term annoyance associated with the cumulative exposure of multiple overflights. A second class of hypotheses addresses the latter issue. This second class of hypotheses either implicitly or explicitly challenges aspects of the conventional approach to predicting long term, noise-induced aircraft noise annoyance. Appendix B discusses the distinction between the two classes of hypotheses in greater detail.

5.1 HYPOTHESES CONCERNING ANNOYANCE OF INDIVIDUAL COMMUTER OPERATIONS

5.1.1 Explanations Related to Absolute Level, Spectral Composition, and Adequacy of Frequency Weighting Network

Although commuter aircraft are much quieter than larger Stage II jets, differences between SEL values for overflights of commuter aircraft and the quieter Stage III jets may be considerably smaller in some airport environs. As suggested in Table 7 and in Section 3.4, some commuter aircraft can be nearly as noisy as some jets in terms of SEL, in part because of the shorter slant ranges to neighborhoods over which they may fly.

Apart from the lower levels of commuter aircraft noise emissions, perhaps the most obvious acoustic difference with regard to larger jet transports is in the spectral character of commuter aircraft noise signatures. As noted in Section 3.3, propellers of commuter aircraft create prominent,

Table 7 Comparison of approximate single event noise levels created by selected commuter and larger jet transport aircraft at FAR Part 36 approach and departure measurement points at full gross weight.

	TYPICAL COMMUTER (DHC-7)	COMMON STAGE II (B-727-200)	COMMON STAGE III (B-757-200)	COMMON STAGE III (MD-80)
Approach (2000 m from runway threshold)	92 EPNdB	102 EPNdB	99 EPNdB	93 EPNdB
Departure (6500 m from brake release)	80 EPNdB	100 EPNdB	87 EPNdB	91 EPNdB

harmonically related tones that sound qualitatively different from either the tones produced by straight turbojet engines (such as compressor tones of the JT-3D engine that the PNL tone correction algorithm was originally designed to detect), or from the buzz tones of high bypass ratio turbofan engines.

Many residents of airport neighborhoods who have no memory of the noise signatures of commercial transport aircraft of the 1950s and early 1960s may well regard the tonal components of commuter aircraft noise as more disturbing than the broadband noise of Stage III aircraft. If so, then revised tone correction procedures for PNL or other measurement scales may be required to more fully account for this annoyance.

5.1.2 Explanations Related to Adequacy of Modeling of Noise Exposure

Several aspects of the modeling of commuter aircraft noise emissions are less precise than that of larger jet transports. For example, although the Official Airline Guide indicates that more than two dozen fixed wing turboprop aircraft types are in scheduled revenue service, the INM database accounts for the noise emissions of these aircraft largely through substitution. Thus, INM models operations conducted by ATR-42 and Dornier 328 aircraft as though they were flown by a DHC-8; operations flown by BAe J31, Dornier 228, and Swearingen Metro aircraft are modeled as though they were flown by a DHC-6; and so forth. Although these substitutions may not be unreasonable with respect to engine noise, they represent cruder approximations to aircraft performance characteristics (propeller configurations and speeds, climb rates, *etc.*) than are tolerated among larger jet transports.

Another source of annoyance of commuter operations identified during conversations about community perspectives was a form of ground runup noise that INM does not address. During peak commuter operation periods (often cyclic throughout the day, and time-shifted by about 45 minutes from jet operations), commuter aircraft departure queues may form on taxiways near runway ends. At large airports, recurring queues of five to ten commuter aircraft are not unusual at some times of day. Noise from high speed propellers among these queued aircraft can produce highly audible and readily identifiable tonal sounds in nearby residential areas.

Differences in air traffic control treatment of commuter and other transport aircraft create another potential source of mis-modeling of commuter aircraft noise. When possible, controllers often segregate commuter and larger transport traffic streams, as by restricting operations of different aircraft types to separate runways. When weather, airport configuration, periods of high runway demand, or even specific pilot request complicate segregation of traffic by aircraft type, controllers will often seek to minimize the effort required to maintain lateral separation between aircraft flying at different speeds by turning commuter aircraft into or out of mixed traffic streams as quickly as possible.

For example, it is standard operating practice at many airports to segregate commuter and larger aircraft traffic by runway when multiple runways are available. Commuter aircraft will often use shorter, displaced threshold, and/or cross-wind runways in good weather, while larger jet transports will operate on a longer main runway. When conditions preclude such segregation of traffic by aircraft type, controllers will often turn commuter aircraft out of a mixed departure stream operating from a single runway as soon as practicable after departure. This practice reduces the controller's workload by making available more airspace for maintaining lateral separation between successive departing aircraft, while increasing runway capacity by decreasing the headway between takeoff runs.

Although commuter aircraft are typically slower than larger jet transports on approach and departure tracks, they are generally more maneuverable, and hence permit controllers certain options for airspace management that are unavailable for larger aircraft. Whereas larger aircraft fly stabilized approaches for several miles before landing, commuter aircraft are sometimes able to approach runway thresholds from a greater variety of flight paths. The net effect is that ground tracks of commuter aircraft overflights may be more dispersed than those of other aircraft.

In fact, under VFR conditions during periods when airports are not operating near peak capacity, flight paths of commuter aircraft may be unconstrained by factors other than aircraft performance and pilot technique. It is therefore possible that noise exposure produced by commuter operations may be mis-modeled in INM calculations to a greater extent than that produced by jet operations, especially when small numbers of flight tracks and standard dispersal assumptions are used to represent actual flight tracks. If these conditions obtain a good proportion of the time (for example, during prolonged periods of good weather at airports with surplus runway capacity), noise contours may not provide as reliable a guide to noise exposure produced by commuter operations as to exposure produced by jet operations.

5.1.3 Explanations Related to Novelty of Noise Exposure

Perhaps the simplest potential explanation for seemingly disproportionate community response to commuter aircraft noise exposure is that increased commuter operations may produce overflights of neighborhoods not previously directly or frequently overflown. For reasons noted above, commuter operations may be distributed geographically in areas (such as sideline neighborhoods) not historically exposed to overflights.

5.1.4 Explanations Related to Nonacoustic Factors

Commuter aircraft typically fly lower and slower than larger jet transports. This implies that their departure flight paths may overfly some residences at lower altitudes, and that their overflight durations may be noticeably longer. Furthermore, commuter aircraft, which are more maneuverable than larger transports, may bank at greater angles and fly on more irregular courses than larger jet transports. Residents of airport neighborhoods unfamiliar with the relative sizes, flight speeds, and noise levels of commuter and larger jet transports may believe that overflights of their homes by commuter aircraft are somehow more threatening or dangerous than those by larger aircraft at greater altitudes. A number of recent and well-publicized accidents involving commuter aircraft may reinforce such beliefs. Fields (1993) considers the relationship between fear of crashes and annoyance to be among the more reliable findings in attitudinal research concerning community response to aircraft operations.

5.2 HYPOTHESES FOCUSING ON INTEGRATION OF THE EFFECTS OF EXPOSURE TO NOISE FROM MULTIPLE OVERFLIGHTS

5.2.1 Explanations Related to Annoyance Integration

The standard approach to predicting the prevalence of long term annoyance in communities from a time-weighted measure of average sound pressure levels (DNL) relies upon the equal energy hypothesis as an explanatory rationale. All integration of the effects of multiple noise intrusions is conducted on the abscissa, rather than the ordinate, of a dosage-response relationship. This is not the only possible approach to predicting the long term effects of multiple noise exposures, nor necessarily the most appropriate for the case of present interest: hundreds or more audible aircraft noise events, produced by a heterogeneous fleet, as depicted in Figure 1. Appendix B provides additional detail on an alternate approach to modeling the annoyance of commuter aircraft overflights.

5.2.2 Explanations Related to Duration of Commuter Aircraft Noise

Commuter aircraft do not fly as fast as jets on either approach or departure, nor do they climb as rapidly as jets on departure. Since commuter aircraft operate at shorter slant ranges from residential neighborhoods for longer periods of time, commuter aircraft overflights may be audible in airport communities for greater lengths of time than larger jet transports. Propeller tones from commuter aircraft may also be more audible in urban background noise than broadband jet noise. If the equal energy hypothesis (*cf.* Appendix B) is accepted at face value, this difference in the duration of noise exposure produced by commuter and jet aircraft is more than compensated by the lower level of noise exposure produced by commuter aircraft. Some contraindications are noted in the following subsections.

5.2.2.1 Lack of correlation between DNL and time above threshold metrics in airport neighborhoods

Most algebraically describable environmental noise metrics that are sensitive to the levels, numbers, and durations of noise events are highly correlated with one another. Total time above a threshold value, however, is defined by a counting operation, and does not necessarily correlate well with integrated exposure metrics such as DNL. This lack of correlation is readily apparent from a comparison of Figure10 with Figures 11, 12, and 13.

Figure 10 shows a clear decrease in integrated noise level in the vicinity of a major civil airport as the noisiest Stage II aircraft have been replaced by quieter aircraft over the last seven years. Figure 11 shows a similar trend (as directly measured by the airport's noise monitoring system) in the time that aircraft produced noise in excess of 85 dB. Figure 12, showing the time that aircraft have produced noise levels in excess of 75 dB over the same time period, shows a less pronounced trend, with some flattening of the relationship in later years. Figure 13, showing the time that aircraft have produced noise levels in excess of 65 dB, shows quite a different trend. Since substitution of quieter for noisier aircraft does not affect time in excess of this lower threshold value, and since total numbers of operations at this airport have increased over the time period of interest, total time above 65 dB has actually increased in recent years. Growth in commuter aircraft operations may account for a good deal of such trends at some airports.

A direct comparison between the time above metric and DNL is of some interest. DNL decreases by 3.5 dB over the time period from 1989 to 1995 due in part to increases in the percentage of quieter, modern aircraft (Stage 3). The amount of time aircraft noise levels are in excess of a threshold of 85 dB decreases from 10.8 minutes to 5.7 minutes over the period of 1989 to 1995. The amount of time aircraft noise levels are in excess of a threshold of 75 dB decreases from 54 minutes to 39 minutes, and deceases from 182 minutes to 170 minutes for a threshold of 65 dB. In decibel (10 log ratio) terms, these differences in time above threshold levels translate to decreases of 2.8 dB at the 85 dB threshold from 1989 to 1995, to decreases of 1.4 dB at the 75 dB threshold, and to decreases of 0.3 dB at the 65 dB threshold. These decreases in time above the threshold levels translate to decibels levels at least 1 dB less than the 3.5 dB decrease for the DNL metric over the period from 1989 to 1995. Thus, substitution of quieter for nosier aircraft may not yield as great a benefit in terms of decreases in time above metric compared to an equal energy metric such as DNL.

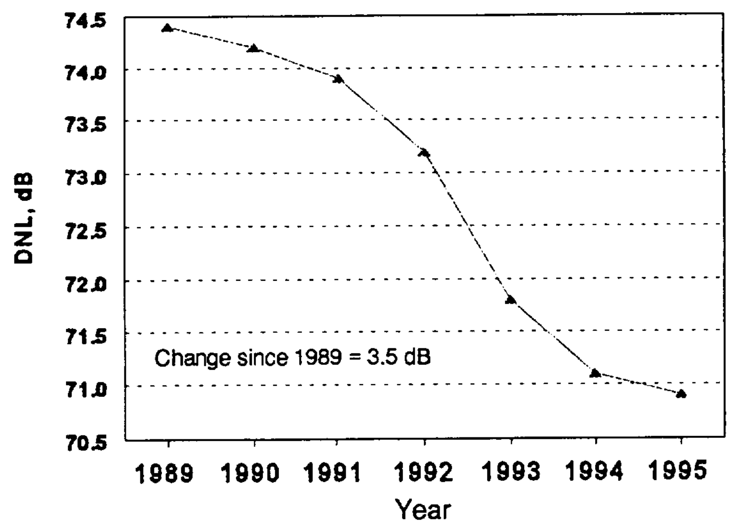


Figure 10 Annual DNL averaged for 11 noise monitoring points in the vicinity of a major civil airport over the last seven years.

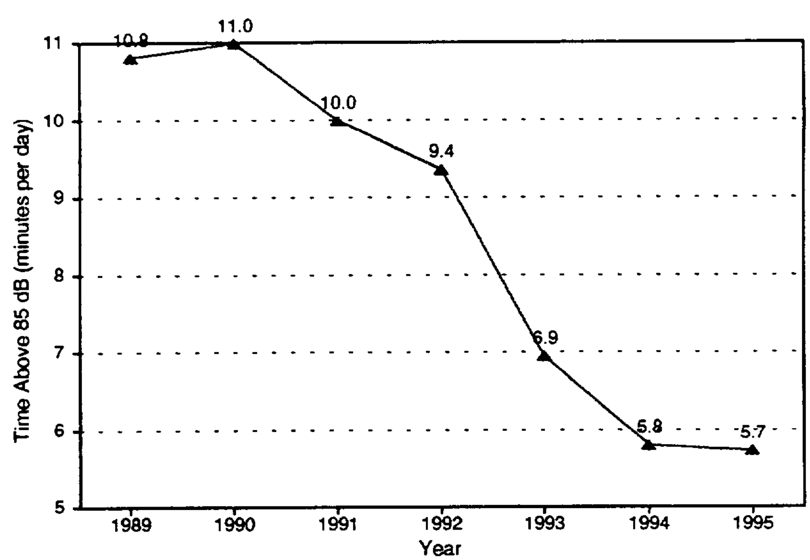


Figure 11 Average daily time above 85 dB in the same setting described in Figure 10.

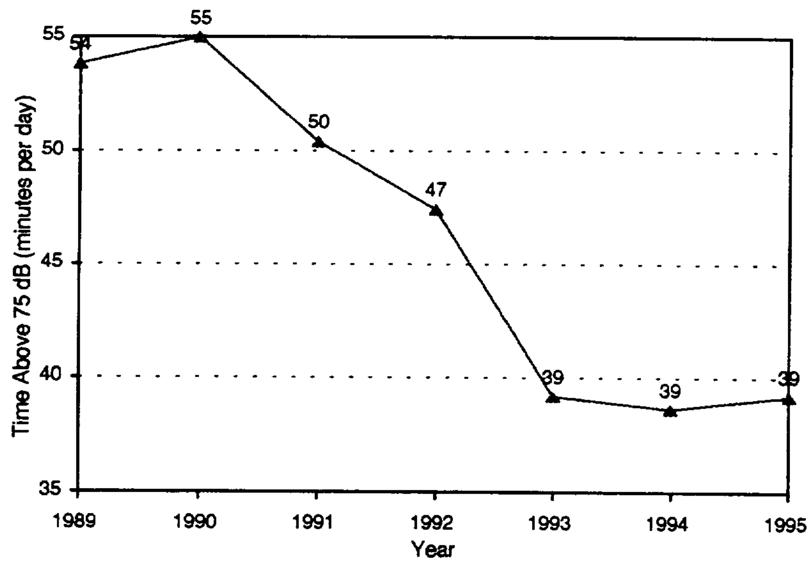


Figure 12 Average daily time above 75 dB in the same setting described in Figure 10.

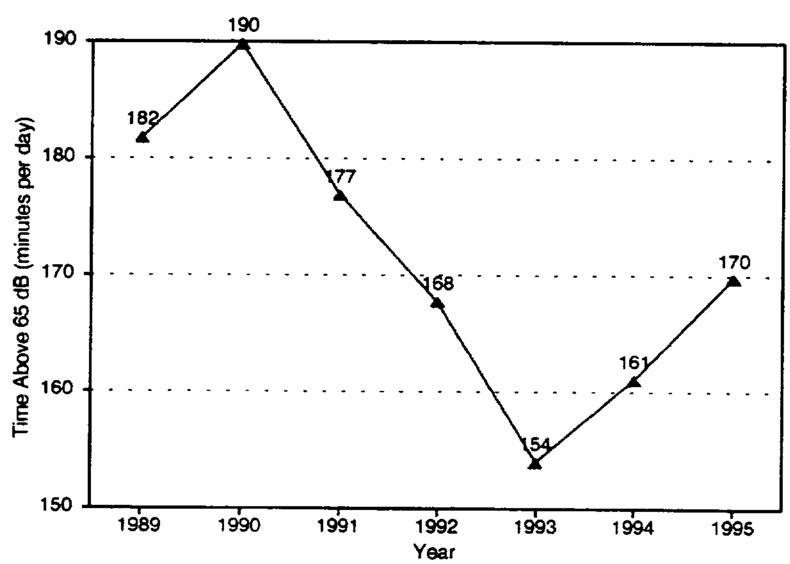


Figure 13 Average daily time above 65 dB in the same setting described in Figure 10.

5.2.2.2 *Analysis of effects of alternate fleet mixes on duration of aircraft noise exposure*

INM 5.0 was exercised to compare noise durations in excess of various threshold levels produced by hypothetical fleets containing various percentages of Stage III jets and commuter aircraft. Five cases were investigated in which various numbers of operations of B-757 aircraft were replaced with operations by DHC-7 aircraft, while maintaining a constant 300 operations per day. Time above threshold values was summed from nine measurement points located 2.5 to 10 miles from the takeoff measurement point on the extended centerline and up to one-half mile to the side of a single hypothetical runway.[2]

The cases investigated were:

(1) 300 daily operations of a fleet consisting of Stage III jet aircraft only
(2) 240 daily operations of jets + 60 commuters (80% jet, 20% commuter)
(3) 210 daily operations of jets + 90 commuters (70% jet, 30% commuter)
(4) 180 daily operations of jets + 120 commuters (60% jet, 40% commuter
(5) 150 daily operations of jets + 150 commuters (50% jet, 50% commuter)

Note that the total numbers of operations remain constant in all cases, unlike the real-world situation discussed in the previous subsection, in which the operational changes included both substitution of quieter for noisier aircraft and annual increases in total operations. Note also that no claim is made that short haul commuter aircraft are likely to displace long haul aircraft service in the same markets.

Table 8 shows the total number of minutes during which the exclusively jet fleet produced noise levels exceeding five threshold values on departure and on approach. The total number of minutes that the noise levels produced by this fleet exceeded threshold levels was greater on approach than on departure for all threshold levels greater than 50 dB.

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[2] Since the "time above" metric scales linearly with numbers of operations, the absolute numbers of minutes in excess of the various thresholds are of less interest than the trends that comparisons of them reveal.

Table 8 Number of minutes that a hypothetical, all Stage III jet fleet produced noise levels exceeding threshold values.

Threshold Level	Departure	Approach
50 dB	989 min	917 min
55	534	678
60	327	495
65	182	353
70	76	234

Figure 14 displays distributions of the reductions in time above noise thresholds for departure operations associated with various substitutions of commuter aircraft for Stage III jets with respect to the base case of an all-jet fleet. Figure 15 presents similar information for approaches. As expected, the percent reduction in time above a threshold level increases with increased substitution of quieter aircraft for both departure and approach operations. Although the shapes of the distributions are similar for the various threshold levels for both departure and approach operations, substitution of commuter aircraft for Stage III aircraft does not yield a numerically equivalent reduction in time above threshold levels.

For instance, substituting commuter aircraft for 30% of the jets produced a comparable reduction in the amount of time noise levels exceeded threshold levels on departure at threshold levels of 65 dB and 70 dB. No such numerically equivalent reduction in time above was observed for any of the approach operations.

Figures 16 to 20 permit direct comparisons of the consequences of substituting increasing numbers of commuter aircraft for jets on the percent reduction in time that noise levels exceed threshold levels. Approach operations tended to exceed departure operations in reductions in time above thresholds of 50 and 55 dB (as in Figures 16 and 17) for all of the fleets considered. Approach and departure operations are virtually identical in the percent reductions in time that noise levels exceed a threshold of 60 dB (as in Figure 18) for all substitution rates. Figures 19 and 20 show that departure operations tended to exceed approach operations in reductions in time above thresholds of 65 and 70 dB across fleets. Although percent reductions in time above values vary with threshold level, the absolute time above values for approaches are usually greater than for departures in this example.

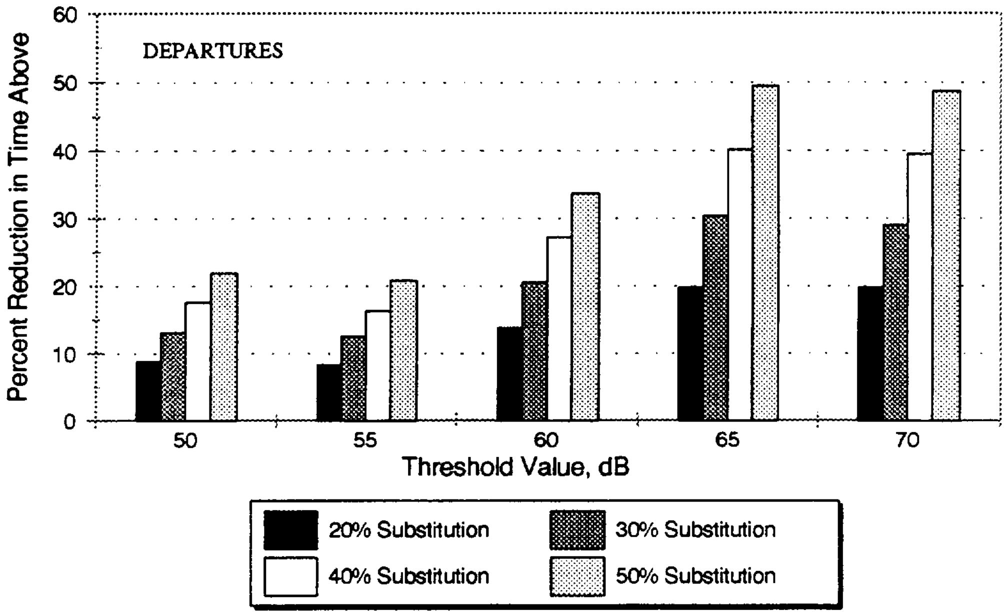

Figure 14 Distributions of reductions in time (re base case of 300 B757 operations) in excess of various threshold values for departure operations by alternate fleets.

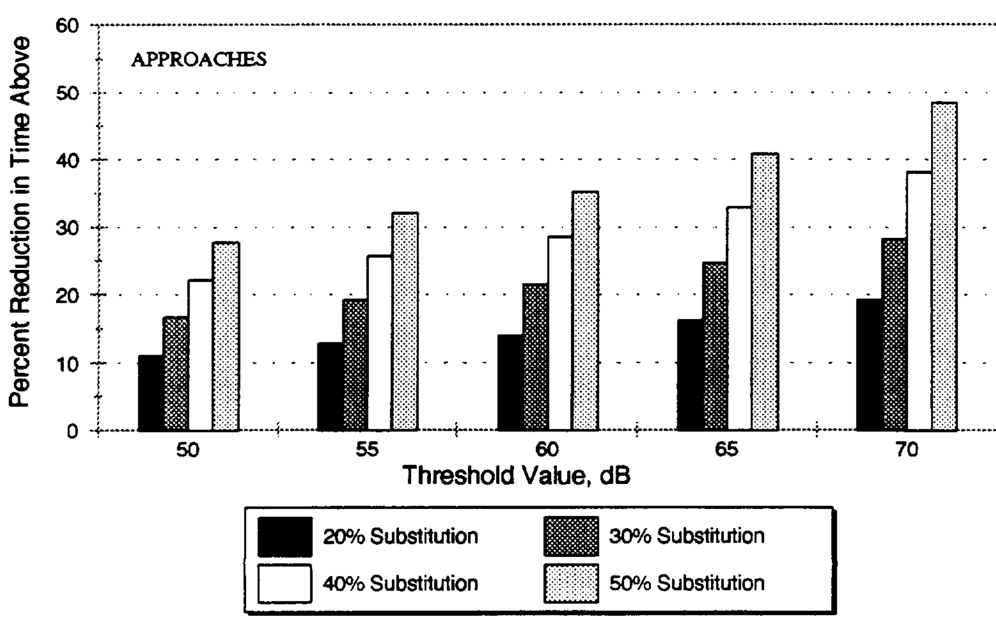

Figure 15 Distributions of reductions in time (re base case of 300 B757 operations) in excess of various threshold values for approach operations by alternate fleets.

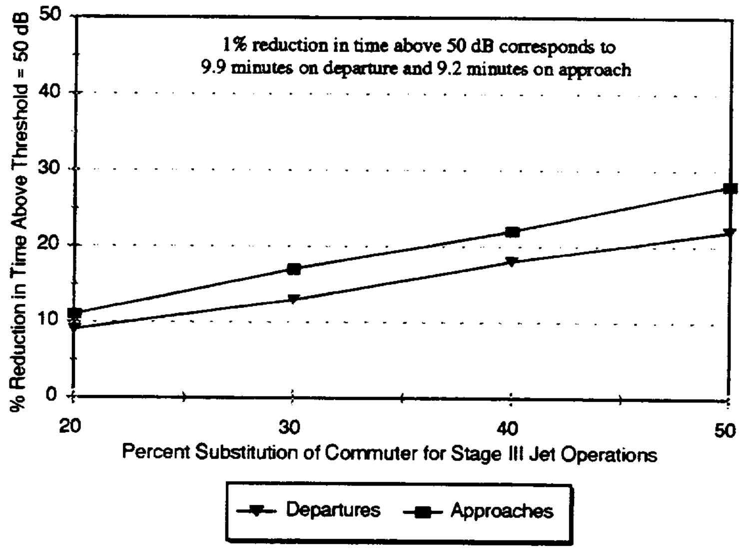

Figure 16 Comparison of reductions in time above 50 dB for approaches and departures of alternate fleets.

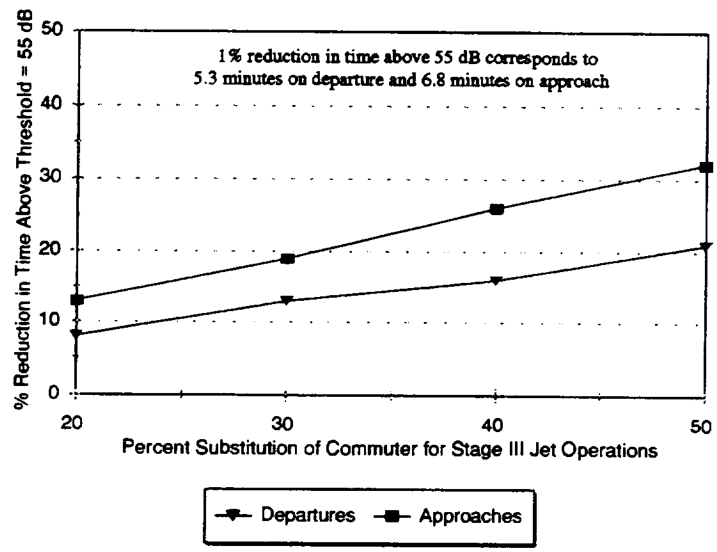

Figure 17 Comparison of reductions in time above 55 dB for approaches and departures of alternate fleets.

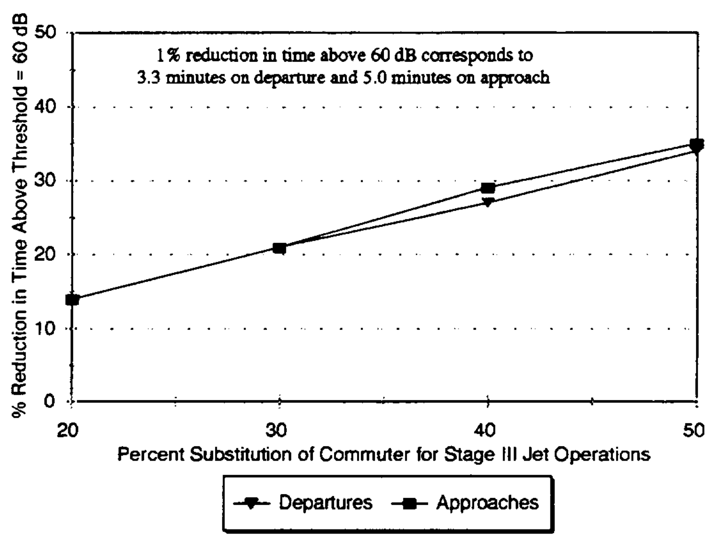

Figure 18 Comparison of reductions in time above 60 dB for approaches and departures of alternate fleets.

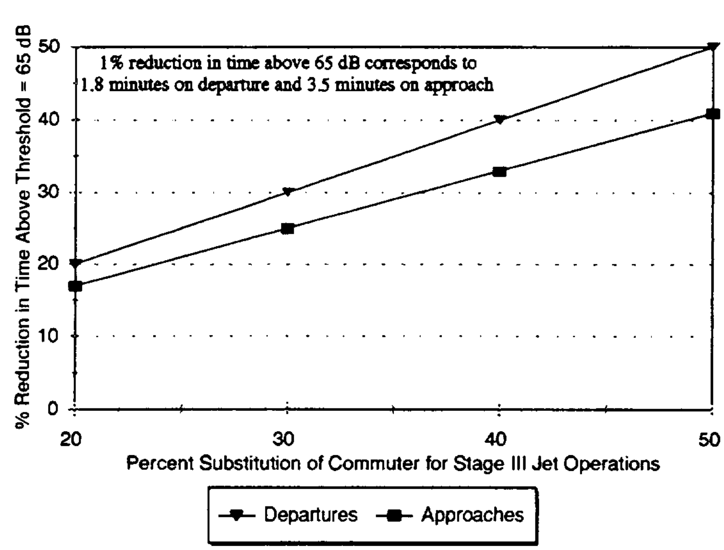

Figure 19 Comparison of reductions in time above 65 dB for approaches and departures of alternate fleets.

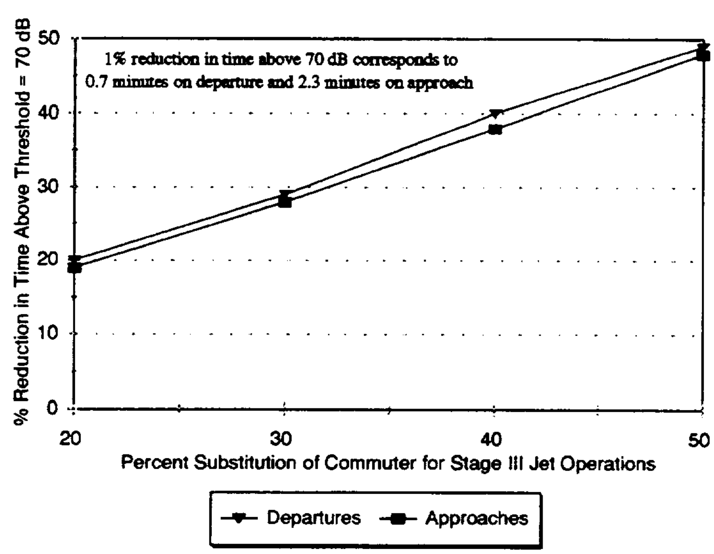

Figure 20 Comparison of reductions in time above 70 dB for approaches and departures of alternate fleets.

These analyses suggest that the benefits to be gained in terms of reduced time above thresholds from substitutions of commuter for modern jet transports differ with threshold level, as observed for the real-world situation as shown in Figures 15-17.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Passenger enplanements on commuter aircraft in the United States have grown rapidly over the last decade, and are very likely to continue to grow at a rate faster than enplanements on larger jet transports in the near term. The resulting increases in commuter aircraft traffic at many airports, as well as related trends in the number of routes and aircraft sizes, have increased the heterogeneity of the commercial air fleet and the character of its noise emissions at many airports.

Several aspects of the noise emissions of commuter aircraft and their manner of operation may engender annoyance disproportionate to the integrated noise level produced by such operations. These include overflight of areas not generally overflown by larger jet transports, overflights at lower altitudes and slower flight speeds, greater numbers of overflights, greater temporal density of overflights, greater duration of audible aircraft noise, *etc.* To the extent that a commuter aircraft noise problem exists at all on a nationwide basis, its origins could well differ from one airport to the next for any of these reasons.

With isolated exceptions, community response to commuter aircraft operations is not yet viewed by airports with as much concern as that associated with operations of larger jet transports. However, few airports have had either the resources or the incentives to look beyond recent complaint experience. Since complaints are not a reliable indication of the prevalence of aircraft noise annoyance, the absence of complaints about commuter operations does not necessarily guarantee that such operations have no effect on the overall acceptability of aircraft operations in airport communities.

Furthermore, like commuter operations themselves, the commuter aircraft noise problem may be evolving rapidly, and may change substantially by the end of the century. By the time that Stage II aircraft have been completely withdrawn from service, the proportion of total operations conducted by commuter aircraft at many airports will have increased, and commuter aircraft will have grown in size and absolute numbers of operations. What is seen today as a "commuter aircraft noise" problem has a potential for becoming the standard aircraft noise problem in the next century.

6.2 RECOMMENDATIONS

Several measures should be taken if the commuter aircraft noise problem is to be explored in greater detail.

(1) A laboratory study of the relative annoyance of propeller and Stage III jet aircraft noise emissions is advisable to confirm the adequacy of SEL and Perceived Noise Level (the fundamental scale of measurement for FAR Part 36 noise certification) in the modern airport noise environment.

(2) Focused laboratory and/or field studies of the annoyance produced by taxiway queues of commuter aircraft may be helpful as well.

(3) A social survey of annoyance associated with commuter aircraft overflights and ground runups in residential areas exposed to commuter aircraft noise to a greater extent than noise from larger jets should be undertaken. Site selection in such a study should be based on a detailed analysis of flight track density maps for commuter and other aircraft.

(4) A quantitative analytic study of plausible alternatives to noise exposure integration as an approach to predicting long term annoyance may provide a firmer underpinning for environmental assessments of the impacts of increased commuter aircraft operations.

(5) The INM database of commuter aircraft noise emissions should be updated and expanded so that fewer substitutions are required in modeling noise exposure in areas overflown by commuter aircraft.

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9 GLOSSARY

Abbreviations and mathematical symbols used in this report follow the practices of *American National Standard S1.4-1944 Acoustical Terminology*. Abbreviations are usually a sequence of capital letters used in text to shorten the reference to frequently used acoustical terms. Mathematical symbols are the letter symbols used for these terms in equations. Thus, sound exposure level is abbreviated as SEL, while its mathematical symbol is L_{AE}. With no additional modifier, the words "sound exposure level" and its abbreviation "SEL" are usually understood to be A-weighted sound exposure level. In this report, there is such frequent reference to both A-weighted and C-weighted sound exposure levels that the abbreviations ASEL and CSEL are used throughout to minimize confusion.

day average sound level: Time-averaged sound level between 0700 and 2200 hours. Unit, decibel (dB); abbreviation, DL; symbol, L_d.

Note: Day average sound level in decibels is related to the corresponding day sound exposure level, L_{Ed}, according to:

$$L_d = L_{Ed} - 10 \log (54000/1)$$

where 54,000 is the number of seconds in a 15-hour day.

day-night average sound level: Twenty-four hour average sound level for a given day, after addition of 10 decibels to levels from 0000 to 0700 hours and from 2200 (10 p.m.) to 2400 hours. Unit, decibel (dB); abbreviation, DNL; symbol, L_{dn}.

Note: Day-night average sound level in decibels is related to the corresponding day-night sound exposure level, L_{Edn}, according to:

$$L_{dn} = L_{Edn} - 10 \log (86400/1)$$

where 86,400 is the number of seconds in a 24-hour day. A-frequency weighting is understood, unless another frequency weighting is specified explicitly.

instantaneous sound pressure: Total instantaneous pressure at a point in a medium minus the static pressure at that point. Unit, pascal (Pa); symbol, p.

loudness level: Of a sound, the median sound pressure level, in a specified number of trials, of a free progressive wave having a frequency of 1,000 Hz that is judged equally loud as the unknown sound when presented to listeners with normal hearing who are facing the source. Unit, phon.

NOTE – The manner of listening to the unknown sound must be specified.

maximum sound level; maximum frequency-weighted sound pressure level: Greatest fast (125 ms) A-weighted sound level within a stated time interval. Alternatively, slow (1,000 ms) time-weighting and C-frequency-weighting may be specified. Unit, decibel (dB); abbreviation, MXFA; symbol, L_{AFmx} (or C and S).

night average sound level: Time-averaged sound level between 0000 and 0700 hours and 2200 and 2400 hours. Unit, decibel (dB); abbreviation, NL; symbol, L_n.

Note: Night average sound level in decibels is related to the corresponding night sound exposure level, L_{En}, according to:

$$L_n = L_{En} - 10 \log(32400/1)$$

where 32,400 is the number of seconds in a 9-hour night.

one-hour average sound level: Time-averaged sound level during a time period of one hour. Unit, decibel (dB); abbreviation, 1HL; symbol, L_{1h}.

Note: One-hour average sound level in decibels is related to the corresponding one-hour sound exposure level, L_{E1h}, according to:

$$L_{1h} = L_{E1h} - 10 \log(3600/1)$$

where 3,600 is the number of seconds in one hour, 1 s is the reference duration for sound exposure, and sound exposure E is in pascal-squared seconds.

peak sound pressure: Greatest absolute instantaneous sound pressure within a specified time interval. Unit, pascal (Pa).

Note: Peak sound pressure may be measured with a standard frequency weighting.

peak sound pressure level; peak frequency-weighted sound pressure level: Level of peak sound pressure with stated frequency weighting, within a stated time interval. Unit, decibel (dB); example abbreviation, PKA; symbol, L_{Apk}.

perceived noise level: Frequency-weighted sound pressure level obtained by a stated procedure that combines the sound pressure levels in the 24 one-third octave bands with midband frequencies from 50 Hz to 10 kHz. Unit, decibel (dB); abbreviation, PNL; symbol, L_{PN}.

NOTE – Procedures for computing perceived noise level are stated in Federal Aviation Regulation Part 36, *Noise Standards: Aircraft Type and Airworthiness Certification*, Appendix B, and in International Civil Aviation Organization Annex 16, Volume 1, *Aircraft Noise*, Third Edition, July 1993.

sound exposure: Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit, pascal-squared second; symbol, E.

Note: If frequency weighting is not specified, A-frequency weighting is understood. If other than A-frequency weighting is used, such as C-frequency weighting, an appropriate subscript should be added to the symbol; e.g., E_C.

Duration of integration is implicitly included in the time integral and need not be reported explicitly. For the sound exposure measured over a specified time interval such as one hour, a 15-hour day, or a 9-hour night, the duration should be indicated by the abbreviation or letter symbol, for example one-hour sound exposure (1HSE or E_{1h}) for a particular hour; day sound exposure (DSE or E_d) from 0700 to 2200 hours; and night sound exposure (NSE or E_n) from 0000 to 0700 hours plus from 2200 to 2400 hours.

Day-night sound exposure (DNSE or E_{dn}) for a 24-hour day is the sum of the day sound exposure and 10 times the night sound exposure. Unless otherwise stated, the normal unit for sound exposure is the pascal-squared second.

sound level; weighted sound pressure level: Ten times the logarithm to the base ten of the ratio of A-weighted squared sound pressure to the squared reference sound pressure of 20 μPa, the squared sound pressure being obtained with fast (F) (125 ms) exponentially weighted time-averaging. Alternatively, slow (S) (1,000 ms) exponentially weighted time-averaging may be specified; also C-frequency weighting. Unit, decibel (dB); symbol L_A, L_C.

Note: In symbols, A-weighted sound level $L_{A\tau}(t)$ at running time t is:

$$L_{A\tau}(t) = 10 \log \left\{ \left[(1/\tau) \int_{-\infty}^{t} p_A^2(\xi)\, e^{-(t-\xi)/\tau}\, d\xi \right] / p_0^2 \right\}$$

where τ is the exponential time constant in seconds, ξ is a dummy variable of integration, $p_A^2(\xi)$ is the squared, instantaneous, time-varying, A-weighted sound pressure in pascals, and p_0 is the reference sound pressure of 20 μPa. Division by time constant τ yields the running time average of the exponential-time-weighted, squared sound-pressure signal. Initiation of the running time average from some time in the past is indicated by $-\infty$ for the beginning of the integral. ANSI S1.4-1983, *American National Standard Specification for Sound Level Meters*, gives standard frequency weightings A and C and standard exponential time weightings fast (F) and slow (S).

sound pressure amplitude: Absolute instantaneous pressure in any given cycle of a sound wave at some specified time. Unit, pascal (Pa).

sound pressure; effective sound pressure: Root-mean-square instantaneous sound pressure at a point, during a given time interval. Unit, pascal (Pa).

Note: In the case of periodic sound pressures, the interval is an integral number of periods or an interval that is long compared with a period. In the case of nonperiodic sound pressures, the interval should be long enough to make the measured sound pressure essentially independent of small changes in the duration of the interval.

sound pressure level: Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 μPa. Unit, decibel (dB); abbreviation, SPL; symbol, L_p.

static pressure: Pressure that would exist at a point in the absence of a sound wave. Unit, pascal (Pa); symbol, p_s.

Note: One pascal is equal to one newton per square meter. The static pressure in air at sea level on a standard day is 101.325 kilopascals (2,116 pounds per square foot; 1 atmosphere).

time-averaged sound level; time-interval equivalent continuous sound level; time-interval equivalent continuous A-weighted sound pressure level; equivalent continuous sound level: Ten times the logarithm to the base ten of the ratio of time-mean-square instantaneous A-weighted sound pressure, during a stated time interval T, to the square of the standard reference sound pressure. Unit, decibel (dB); respective abbreviations, TAV and TEQ; respective symbols, L_{AT} and L_{aeqT}.

Note: A frequency weighting other than the standard A-weighting may be employed if specified explicitly. The frequency weighting that is essentially constant between limits specified by a manufacturer is called flat.

In symbols, time-averaged (time-interval equivalent continuous) A-weighted sound level in decibels is:

$$
\begin{aligned}
L_{AT} &= 10 \log\left\{\left[(1/T)\int_o^T p_A^2(t)\,dt\right]/p_0^2\right\} \\
&= L_{AeqT}
\end{aligned}
$$

where p_A^2 is the squared instantaneous A-weighted sound pressure signal, a function of elapsed time t; in gases reference sound pressure p_0 = 20 μPa; T is a stated time interval. In principle, the sound pressure signal is not exponentially time-weighted, either before or after squaring.

sound exposure level: Ten times the logarithm to the base ten of the ratio of a given time integral of squared instantaneous A-weighted sound pressure, over a stated time interval or event, to the product of the squared reference sound pressure of 20 micropascals and reference duration of one second. The frequency weighting and reference sound exposure may be otherwise if stated explicitly. Unit, decibel (dB); abbreviation, SEL; symbol, L_{AE}.

Note: In symbols, (A-weighted) sound exposure level is:

$$\begin{aligned} L_{AE} &= 10 \log\left\{\left[\int_o^T p_A^2(t)\,dt\right]/p_o^2 t_o\right\} \\ &= 10 \log\left(E/E_o\right) \\ &= L_{AT} + 10 \log\left(T/t_o\right) \end{aligned}$$

where p_A^2 is the squared instantaneous A- weighted sound pressure, a function of time t; for gases p_o = 20 μPa; t_o = 1 s; E is sound exposure; $E_o = p_o^2 t_o$ = (20 μPa)^{2}s is reference sound exposure.

Additional Terms:

C-weighted sound exposure level: Sound exposure level, as defined above, where C-weighted sound pressure is used instead of A-weighted sound pressure. Unit, decibel; abbreviation, CSEL; symbol, L_{CE}.

energy average: Colloquial term for time-mean-square average of the sound pressures of a series of sound signals.

energy summation: Colloquial term loosely used to indicate addition of noncoherent sound signals by the sum of the squares of their sound pressures or the sum of their sound exposures.

peak overpressure: Maximum positive pressure produced by an impulsive sound. Often used to describe the magnitude of a sonic boom, in pounds per square foot (psf). One pound per square foot is equal to 47.89 pascals or a flat sound pressure level of 127.6 decibels.

APPENDIX A AIRPORT-SPECIFIC ANALYSES

This appendix contains information about the categorization of airports by proportion of commuter flight operations, and about the experiences of certain airports with community response to commuter operations.

A.1 SOURCES OF INFORMATION ABOUT COMMUTER AIRCRAFT OPERATIONS

A week's worth of information about scheduled departures at civil airports nationwide during the month of August, 1995 was analyzed to establish proportions of commuter operations. Although this is too short a period to take proper account of seasonality effects, summer is a peak travel month at many U.S. airports, and a time when community response is often exacerbated by outdoor lifestyles and open windows. Information about community response to commuter flight operations was developed from conversations with airport and airline officials, and visits to individual airports.

A.2 TABULAR AND GRAPHIC SUMMARIES OF INFORMATION

Table 9 lists airports by numbers of operations and percentages of commuter operations. The columns of Table 9 (see also Figure 2) show the proportions of commuter departures to all destinations from these 238 airports.

Figure 21 shows the current distribution of proportions of commuter aircraft operations at civil airports as classified by FAA's National Noise Impact Model[3] that fall within 5%-wide intervals of percentages of commuter aircraft operations. Ignoring those airports served only by commuter aircraft, the distribution appears somewhat bimodal, with greatest concentrations of airports in ranges from 30-35% and 70-80%. Figure 22 plots the numbers of aircraft departures from each airport. The abscissa, the percent of departures by commuter aircraft, is a direct indication of an airport's fleet mix. Smaller airports—those with fewer than 100 departures per day—tend to have little (if any) scheduled jet service. Busier airports—those with more than 300 departures per day—exhibit a range

[3] The relevant NANIM categories for present purposes are as follows:
LLR: Large, Long Range (more than 100 operations per day, at least 15% of departures to destinations farther than 1500 miles);
LMR: Large, Medium Range (more than 100 operations per day, with 5 - 15% of departures to destinations farther than 1500 miles);
LSR : Large, Short Range (more than 100 operations per day, less than 5% of departures to destinations farther than 1,500 miles);
MSR: Medium, Short Range (10-100 operations per day, less than 5% of departures to destinations farther than 1500 miles; and
SSR: Small, Short Range (less than 10 operations per day, less than 5% of departures to destinations farther than 1500 miles).

of 10-60% of commuter operations. Figure 23 replots the data of Figure 22 by excluding airports with fewer than 100 departures per day.

Figure 25 shows the mean and standard deviation of the distribution of the 63 airports shown in Figures 23 and 24. Slightly fewer than a third of all departures at the larger airports considered in this figure are commuter flights. The standard deviation of the distribution is about half of the size of the mean, or about 15%.

Table 9 Tabulation of daily departures at 238 U.S. civil airports by aircraft type during August 1995.

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
DFW	LMR	1218	828	390	32.0%
ORD	LLR	1177	947	229	19.5%
LAX	LLR	1009	663	346	34.3%
ATL	LMR	994	816	177	17.9%
STL	LMR	680	507	174	25.5%
BOS	LMR	656	343	314	47.8%
MIA	LLR	649	422	227	35.0%
DEN	LMR	591	431	160	27.1%
MSP	LMR	590	424	165	28.1%
DTW	LMR	585	452	133	22.8%
PIT	LMR	562	369	192	34.2%
SFO	LLR	555	427	127	23.0%
EWR	LLR	552	389	162	29.4%
SEA	LLR	541	351	190	35.1%
PHX	LMR	529	455	74	14.0%
CLT	LSR	519	361	157	30.3%
CVG	LMR	495	302	193	39.0%
IAH	LMR	485	390	95	19.6%
JFK	LLR	463	305	157	34.0%
PHL	LMR	462	313	149	32.2%
LGA	LSR	456	340	117	25.5%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
MCO	LMR	388	248	140	36.1%
LAS	LMR	384	340	44	11.4%
IAD	LLR	366	143	223	61.0%
DCA	LSR	351	266	85	24.3%
SLC	LMR	350	280	70	20.0%
HNL	LLR	341	258	82	24.2%
MEM	LMR	338	225	114	33.6%
PDX	LLR	304	178	126	41.5%
CLE	LSR	304	193	111	36.5%
BWI	LSR	304	190	113	37.3%
SAN	LLR	294	207	86	29.4%
MCI	LSR	259	193	66	25.6%
BNA	LSR	254	126	128	50.3%
TPA	LSR	248	137	111	44.6%
ANC	LLR	205	107	98	47.8%
OAK	LMR	199	198	1	0.6%
FLL	LSR	198	116	82	41.0%
HOU	LSR	185	158	27	14.7%
MSY	LSR	185	145	40	21.7%
IND	LMR	185	117	68	36.8%
MKE	LSR	179	102	77	42.8%
SJC	LLR	164	150	14	8.7%
SDF	LMR	161	142	19	12.0%
RDU	LSR	159	127	32	20.0%
CMH	LMR	157	111	46	29.0%
ONT	LMR	157	134	23	14.0%
SMF	LMR	152	109	43	28.0%
GSO	MSR	150	87	64	42.0%
ABQ	LSR	150	113	38	25.0%
DAL	LSR	150	129	21	14.0%
SNA	LLR	140	109	31	22.1%
SAT	LSR	136	112	23	17.1%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
AUS	LSR	124	106	18	14.6%
DAY	LMR	122	73	48	39.7%
OGG	LSR	119	91	27	22.9%
RNO	LSR	116	90	26	22.4%
ALB	MSR	111	37	74	66.9%
GEG	MSR	110	62	49	44.2%
JAX	LSR	109	66	43	39.4%
BUR	LSR	109	93	15	14.1%
SYR	LSR	108	39	69	64.1%
JNU	MSR	104	19	85	82.0%
BUF	LSR	104	58	46	43.8%
ELP	LSR	99	87	13	12.6%
ROC	LSR	99	48	51	51.1%
BET	SSR	98	4	93	95.6%
PBI	LSR	94	62	32	34.2%
OKC	LSR	89	68	21	23.9%
BHM	MSR	85	58	27	31.3%
ORF	LSR	84	49	35	41.3%
TUL	LSR	84	63	21	25.5%
OMA	MSR	83	68	15	18.1%
BOI	MSR	81	53	27	33.7%
PVD	MSR	77	38	40	51.3%
TUS	LSR	77	57	20	26.2%
FAI	MSR	75	18	57	75.7%
FAT	MSR	75	7	68	90.5%
LIT	MSR	74	47	27	36.9%
ACK	SSR	71	1	71	99.2%
PWM	MSR	71	20	51	72.1%
GRR	MSR	71	29	42	59.2%
RIC	LSR	71	50	21	30.0%
DSM	MSR	70	46	24	34.2%
COS	MSR	69	60	9	12.9%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
RSW	LSR	67	41	26	38.2%
KTN	MSR	65	9	56	86.2%
HPN	MSR	64	16	48	75.5%
PNS	MSR	64	19	45	69.6%
BTV	MSR	63	13	50	78.7%
ICT	MSR	61	36	25	41.4%
SBA	MSR	57	6	51	89.5%
JAN	MSR	57	20	37	65.2%
MDT	LSR	55	28	27	49.2%
ISP	MSR	54	15	38	71.2%
ROA	MSR	52	14	38	73.3%
TOL	MSR	52	30	22	42.3%
LIH	MSR	52	45	7	13.9%
SHV	MSR	51	16	35	68.2%
KOA	MSR	50	40	9	18.7%
OTZ	SSR	49	4	46	92.2%
TYS	MSR	49	32	17	35.6%
CID	MSR	48	21	27	56.4%
PSP	MSR	47	3	44	93.7%
SGF	MSR	47	9	38	81.3%
SBN	MSR	47	11	36	76.7%
MHT	MSR	45	20	25	55.3%
EVV	SSR	45	3	43	93.7%
GSP	MSR	45	26	19	42.8%
LBB	MSR	44	20	24	54.4%
ABE	MSR	42	25	17	40.7%
CAE	MSR	42	32	10	23.0%
LEX	MSR	41	21	21	50.2%
SRQ	MSR	41	20	21	51.9%
MSN	MSR	41	22	19	46.7%
MRY	SSR	41	4	37	90.1%
FWA	MSR	40	11	29	72.6%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
FSD	MSR	39	19	21	52.9%
DLG	SSR	39	2	37	94.9%
AKN	SSR	39	3	35	91.9%
SWF	MSR	39	21	18	45.9%
SPI	SSR	38	0	38	100.0%
BGR	MSR	38	7	31	82.0%
CRP	MSR	38	11	26	69.0%
BIL	MSR	37	17	21	55.0%
BTR	MSR	37	13	24	65.0%
OME	SSR	36	4	32	89.2%
MAF	MSR	35	21	14	40.1%
LAN	MSR	34	8	26	75.5%
EUG	MSR	33	9	24	73.1%
CHS	MSR	33	25	8	22.9%
ITO	MSR	33	33	0	0.0%
CRW	MSR	32	7	25	76.0%
MLI	MSR	32	13	18	57.0%
BGM	SSR	31	4	27	87.0%
ADQ	SSR	31	2	29	93.0%
AZO	MSR	31	8	23	75.0%
HSV	MSR	31	20	10	34.0%
PIA	MSR	30	6	24	81.0%
MOB	MSR	30	15	14	47.0%
FNT	SSR	29	2	27	92.0%
BFL	SSR	29	1	28	96.0%
GRB	MSR	29	8	21	73.0%
MBS	MSR	28	11	18	61.0%
PSC	SSR	27	4	23	85.3%
CAK	MSR	27	4	23	85.2%
SAV	MSR	27	21	6	22.8%
CHO	SSR	27	0	27	100.0%
BIS	MSR	27	7	20	75.0%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
PFN	SSR	27	4	23	85.0%
FAR	MSR	27	10	17	64.0%
PIE	SSR	26	20	7	25.0%
SUX	SSR	26	2	24	92.0%
TVC	SSR	26	3	23	88.0%
MGM	MSR	26	7	19	72.80%
CWA	SSR	26	0	26	100.00%
CHA	MSR	25	10	15	60.30%
CMI	SSR	25	0	25	100.00%
PHF	SSR	25	6	19	77.50%
HRL	MSR	23	16	8	32.90%
GJT	SSR	23	0	23	100.00%
ATW	MSR	23	8	16	67.30%
TRI	MSR	23	9	14	62.30%
YKM	SSR	23	0	23	100.0%
MLU	MSR	23	6	17	73.4%
GNV	MSR	22	4	18	82.2%
AVL	MSR	22	8	14	64.3%
RAP	MSR	22	8	14	63.9%
RFD	SSR	22	9	13	57.8%
AMA	MSR	22	12	10	47.1%
BLI	SSR	22	2	20	92.1%
LFT	SSR	22	0	22	100.0%
LNK	MSR	22	10	12	54.0%
SMX	SSR	21	0	21	100.0%
ACY	MSR	21	3	18	84.4%
ILM	MSR	20	6	14	69.8%
MLB	MSR	20	8	12	59.7%
HVN	SSR	20	3	17	84.7%
MSO	MSR	19	9	10	52.3%
AVP	MSR	19	7	12	62.3%
CSG	SSR	19	3	16	83.8%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
JAC	MSR	19	4	15	78.5%
MFE	MSR	18	12	6	32.0%
AGS	MSR	18	7	11	61.7%
ITH	SSR	18	3	15	83.9%
DEC	SSR	17	1	16	95.8%
GTF	MSR	17	9	8	46.7%
DAB	MSR	17	11	6	35.3%
MFR	SSR	17	4	13	76.5%
FCA	SSR	17	6	11	63.6%
PSG	SSR	17	2	15	88.0%
LRD	SSR	17	2	14	87.1%
BZN	MSR	16	8	8	49.1%
GRI	SSR	16	0	16	100.0%
LSE	SSR	15	4	11	74.8%
ELM	SSR	15	4	12	75.7%
IDA	MSR	15	4	11	73.6%
FAY	MSR	15	6	9	59.6%
DLH	MSR	14	5	9	65.3%
HTS	SSR	14	0	14	100.0%
HLN	SSR	14	3	11	78.4%
OAJ	SSR	14	0	14	100.0%
BRW	SSR	13	3	10	74.2%
GFK	SSR	13	5	7	57.3%
EKO	SSR	12	0	12	100.0%
PIR	SSR	12	0	12	100.0%
BTM	SSR	12	2	10	82.7%
MOT	MSR	12	3	9	74.1%
CPR	SSR	11	3	8	70.0%
SIT	SSR	11	5	6	55.7%
UCA	SSR	11	0	11	100.0%
EFD	SSR	11	3	7	68.4%
ASE	MSR	11	10	1	6.7%

AIRPORT	NANIM CATEGORY[1]	TOTAL DAILY DEPARTURES	JET DEPARTURES	COMMUTER DEPARTURES	PERCENT COMMUTER DEPARTURES
ERI	SSR	11	4	7	62.7%
ABY	SSR	11	2	8	79.7%
BFF	SSR	10	0	10	100.0%
GUC	SSR	10	0	10	100.0%
TLN	MSR	10	7	3	34.3%
DUT	SSR	10	2	8	79.7%
RST	MSR	10	10	0	0.0%
YNG	SSR	9	0	9	100.0%
PUB	SSR	8	0	8	100.0%
OSH	SSR	8	0	8	100.0%
ISO	SSR	7	0	7	100.0%
BRO	SSR	7	4	3	42.9%
LBF	SSR	7	0	7	100.0%
WRG	SSR	6	2	4	68.0%
COD	SSR	6	0	6	100.0%
LGB	MSR	6	6	0	0.0%
HDN	MSR	5	0	5	100.0%
FOE	SSR	4	0	4	100.0%
CDB	SSR	4	1	3	73.3%
CDV	SSR	4	2	2	48.1%
ORH	SSR	4	0	4	100.0%
LWB	SSR	4	0	3	92.0%
TTN	SSR	3	3	0	0.0%
YAK	SSR	2	2	0	0.0%
FMY	SSR	1	0	1	100.0%

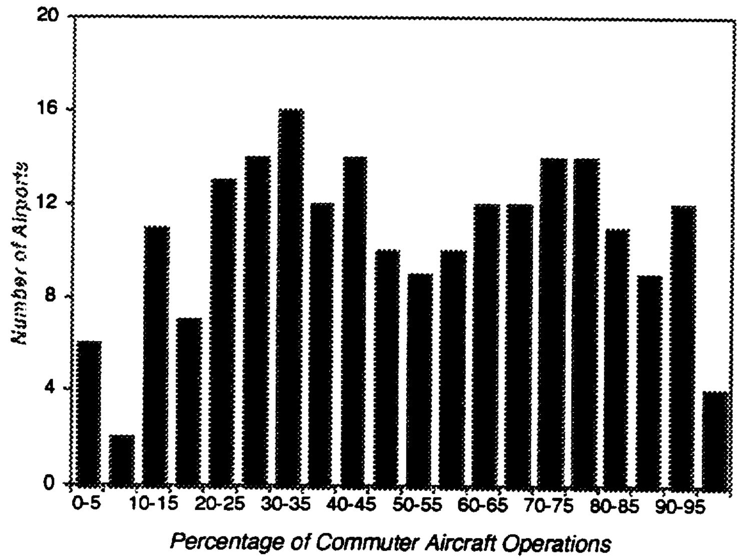

Figure 21 Number of airports associated with various percentages of commuter operations.

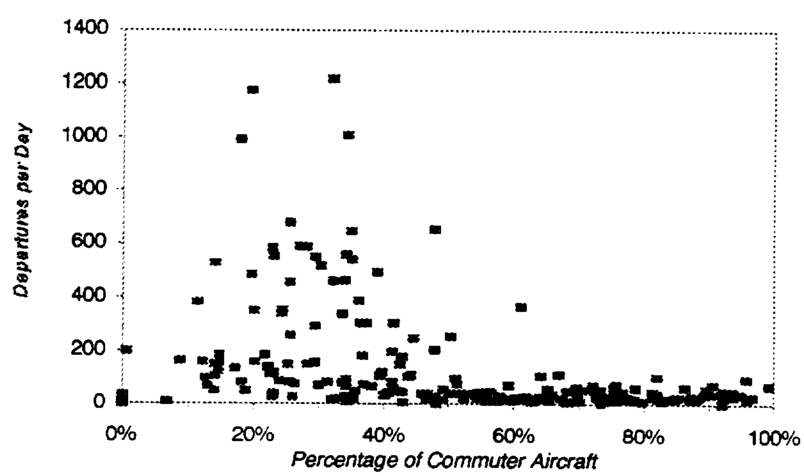

Figure 22 Numbers of aircraft departures per day from 238 U.S. airports as a function of percentage of commuter aircraft.

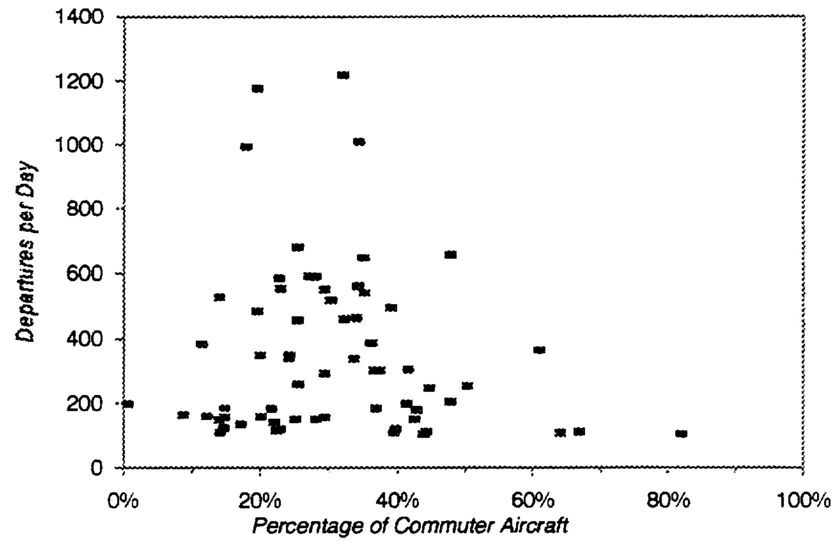

Figure 23 Number of aircraft departures from each airport with 100 departures or more per day as a function of percentage of commuter aircraft.

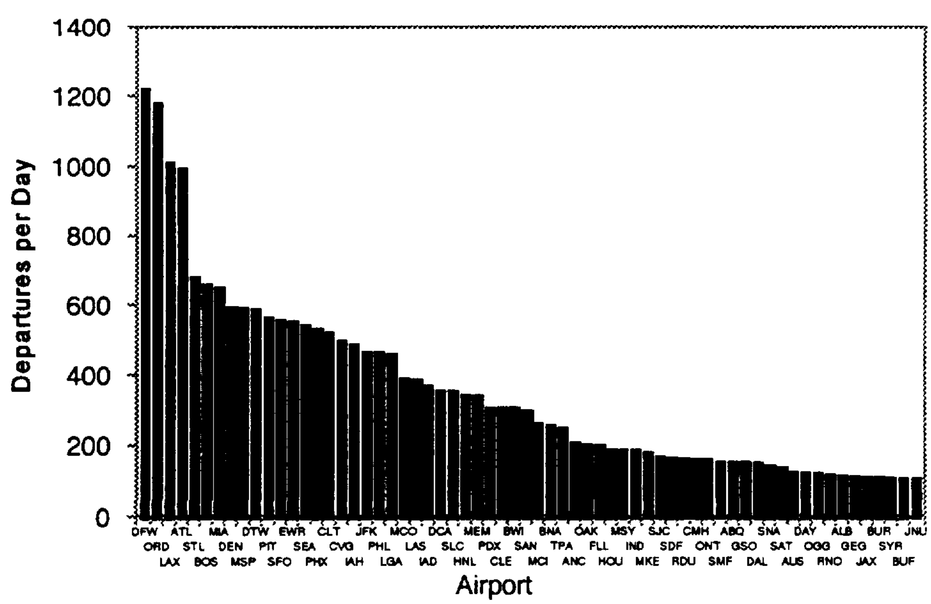

Figure 24 Number of aircraft departures from designated airports with 100 or more departures per day.

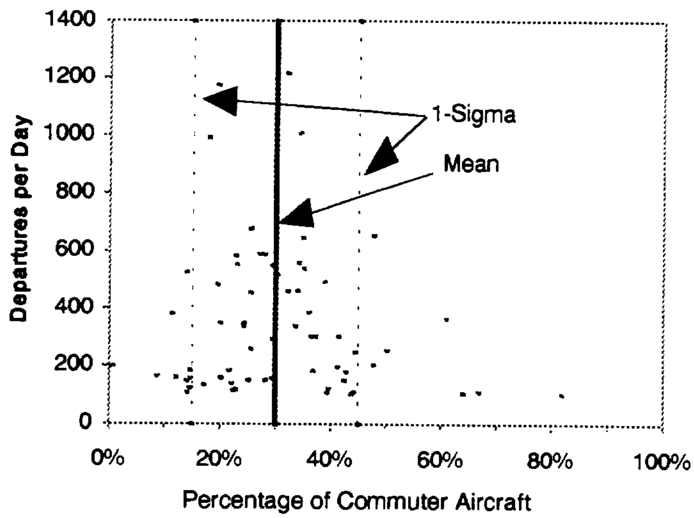

Figure 25 Mean and standard deviation of the distribution of departures from the airports shown in Figure 27.

A.3 SUMMARY OF INFORMATION GAINED FROM SITE VISITS

A.3.1 Lambert Field (STL)

STL is a large, medium range airport with an unusually small proportion of commuter aircraft operations. About a quarter of its current annual total of 530,000 operations is conducted by commuter aircraft. The commuter fleet operating at STL is composed of relatively large (ATR-42/72 class) aircraft. These are operated by Trans World Express under a code-sharing agreement with TWA. This arrangement provides TWA with feed traffic of about 1 million enplanements per year, or roughly 5% of its enplanements at STL.

Commuter and jet operations are conducted on the same main parallel runways, although commuter aircraft are frequently turned off the runway heading on departure much sooner than jets. No effort is made to maintain separate traffic streams for commuter and jet aircraft on approach. Although the airport is operating near capacity, the fact that commuter flights are scheduled to provide feed traffic for a single airline creates a staggering of peak demand periods for commuter and jet operations, which in turn produces a cyclic separation of commuter and jet flight activity throughout the day.

Several factors limit the proportion of commuter operations at STL. First, since TWA is by far the dominant carrier at the airport, and since the commuter operations at STL are largely an adjunct to TWA's operations, there is little market incentive for other commuter airlines to offer regional service. Second, competition from Southwest Airlines, which offers frequent, low cost non-stop jet service to nearby cities (*e.g.*, Chicago, Kansas City) further discourages the introduction of additional regional turboprop service. STL offers no turboprop service to destinations more distant than about 300 miles.

STL management reports no complaints about commuter aircraft noise. The major factors that may contribute to this lack of community response to commuter operations *per se* include the following:

(1) Less than 40% of jet transport operations at STL are conducted by Stage III aircraft. TWA's fleet includes a high proportion of leased Stage II (notably DC-9) aircraft. SEL values for these aircraft are considerably higher than those of the ATR-72 operated by Trans World Express at STL.

(2) Both the Missouri Air National Guard and McDonnell Douglas operate F-15s from STL. Air National Guard sorties commonly include flights of pairs of F-15s, while tests of newly manufactured F-15s often include afterburner takeoffs at full military power. Although military operations constitute only a very small percentage of total airport operations, they are very noticeable.

(3) STL operates in west flow about 60% of the time and in east flow about 40% of the time. Since neighborhoods are not consistently overflown by either departure or approach traffic, this variability in traffic flow creates a corresponding variability in the distribution of daily noise exposure values in airport communities. The overall heterogeneity of the aircraft noise exposure environments in airport neighborhoods (due both to long term variability in day-to-day DNL values and short term variability in SEL values of commuter and jet transport overflights) may serve to focus attention on the most noticeable aircraft: Stage II and military aircraft.

A.3.2 Boston Logan International (BOS)

BOS is a large, medium range airport at which approximately half of all operations are conducted by commuter aircraft. Commuter and jet operations are conducted on the same runways except that, unlike the jets, commuter aircraft use Runway 22R for approaches and Runway 4L for departures. Commuter aircraft are frequently turned off the runway heading on departure much sooner than jets, and they join the ILS glide slope later than jets. This practice allows commuter overflights of areas not overflown by jets, particularly in Back Bay and East Boston. These communities are less accustomed to aircraft overflight noise than others in the vicinity of BOS.

Complaints specifically mentioning commuter air traffic have nonetheless been very few. In 1995, only 3% of all complaints at BOS related to commuter air traffic, even though commuter aircraft represented 50% of total operations. Complaints related to commuter aircraft traffic appear to be increasing, however, and may eventually represent a larger proportion of the complaints. Two years ago, complaints relating to commuter air traffic represented only 0.3% of the total number of complaints. Total complaints for all aircraft decreased from 3,939 in 1993 to an estimated 2,608 for the current year. Total complaints related to commuter aircraft were only 65 by October 24, 1995.

A.3.3 Los Angeles International (LAX)

LAX, classified by NANIM as a large, long range airport, is a coastal airport that presently supports about 2000 operations per day (732,000 in 1995) on two pairs of fully independent parallel runways. The commercial fleet using the airport consists of 87% Stage III aircraft. The principal commuter aircraft operating at LAX are British Aerospace Jetstream 31 (42% of commuter operations) and EMB-120s (20% of commuter operations). Total enplanements were 53.9 million for 1995, a 6.4 percent increase above the enplanements for the previous year. LAX is the fourth busiest airport in the world and the third busiest in the nation in terms of total enplanements.

Commuter and jet operations are conducted on the same runways. Prevailing winds dictate that about 96% of all operations take off and land to the west. As at other airports at which the more maneuverable commuter aircraft operate, these aircraft are often turned off the runway heading much sooner than jets on departure, and join the ILS glide slope later than jets. Thus, commuter aircraft overfly some areas not overflown by jets. Total noise complaints range from 50 per month in the winter to 150 per month during the summer. Very few of these complaints identify commuter aircraft as a source. The airport administration does not presently consider noise problems associated with the commuter fleet operating at LAX to be as consequential as those associated with larger jet transports.

Commuter aircraft departing LAX from the south runways in normal (westerly) traffic flow sometimes turn south and overfly residential areas of El Segundo rather than waiting to cross the shoreline before turning. Citizens have videotaped many such overflights, claiming that about 800 commuter operations per month overfly El Segundo at low altitudes, and have enlisted the aid of their Congressional representative to intervene with FAA to prohibit the practice. According to FAA Regional Deputy Administrator Elly Brekke (as quoted in the Noise Regulation Report of 4 March 1996), "Commuter planes are big concern" to residents of El Segundo. Effective in June of 1996, FAA will require commuter aircraft to follow the same standard instrument departure procedures from LAX as larger jet transports to prohibit further "early" (pre-shoreline) turns by commuter aircraft.

A.3.4 Orange County (SNA)

SNA is a large, long range airport as classified by NANIM, although at about 100,000 scheduled commercial operations per year, it is clearly smaller than other airports in this category. Unscheduled business jet and other general aviation operations bring the total number of annual operations at SNA to about 480,000. The commercial fleet using the airport is composed exclusively of Stage III aircraft. The predominant commuter aircraft operating at SNA is the British Aerospace Jetstream 31. The remaining commuter aircraft types (totaling about half of the Jetstream 31 operations) include the Fairchild Metro/Merlin and the Embraer EMB-120.

Commuter and jet operations are conducted on the same runway. Prevailing winds dictate that about 90% of the operations use Runway 19R. As at other airports, commuter aircraft are often turned off the runway heading much sooner than jets on departure and join the ILS glide slope on approach later than larger jet transports. These airspace management techniques lead to commuter overflights of residential neighborhoods that are not overflown by jets. However, very few of the 150 monthly complaints received by the airport administration about noise identify commuter aircraft as a source.

Two other types of aircraft—business jets and general aviation aircraft—use SNA. The level of business jet operations is about a tenth of commercial operations. Other aircraft operations (mostly those of small, single-engine propeller aircraft) are about four times as numerous as commercial operations. Although the business jet operations amount to only 10% of the commercial fleet, they account for about 40-50% of the noise complaints. In spite of their large numbers, general aviation aircraft operations rarely cause complaints.

A.3.5 San Diego (SAN)

NANIM classifies SAN as a large, long range airport. The commercial fleet using the airport consists of 87% Stage III aircraft. Commuter aircraft operating at SAN are primarily British Aerospace Jetstream 31 and Fairchild Metro/Merlin (66%). The remaining one third of commuter operations are conducted by EMB-120 and Saab SF 340 aircraft. Total operations at SAN were about 227,000 in 1995. Of this total, 62% were commercial jet carriers, 28% were commuters, 8% were business jets and general aviation aircraft (with very few small private piston engine aircraft), and 2% were military. Total enplanements were 13.3 million for 1995, a 2.6% increase above the enplanements for 1994.

Commuter and jet operations are conducted on the same runway. Prevailing winds dictate that about 95% of the operations use Runway 27. Total noise complaints average about 60 per month, with higher numbers during summer months. Very few complaints about noise identify commuter aircraft as a source. The airport administration is not greatly concerned about noise problems associated with the commuter fleet operating at SAN.

A.3.6 Minneapolis-St. Paul (MSP)

MSP is classified by NANIM as a large, medium range airport supporting somewhat less than 800 operations per day. The number of operations by major carriers, regional, and charter operators has grown by 6.5% in the last year. The number of passengers grew by nearly 10% in the same time period, to a total of nearly 27 million origination, destination, and connecting enplanements and deplanements. The number of commuter operations has actually decreased by about 7% over the last year, due in part to the substitution of larger for smaller aircraft. Mesaba Airlines, operating as Northwest Interlink, carried 1.5 million passengers last year, delivering feed traffic to Northwest's hubs in Minneapolis and Detroit. Mesaba is planning to replace the airline's entire fleet of 26 19-seat Fairchild Metro 3 and 25 Dash-8 aircraft with 30 new Saab 340BPlus and 20 340A 34-seat turboprops.

As at CVG and STL, a single major carrier dominates long haul operations at MSP. Slightly more than half of the operations at MSP were conducted by Stage II aircraft in 1994, a decrease of about 10% over 1994. Stage II DC-9s and B-727s are still the most common air carrier aircraft operating at MSP, recently accounting for 32% and 15% of air carrier operations, respectively. Excessive noise complaints accounted for almost all of the 1200-odd complaints received by the Metropolitan Airports Commission Aviation Noise Program during a recent month.

Despite the relatively large percentage of Stage II aircraft remaining in the fleet at MSP, it is not uncommon for commuter and small jet aircraft to be represented among the ten noisiest overflights each month at several of the airport's noise monitoring points located two miles or more from runway ends. For example, at a site where the maximum A-level created by a B-727 was 87.3 dB, a Swearingen Metroliner 4 creating a level of 82.8 dB was the fourth noisiest overflight during November of 1995. At another monitoring site where the highest level overflight by a B-727 created a maximum A-level of 88.8 dB, Swearingen Metroliner 4s were the fourth and ten noisiest overflights of the month, at 83.9 and 80.5 dB, respectively. Likewise, a Swearingen Metroliner 4 at another monitoring site, creating a maximum A-level of 84.9 dB, was the tenth noisiest overflight. At yet another site (at which the noisiest noise event of the month was a B-747 creating a maximum A-level of 94.3 dB), a Fokker 100 overflight that created a maximum level of 84.5 dB was the third noisiest flight of the month.

Figures 26 and 27 show flight tracks for jet and turboprop operations at MSP over a five day period in November, 1995. Comparison of the two figures indicates that turboprop operations utilize runway sideline airspace that is unavailable to less maneuverable jet aircraft. Thus, even though jet operations were about three times as numerous turboprop operations during this week, the bulk of the overflights in certain localized areas were conducted by turboprops.

Figure 26 Air carrier jet departures at MSP during the week of 26 November, 1995.

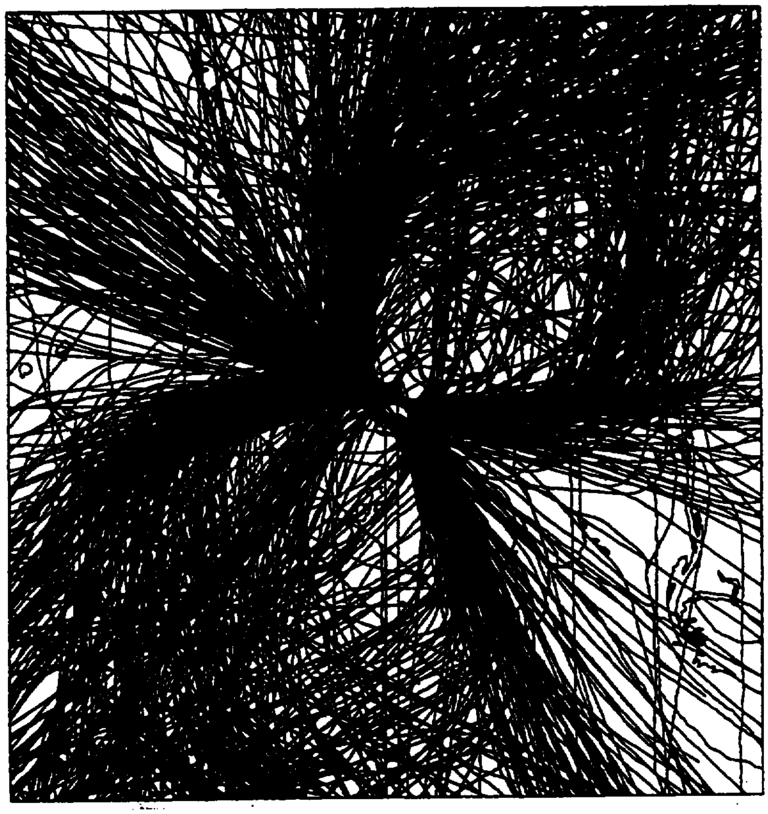

Figure 27 Commuter turboprop departures at MSP during the week of 26 November, 1995.

A.3.7 Cincinnati (CVG)

CVG is classified by NANIM as a large, medium range airport. It currently occupies about 6,000 acres, and is actively acquiring land and/or avigation easements. About 62% of the operations at the airport are conducted by Stage III aircraft. The airport supported 505 daily operations during December of 1995, providing direct (non-stop) service to 96 domestic and 6 international cities. Delta and ComAir (Delta's code sharing commuter carrier) dominate both departures and enplanements at CVG, although more than a dozen other major and commuter carriers provide a small number of passenger flights to other hubs.

Enplanements during 1995 reached 15.1 million, an increase of more than 11% from 1994's 13.6 million enplanements, attributable primarily to growth in the Delta and ComAir hubs during the year, which added more than 70 new flights. The Kenton County Airport Board characterizes this growth as "unexpected," although it continues a trend starting at least as early as 1993, when total enplanements were only 12.3 million passengers.

CVG is now the seventh largest commuter hub in the country, and the second fastest growing hub airport in the United States (after Miami). ComAir currently operates more daily flights (220) than Delta (212 per day) at CVG, with a prop-powered fleet composed primarily of SAAB 340 and Brasilia aircraft. (Smaller Metroliner aircraft have almost ceased operating from CVG.) Operations by 50-passenger Regional Jets already carry nearly half of the transfer traffic, and are increasing rapidly. ComAir, which averages about 7 turns per day at its gates at a separate commuter terminal, provides jet service to destinations as distant as Oklahoma City. Delta sometimes takes over developed city pair routes from ComAir at the point at which Delta can economically serve them with larger jet transports. ComAir coordinates its schedules with Delta to provide transfer traffic for Delta's nine peak periods per day. If current trends continue, commuter aircraft operations at CVG may eventually constitute as much as 60% of total operations.

CVG receives an average of about 200 noise complaints per month, peaking at a rate of about 400 per month during summer months. Only a very small number of these complaints concern commuter aircraft noise explicitly, although it is not possible in many cases to determine which aircraft types are of immediate concern to complainants.

A.3.8 Dulles International (IAD)

IAD is classified by NANIM as large, long range airport. It is a rapidly growing airport that provides direct service to many international destinations, serving approximately six million passengers per year with about 850 operations per day. The airport, which is currently operating with spare capacity, is constructing two new runways and landside improvements that will be able to support 750,000 operations per year by the year 2010.

Despite the fact that IAD is a coastal airport[4] that provides direct service to many international destinations, it is also a "commuter hub" with an unusually high percentage of commuter operations (61%). United Airlines, a major carrier at IAD, several years ago substituted code-shared commuter service (primarily in J31 and Embraer-class aircraft) for about 100 jet operations per day as a means of increasing passenger feed to its international and longer range domestic routes. United

[4] Coastal airports are not generally as convenient or cost-effective as mid-continental airports as hubs for hub-and-spoke networks.

has reclaimed some of these routes for jet service as they have proved capable of supporting service by larger equipment.

Commuter and larger aircraft are not segregated into separate arrival or departure streams at IAD, in part because the airport has more than adequate runway capacity and 20 miles of flat, unobstructed terrain for approaches and departures. If necessary during peak periods, commuter aircraft are permitted to operate from *de facto* displaced thresholds from the airport's 11,500 foot-long runways.

IAD has only minor (if any) noise problems, due in large part to its design and to the continuing willingness of surrounding communities to enforce compatible land development policies. The airport authority received only about 300 aircraft noise complaints last year, of which about a third were from a single individual. Few of these complaints concerned commuter operations.

A.3.9 Washington National (DCA)

DCA is classified by NANIM as a large, short range airport. It accommodates about 16 million passengers per year on nearly exclusively domestic routes to destinations as distant as 1250 miles, including Dallas, Atlanta, Chicago, and Boston. Seventy-one percent of the fleet currently serving the airport is composed of Stage III aircraft. The percentage of commuter operations at DCA (24%) is unusually low because it is fixed by an FAA-instigated capacity limit.[5] Of the 60 IFR reservations permitted per hour at DCA, 37 are reserved for air carrier operations, 11 for commuter operations (defined in this case as aircraft with 50 or fewer seats), and 12 for general aviation flights.

DCA is effectively built out: It operates at capacity, and has no plans for future airside development. Entry to further turboprop operations is banned not only by the airport's capacity limitation, but also by market forces. Demand for air shuttle service among downtown Washington, New York, and Boston airports is more than adequate to support load factors that justify all jet service.

[5] Along with ORD, JFK, and LGA, DCA is one of four "high density controlled" airports in the United States for which air traffic is limited to a fixed hourly allocation of IFR reservation "slots."

The airport operating authority received about 2700 noise complaints last year, of which all but 600 were from a single individual. Few of these complaints concerned commuter aircraft. The airport has its own departure procedure that requires a full power climb to 1500 feet, followed by a power cutback. Whereas jet aircraft are held to approaches and departures that follow the Potomac river for 5 miles downstream and 10 miles upstream, commuter aircraft are permitted to diverge from these procedures outside the 3 DME arc.

APPENDIX B DISCUSSION OF ANNOYANCE INTEGRATION ISSUES

B.1 THE ROLE OF THE EQUAL ENERGY HYPOTHESIS IN ANALYSES OF COMMUTER AIRCRAFT NOISE EFFECTS

The equal energy hypothesis holds that the annoyance created by noise exposure is directly proportional to the total energy of the noise: *i.e.*, the time integral of intensity, or the sum of the mean-square values of the sound exposures of a set of discrete noise events. The hypothesis implies (1) that people are indifferent between the annoyance of noise intrusions of short duration but high level and the annoyance of noise intrusions of long duration but compensatingly low level, and (2) that all other things being equal, the effect of annoyance of multiple noise events scales as 10 log N, where N represents the number of individual events. Thus, the equal energy hypothesis intentionally confounds the effects of level, duration, and number of noise events on annoyance, and implies that noise-induced annoyance grows equally with increases in either the level or duration of sounds.

No compelling evidence suggests that the equal energy hypothesis is anything more than an expedient means for describing noise exposure which correlates to a useful degree with the prevalence of annoyance in communities (at least over a range from about L_{dn} = 55 to 75 dB). In other words, the fact that DNL as a predictor variable can account for about half of the variance in community response data does not necessarily imply that annoyance is uniquely *caused* by a time-weighted average of sound levels. DNL as a noise metric embodies tacit assumptions about frequency weighting, time of day of exposure, and the fungibility of level, duration, and number of events as determinants of annoyance (which can correlate highly with DNL for a homogeneous aircraft fleet) that may have little to do with the factors that actually generate annoyance in residential populations.

For example, the number of times per day that people notice and are annoyed by aircraft noise events may be a more direct cause of long term annoyance than the noise exposure produced by each overflight. As heterogeneity in SEL values of overflights increases due to growth in the proportion of commuter operations at airports served primarily by larger jet aircraft, so does the strain placed on the equal energy hypothesis as an explanatory mechanism.

B.2 ANNOYANCE INTEGRATION AS AN ALTERNATIVE TO EXPOSURE INTEGRATION

Standard practice for predicting the prevalence of long term annoyance on the basis of integrated noise exposure does not specifically consider reactions to individual noise events. Instead, all predictions are based on summed exposures. This section describes an alternative approach to modeling long term annoyance, from summation of individual annoyance decisions rather than from integration of noise exposure. Such an approach may prove helpful in modeling the contributions to annoyance of commuter aircraft operations at airports with mixed fleets.

As described by Fidell, Sneddon and Green (1990), decisions about the annoyance of individual aircraft overflights may be modeled as the result of a comparison of a measure of the magnitude of an overflight (for example, its SEL) to the value of a time-varying tolerance index at the time of occurrence of the overflight. Thus, the same noise intrusion can be differentially annoying at different times. Since not every aircraft overflight heard in an airport neighborhood is necessarily judged to be annoying, long term attitudes are not necessarily sensitive only to the sum of individual event exposures. Instead, they may be more credibly predicted by an accumulation of annoyance decisions.

This approach to modeling annoyance is of interest for present purposes because individuals may not be able to directly recall long sequences of many thousands of SEL values of individual aircraft overflights when asked to report their long term annoyance. It is at least as plausible that respondents recall context-coded abstractions of the events, such as their reactions to single events. If this is so, then an accumulation of short term annoyance decisions may serve as a more direct basis for understanding and predicting long term annoyance.

B.3 DESCRIPTION OF ANNOYANCE INTEGRATION MODEL

The annoyance integration model consists of two parts, as illustrated in Figure 28. The first part is concerned with determining whether a given intrusive sound is annoying, while the second part deals with the accumulation of annoyance reactions to individual noise intrusions into a long term measure of annoyance.

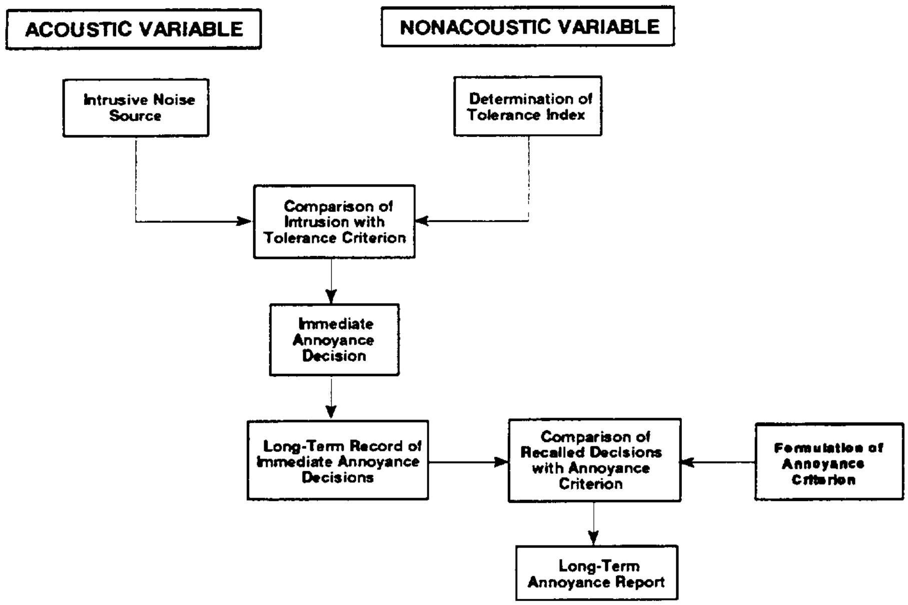

Figure 28 Simplified annoyance decision model.

The decision to classify a noise intrusion as annoying is made by comparing some measure of the magnitude of the noise with a criterion (a "tolerance index") that is assumed to vary according to the affective state of the listener and concentration on ongoing activity. "Affective state" refers to an individual's mood and attitude toward the noise source at the time a noise intrusion occurs. Common experience indicates that people are not always equally tolerant of noise intrusions. Even when they are not occupied in any overt activity, people may for a variety of reasons react more strongly to noise intrusions at some times than at others. "Concentration on ongoing activity" refers to the sensitivity to disturbance (distraction, interference, disruption of attention, *etc.*) of the activity in which a person is engaged at the time of occurrence of a noise intrusion. The tolerance index serves as a mechanism to account for the common observation that the same acoustic signal does not always provoke the same intensity of annoyance at different times in the same individual, and for the fact that different individuals may find the same signal differentially annoying.

The second part of the model concerns itself with combining short term annoyance decisions into a long term attitude. It is assumed that only two pieces of information are retained from the sensory memory: the time of occurrence of each annoyance decision and some measure of its degree of annoyance (*e.g.*, slight, moderate, or greater). Long term annoyance develops from some form of integration (weighted summation, curvilinear growth function, *etc.*) of individual annoyance decisions. The number of accumulated annoyance decisions per unit time (say, a 24 hour time period for the sake of convenience of comparison with DNL-based predictions of annoyance) is compared with the value of a criterion for an annoyance rate. If the accumulation of annoyance decisions in a period of time exceeds the tolerable rate, individuals describe themselves as annoyed for the time period.

The value of the tolerance criterion may also be affected by nonacoustic (response bias) factors. Thus, a respondent in a social survey asked "How annoyed have you been by aircraft noise over the past (time period)?" is assumed to answer by comparing the number of accumulated annoyance decisions during the time period with one or more criterion values: say, 10 annoyance decisions per unit time for slight annoyance, 25 annoyance decisions per unit time for moderate annoyance, *etc.*

B.4 COMPARISON OF BEHAVIOR OF INTEGRATED EXPOSURE AND INTEGRATED ANNOYANCE MODELS

A Monte Carlo simulation was conducted to illustrate differences between the conventional (integrated exposure) approach to predicting annoyance and an integrated annoyance approach. The simulation was performed as follows:

(1) Noise events representing individual aircraft overflights were selected at random from each of two Gaussian distributions of SEL values: one for jet aircraft, and one for commuter aircraft, as suggested in Figure 1 of this report.

(2) A normally distributed value for the tolerance index was selected at random to represent the time-varying sensitivity of people to aircraft noise intrusions.

(3) An "annoyance counter" was incremented each time a randomly selected SEL value exceeded the randomly selected value of the tolerance index. Noise events whose values did not exceed the tolerance index did not contribute to the integration of annoyance.

These steps were iterated until various numbers of noise events had been processed and a final annoyance count had been obtained; or in effect, until the integrated annoyance of a day's worth of exposures to individual commuter and jet aircraft overflights had been simulated. Several cases, representing various fleet mixes and different means and variances of the distributions of SEL values of aircraft overflights, were evaluated. The mean of the tolerance index was held constant at 100 and its standard deviation was fixed at 10 in the first three cases described below.

Table 10 summarizes a set of base case simulation runs corresponding to an airport served by a homogeneous fleet of all jet aircraft. All SEL values for aircraft overflights were therefore drawn from the same distribution. As expected, no differences were observed in the base case illustrated in Table 10 between the predictions of the integrated exposure and annoyance counting models. DNL grew by 8 dB (from 62.5 to 70.4 dB) as the number of operations of a homogeneous fleet of all jet aircraft increased from 120 to 740 per day. As expected, the annoyance count also grew by 8 dB (10 log 127/20), demonstrating that the integrated exposure and integrated annoyance models yield similar predictions in the base case.

Table 10 Comparison of rate of growth of integrated noise exposure and integrated annoyance for base case simulation (all jet fleet).

NUMBER OF AIRCRAFT OPERATIONS	DAY-NIGHT AVERAGE SOUND LEVEL	ANNOYANCE COUNT (SEL EXCEEDS TOLERANCE THRESHOLD)
120	62.5 dB	20
140	63.0	23
180	64.2	31
260	65.8	43
420	67.9	69
740	70.4	127

Tables 11 and 12 summarize the results of two additional sets of simulation runs, in which the jet aircraft noise events were assumed to have a mean SEL of 90 dB, and the commuter aircraft events had a mean SEL of 80 dB. The standard deviation for both exposure distributions was held at 2 dB in Table 11 and at 3 dB in Table 12. These cases correspond loosely to points on the ground fairly close to the approach end of a runway at a mid-size airport. The predictions of the integrated exposure and integrated annoyance models show some divergence in these cases.

In Table 11, integrated exposure increases by 2.1 dB (from 61.1 dB to 63.2 dB) as the number of commuter operations increases from 20 to 640 a day, while integrated annoyance increases by 3 dB (10 log 31/17). In Table 12, integrated exposure increases by 2.2 dB (from 61.77 dB to 63.9 dB) as the number of commuter operations increases from 20 to 640 a day, while integrated annoyance increases by 3.1 dB (10 log 35/17). In other words, the annoyance integration model exhibits a somewhat greater sensitivity to numbers of events than the conventional exposure integration model in this case.

Table 11 Comparison of rate of growth of integrated noise exposure and integrated annoyance for simulation in which mean SEL of jet aircraft exceeds mean SEL of commuter aircraft by 10 dB, with a constant 2 dB standard deviation for both distributions.

NUMBER OF COMMUTER OPERATIONS	NUMBER OF JET OPERATIONS	DAY-NIGHT AVERAGE SOUND LEVEL	ANNOYANCE COUNT (SEL EXCEEDS TOLERANCE THRESHOLD)
20	100	61.1 dB	17
40	100	61.2	18
80	100	61.4	19
160	100	61.7	19
320	100	62.3	25
640	100	63.2	31

Table 12 Comparison of rate of growth of integrated noise exposure and integrated annoyance for simulation in which mean SEL of jet aircraft exceeds mean SEL of commuter aircraft by 10 dB, with a constant 3 dB standard deviation for both distributions.

NUMBER OF COMMUTER OPERATIONS	NUMBER OF JET OPERATIONS	DAY-NIGHT AVERAGE SOUND LEVEL	ANNOYANCE COUNT (SEL EXCEEDS TOLERANCE THRESHOLD)
20	100	61.7 dB	17
40	100	61.8	20
80	100	61.9	19
160	100	62.3	19
320	100	63.0	28
640	100	63.9	35

Table 13 summarizes yet another set of simulation runs, in which the standard deviations of the distributions of jet and commuter SELs differ by a factor of two. The greater variability of the distribution of SEL values for commuter aircraft is intended to grossly reflect the greater flight track dispersion typical of commuter aircraft operations. The mean of the distribution of the tolerance index is shifted to a higher value for these calculations (to reflect a highly adapted and self-selected population living in proximity to an airport runway), and its standard deviation is increased.

Table 13 Comparison of rate of growth of integrated noise exposure and integrated annoyance for simulation in which mean SEL of jet aircraft exceeds mean SEL of commuter aircraft by 10 dB, with a 3 dB standard deviation for jets and a 6 dB standard deviation for commuter aircraft. The mean of the tolerance index distribution is set at 110 and its standard deviation at 15 for these predictions.

NUMBER OF COMMUTER OPERATIONS	NUMBER OF JET OPERATIONS	DAY-NIGHT AVERAGE SOUND LEVEL	ANNOYANCE COUNT (SEL EXCEEDS TOLERANCE THRESHOLD)
20	100	61.8 dB	9
40	100	62.0	11
80	100	62.4	12
160	100	62.9	15
320	100	63.9	21
640	100	65.4	31

As shown in Table 13, integrated exposure grew by 3.6 dB while the integrated annoyance predictions grew by 5.4 dB (10 log 31/9). The divergence between integrated exposure and integrated annoyance predictions is thus greater in this unequal variance/high tolerance threshold case than in the equal variance/low tolerance threshold cases discussed previously. In other words, the integrated annoyance model can show even greater sensitivity to numbers of events in response to variation in model assumptions.

B.5 IMPLICATIONS OF ANNOYANCE INTEGRATION MODEL

The practical significance of the relative difference in sensitivity of the integrated exposure and integrated annoyance models to numbers of aircraft operations depends in large part upon the manner in which integrated annoyance is transformed into a prediction of the prevalence of annoyance in communities. Like the transformation recommended by FICON in its preferred dosage-response relationship for converting summed SELs of overflights into prevalence of long term annoyance, a non-linear transformation of short term integrated annoyance counts into prevalence of long term annoyance seems reasonable.

If the curvilinear transform functions used to interpret each model's outputs in terms of prevalence of annoyance are parallel, then the greater sensitivity of the annoyance integration model to numbers of events in the cases noted above will also be reflected in predictions of the prevalence of annoyance. Since the slope of the FICON dosage-response relationship is about 2 to 3 percent highly annoyed per decibel of noise exposure in the range of practical interest, then differences on the order of 1 dB in relative sensitivity of the integrated exposure and integrated annoyance models to numbers of events will lead to differences of similar magnitude (that is, 2 to 3%) in predictions of prevalence of annoyance when large numbers of commuter operations are added to a constant number of jet operations. Thus, an annoyance integration model can predict increases in the prevalence of annoyance that are at least modestly disproportionate to increases in noise exposure when the number of events increases, as may be the case at growing airports that attract increased commuter service.

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This report examines several approaches to understanding "the commuter aircraft noise problem." The commuter aircraft noise problem in the sense addressed in this report is the belief that some aspect(s) of community response to noise produced by commuter aircraft operations may not be fully assessed by conventional environmental noise metrics and methods. The report offers alternate perspectives and approaches for understanding this issue. The report also develops a set of diagnostic screening questions; describes commuter aircraft noise situations at several airports; and makes recommendations for increasing understanding of the practical consequences of greater heterogeneity in the air transport fleet serving larger airports.

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