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Relationship between Aircraft Noise Contour Area and Noise Levels at Certification Points

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Abstract

The NASA Quiet Aircraft Technology (QAT) program curently uses the average of predicted noise reductions at three community locations as metrics of progress and success in meeting program noise reduction goals. As the QAT program has expanded to include reductions in airframe noise as well as reduction due to optimization of operating procedures for lower noise, there is concern that the current three-point methodology may not represent a fair measure of benefit to airport communities. The use of sound exposure level contour area reduction has been proposed as an alternative or supplemental metric, which can be directly related to total noise exposure and impact in actual airport environs. This paper addresses several topics related to this proposal: (1) an analytical basis for a relationship between certification noise levels and noise contour areas for departure operations is developed, (2) the relationship between predicted noise contour areas and the noise levels measured or predicted at the certification measurement points is examined for a wide range of commercial and business aircraft, and (3) reductions in contour area for low-noise approach scenarios are predicted and equivalent reductions in source noise are determined. The FAA's Integrated Noise Model, version 6.1, was used to predict noise levels and contour areas.

Introduction

Both the NASA Quiet Aircraft Technology (QAT) program and its predecessor the Advanced Subsonic Technology Noise Reduction (ASTNR) program have used the average of predicted noise reductions at three community locations as metrics of progress and success in meeting program noise reduction goals. These locations correspond to the measurement points specified in national and international noise certification standards. The original objective of the noise certification process was to prevent the escalation of noise levels of civil turbojet and transport aircraft [ref. 1]. It is generally assumed that technology, which reduces noise levels of future aircraft at these locations, will reduce noise levels in communities around airports and thereby reduce annoyance, complaints, and other adverse impacts of aircraft noise.

The noise metric selected for use in the noise certification procedure was the Effective Perceived Noise Level (EPNL), which considers frequency content, duration and tone content in addition to the sound pressure level of an aircraft noise event [ref. 2]. Two points are specified in the current (Stage 3) regulations for departure operations. One point is directly under the departure flight track a distance of 6500 m from brake release. The aircraft power has been cut back from full takeoff power to a reduced level that maintains certain safety related velocity and climb parameters prior to overflight of that measurement point. The other measurement point for departure is 450 m to the side of the runway centerline at a point of maximum noise level, after lift-off, while the aircraft is still under full take-off power. The third point is 2000 m from the touch down point during approach operations. At this point the aircraft is stabilized on the approach path with landing gear and flaps extended and at a power setting that maintains a safe velocity on a 3-degree glide slope. For consistency in this report, these points and associated noise levels will be referred to respectively as Takeoff (TO), Sideline (SL) and Approach (AP), as they are in the Federal Aviation Regulations Part 36 Noise Standards document [ref 3].

As the QAT program has expanded to include reductions in airframe noise as well as reduction due to optimization of operating procedures for lower noise, there has been concern that the current three point methodology used to assess the progress and success of the program may not represent a fair measure of benefit to airport communities. Reductions in airframe noise, which can be the dominant source on modern aircraft with high bypass ratio engines at the close-in approach measurement point, may have little benefit at more remote locations where the aircraft is in a “clean” configuration with landing gear, slats, and flaps in retracted positions. Therefore a given dB reduction at the approach measurement point, may not have the same effectiveness in reducing total airport noise exposure as the same dB reduction in fan or jet noise for departure operations. On the other hand, significant reductions in noise impact due to low-noise operations at distances greater than about 6000 m from touchdown will not be accounted for at all by noise levels at the approach certification point. As a consequence some alternative or supplemental metrics for the QAT program are being investigated.

The noise impact on airport communities is most commonly described in terms of noise exposure using the metric, Day-Night Average Sound Level (DNL) [ref 2]. The frequency content of the sounds is accounted for by use of the A-weighted sound level at any given instant in time. The time varying and multiple-event character of the airport noise is accounted for through energy averaging or summation of the A-weighted sound level over a 24-hour period. A 10 dB penalty is given to events that occur during the late night-early morning period, 2200 hours to 0700 hours. It is assumed that situations which have different numbers, different sound levels and different times of occurrence of events are equivalent in adverse impact if the situations have the same noise exposure measured in DNL. Consequently contours of equal DNL noise exposure are predicted or measured in the areas around airports to describe impact, define land use compatibility, and determine eligibility for noise mitigation efforts. DNL is specified for use in the Federal Aviation Regulations Part 150 Airport Noise Compatibility Planning document [ref 4].

Because of the energy averaging or summation used in the calculation of DNL, at any given point it is easy to account for the contribution of a single aircraft operation to the total exposure if energy of the single operation is known at the point. The Sound Exposure Level (SEL) for a time varying event like an aircraft flyover is defined as the A-weighted sound pressure level of a constant level event with duration of one second that has equal energy as the time varying event. Thus the combination for any number of events expressed in SEL can be easily combined into a total exposure in DNL. The use of contour area reduction in SEL is perhaps an attractive alternative or supplemental metric for the QAT program which can be directly related to total noise exposure and impact in actual airport environs. Other characteristics needed for the single event contour noise metric are that it can be related to the existing three-point assessment methodology and that it fairly represents airframe and operations noise reduction efforts.

This paper will address several topics related to the above stated concerns and needs. First, the paper will develop an analytical basis for a tradeoff relationship between certification noise levels and noise contour areas for departure operations. Second, the paper will examine the relationship between predicted noise contour areas and the noise levels measured or predicted at each of the certification measurement points for a wide range of commercial and business aircraft. Third, the paper will examine predicted reduction in contour area for low-noise approach scenarios and determine equivalent reduction in source noise. Predicted noise levels and contour areas for this study were obtained using the Integrated Noise Model, Version 6.1, developed by the Federal Aviation Administration [ref 5]. Measured certification noise levels were obtained from the web site for FAA Advisory Circular 36-1G, Appendix 1: Aircraft Noise Data for U.S. Certified Turbojet Powered Aircraft, http://www.aee.faa.gov/Noise/aee100_files/AC36-3G&1G/Appendix1.xls.

Analytical Basis for Relationship between Noise Levels at Certification Measurement Points and Noise Contour Areas

An airport noise contour is usually defined as a region about an airport with single or multiple runways within which the noise exposure is greater than or equal to a given level. To provide an analytical basis for a relationship between certification noise levels and the total area exposed to the given or greater noise levels, a simple geometric analysis is developed, which relates distances from the airport to certification noise levels for takeoff and sideline conditions. A generalized shape of a noise contour that is symmetric about a runway centerline is assumed as in figure 1.

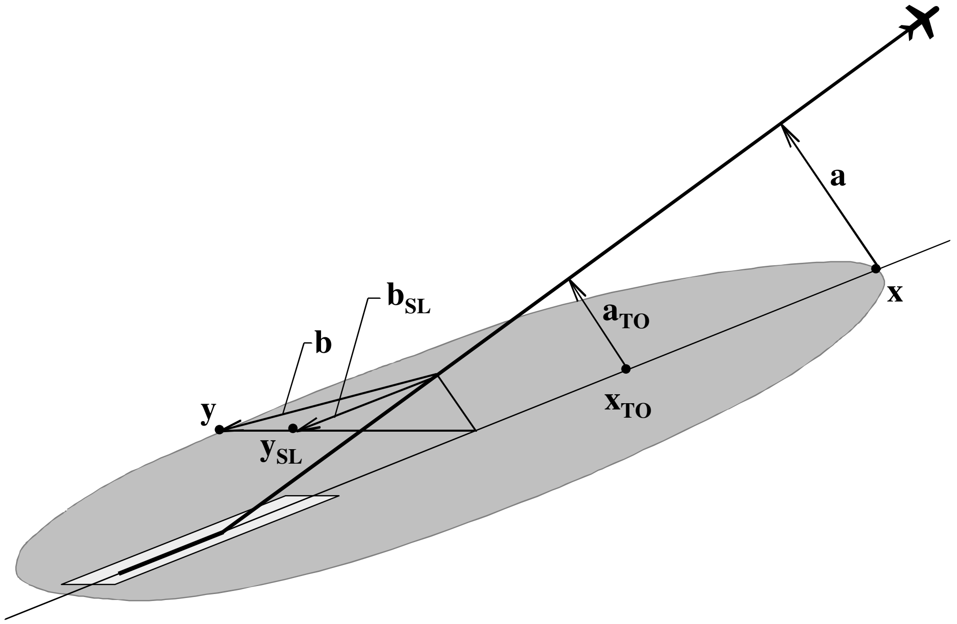


Figure 1. Generalized departure noise contour and geometric relationships to noise certification measurement locations

The noise level at all points on the contour is assumed to equal some value L; the takeoff and sideline certification levels are L_{TO} and L_{SL}, respectively. Constant power and acoustic output at the aircraft is assumed. If the sound pressure is assumed to be inversely proportional to distance, it can be shown that the difference between the takeoff certification level and the level at the end point of the contour is given by

$$L_{TO} - L \approx C \cdot \log(a/a_{TO}) \tag{1}$$

where C is some constant (20 for spherical spreading), a is the minimum distance from the aircraft flight path to the end point of the contour (or distance to the aircraft where the instantaneous noise level is at the maximum value during the flyover), and a_{TO} is the minimum distance from the aircraft to the takeoff certification noise measurement point. Since the distance from brake release to the takeoff certification measurement point, x_{TO}, and to the end of the noise contour, x, is usually large compared to the takeoff roll distance

$$a/a_{TO} \approx x/x_{TO} \tag{2}$$

and

$$L_{TO} - L \approx C \cdot \log(x/x_{TO}) \tag{3}$$

Thus the takeoff certification level of an aircraft is directly related to the length of a given noise contour for that aircraft through a reasonable logarithmic relationship.

Similarly, the difference between the sideline certification noise level and the level in the contour can be shown to be

$$L_{TO} - L \approx C \cdot \log(b/b_{SL}) \tag{4}$$

where b is the minimum distance from the aircraft to the maximum half-width of the contour and b_{SL} is the minimum distance from the aircraft to the sideline certification point. Thus the sideline noise certification level is similarly related to the width of the contour. If the maximum half-width of the contour, y, is greater than the distance from the runway centerline to the sideline certification point, $y_{SL,}$ then

$$b/b_{SL} \approx \quad y/y_{SL} \tag{5}$$

and

$$L_{SL} - L \approx C \cdot \log(y/y_{SL}) \tag{6}$$

Rewriting (3) and (6) in exponential form yields

$$x = x_{TO} \left\{ \frac{10^{L_{TO}/C}}{10^{L/C}} \right\} \tag{7}$$

and

$$y = y_{SL} \left\{ \frac{10^{L_{SL}/C}}{10^{L/C}} \right\} \tag{8}$$

Assuming that the contour area is in general proportional to the product of the length and width parameters, x and y, the multiplication of (7) and (8) yields

$$\text{Area} \propto \left(x_{TO} \cdot y_{SL}\right)\left\{\frac{10^{\left(L_{TO}+L_{SL}\right)/C}}{10^{2L/C}}\right\} \tag{9}$$

Rewriting in logarithmic form yields

$$\log\left(\text{Area}\right)=\frac{1}{C}\left(L_{TO}+L_{SL}\right)+D_L \tag{10}$$

where D_L is a constant that depends on the particular noise contour of interest, the exact form of the distance to sound pressure relationship, and the distances to the takeoff and sideline measurement points.

Based on the above simple analysis, it appears reasonable that for a takeoff operation the combination of takeoff and sideline certification measurements and a contour area rule are equivalent. The relationship in equation 10 could also be written in terms of the average of the TO and SL levels if the constant 1/C is replaced by 2/C. Conceptually the average of two sound pressure levels may be more appealing, rather than the sum of the two levels. In either case, a dB for dB trading relationship between takeoff and sideline certification noise levels would result in nearly a constant area within a given noise level contour and thereby would be an effective means of limiting noise impact of departure operations on airport communities.

Noise Certification and INM Data Sets Used in Contour Area and Noise Level Analyses

An initial set of 43 aircraft was selected to cover a wide range of commercial transport and business jet aircraft. This set included six Stage 2 aircraft in order to expand the range of contour area and certification levels for initial trend analyses. Information on aircraft model, engine model, engine bypass ratio (BPR), maximum takeoff weight (MTOW), maximum landing weight (MLW), certification noise levels, and several other parameters obtained from the FAA website for the advisory circular on U.S. measured certification levels is presented in Table I. Also presented in Table I are the aircraft type designation and takeoff weight (TOW) from the INM aircraft database.

Because of the different variants on many of the aircraft it was difficult to ascertain the match between the certification and INM aircraft database for each aircraft. No exact match was found for the INM 757300 case and certification data for a 757-200 with the same engine and very nearly the same takeoff weight was substituted. Except for this one case, examination of the data for the maximum takeoff weight (MTOW) listed in the certification database and the INM TOW, indicates that the INM data was always equal to or less than the value listed for the certification database.

Table I. Aircraft identification information and certification noise levels.

INM aircraft designation	Manufacturer	Model	Engine model	No. engs.	Stage	BPR	MTOW, 1000kg	INM TOW, 1000kg	MLW, 1000kg	Thrust, 1000N	Noise level (EPNL), dB		
											TO	SL	AP
707QN	Boeing	B-707-300B ADV/C (QNC)	JT3D-3B	4	2	1.40	151.95	149.70	112.26	80.07	104.4	98.9	107.9
717200	Boeing	B-717-200	BR700-715C1-30 (MP)	2	3	4.66	54.88	54.88	49.90	93.41	82.2	91.5	92.1
720B	Boeing	B-720B (QNC)	JT3D-3B	4	2	1.40	106.14	95.25	79.38	80.07	99.3	103.2	101.6
727D17	Boeing	B-727-200	JT8D-17RQN	3	2	0.97	94.35	85.73	64.64	77.40	102.4	104.2	103.2
727EM2	Boeing	B727-200 (FED EX; STC SA5839NM)	JT8D-15 w/BURBANK INLET+ FAN CSD	3	3	1.03	91.17	85.73	75.30	68.95	97.7	97.6	98.6
737300	Boeing	B-737-300	CFM56-3-B1	2	3	5.00	63.28	63.00	54.88	88.96	87.5	89.9	100.1
737800	Boeing	B-737-800	CFM56-7B27/2B1 DAC	2	3	5.10	79.02	78.15	66.36	121.44	85.9	94.3	96.8
737N17	Boeing	B-737-200 ADV (NORDAM; STC ST00131SE)	JT8D-17/-17A w/LGW HUSHKIT	2	3	1.01	52.39	47.63	44.45	71.17	89.7	97.5	96.0
74720B	Boeing	B-747-200	JT9D-7Q	4	3	4.90	377.84	351.53	272.16	235.76	103.2	103.5	106.6
747400	Boeing	B-747-400	PW4056	4	3	4.80	396.89	382.38	295.74	252.44	101.6	99.7	104.7
747SP	Boeing	B-747-SP	JT9D-7A	4	3	5.10	317.97	283.50	210.92	209.07	102.0	101.1	102.9
757300*	Boeing	B-757-200	PW 2037	2	3	5.80	99.79	100.70	89.81	169.92	86.2	94.0	97.7
757PW	Boeing	B-757-200	RB211-535E4-B	2	3	4.10	99.79	94.80	89.81	191.72	81.3	94.4	95.0
757RR	Boeing	B-757-300	RB211-535E4-B	2	3	4.10	124.74	122.20	101.60	191.72	88.4	94.8	95.4
767300	Boeing	B-767-300	PW 4060	2	3	4.80	184.61	166.79	145.15	266.89	93.2	97.0	100.2
767400	Boeing	B-767-400	CF6-80C2B8F	2	3	5.00	204.12	191.61	158.76	282.46	91.2	96.8	98.7
777200	Boeing	B-777-200	GE90-76B	2	3	8.40	247.21	242.67	208.65	338.06	88.8	93.2	97.8
777300	Boeing	B-777-300	RR TRENT 892	2	3	5.90	299.37	288.53	237.68	400.34	94.2	96.9	100.4
A300	Airbus	A300B4-203	CF6-50-C2	2	3	4.30	164.97	161.92	136.00	230.42	94.0	96.9	102.4
A30062	Airbus	A300B4-622R	PW-4158	2	3	4.85	174.63	170.51	138.12	258.00	93.1	97.9	101.9
A310	Airbus	A310-304	CF6-80C2A2	2	3	5.00	160.00	150.00	130.00	237.98	92.9	96.1	98.8
A319	Airbus	A319-131	V2522-A5	2	3	4.90	72.00	64.00	68.00	97.86	85.3	91.4	94.5
A320	Airbus	A320-211	CFM56-5A1	2	3	6.00	73.48	73.48	64.50	111.21	87.8	94.3	96.4
A330	Airbus	A330-301	CF6-80E1A2	2	3	5.05	230.00	211.83	190.00	292.69	94.2	97.2	98.7
A340	Airbus	A340-212	CFM56-5C3	4	3	6.60	270.00	256.96	200.00	144.57	96.1	95.4	97.2
BAE146	BAE Systems (BAe)	146-200A	ALF502R-5	4	3	5.70	42.18	41.28	36.74	31.00	85.2	87.3	95.8
CL600	Bombardier	CL-600	ALF-502L/L-2/L-2C	2	3	5.00	18.71	16.33	16.33	33.36	84.7	89.5	91.6
CNA55B	Cessna	550 CITATION Bravo	PW530A	2	3		6.71	6.71	6.12	9.79	73.7	85.2	91.2
CNA750	Cessna	750 CITATION X	AE3007C	2	3	5.30	16.19	16.19	14.42	22.24	72.3	83.0	90.2
EMB14L	EmbrAer	EMB-145LR	AE3007A1/1	2	3	4.76	22.00	22.00	19.30	33.72	79.4	84.6	92.5
F10065	Fokker	F100	TAY MK650-15	2	3	3.00	44.45	43.55	39.92	65.52	81.8	91.7	93.0
FA20	Dassault	FALCON 20-F (M1400)	CF700-2D-2	2	2	2.00	13.00	13.00	12.39	20.02	90.0	92.3	103.0
GII	Gulfstream	G-II GULFSTREAM	SPEY 511-8	2	2	0.64	29.71	25.40	26.54	50.71	92.5	103.0	98.3
GIV	Gulfstream	G-IV	TAY 611-8	2	3	3.00	33.20	28.76	26.54	61.61	76.8	87.3	91.0
GV	Gulfstream	G-V	BR700-710A1-10	2	3	4.20	41.05	34.89	34.16	65.39	80.3	89.1	90.8
IA1125	Israel Aircraft	1125 ASTRA	TFE731-3A-200G	2	3		11.20	10.66	9.39		84.1	89.7	89.8
L10115	Learjet	35A/36A	TFE731-2-2B	2	3	2.64	8.30	8.30	6.94	15.57	79.2	86.7	91.4
LEAR35	Lockheed	L-1011-500	RB211-524B	3	3	4.50	224.98	213.19	166.92	222.41	98.4	97.8	101.5
MD11GE	McDonnell Douglas	MD-11	CF6-80C2D1F	3	3	5.30	273.29	263.08	195.04	273.57	92.8	96.3	103.6
MD11PW	McDonnell Douglas	MD-11	PW4460	3	3	5.00	285.99	263.08	218.40	266.89	95.8	96.1	104.4
MD81	McDonnell Douglas	MD-80	JT8D-209	2	3	1.83	63.50	62.14	58.06	85.63	88.9	94.7	92.8
MD9028	McDonnell Douglas	MD-90-30	V2528-D5	2	3	4.80	75.30	70.76	64.41	124.55	82.6	91.0	91.9
SAB80	Sabreliner	SABRELINER 80A/80SC	CF700-2D-2	2	2	2.00	11.57	11.14	9.98	20.02	91.2	91.4	101.1

INM cases were set up for each of the aircraft in Table I using the longest stage-length standard departure profile. A straight departure track on the runway centerline was specified for each single-flight operation. Locations corresponding to the TO certification point under the flight track and 6500 m from brake release and to points 450 m from the runway centerline, spaced 200 m apart starting at 1000 m from brake release, were specified to capture the predicted TO and SL certification noise levels. Noise levels at the TO and SL certification points predicted by INM, along with the reported certification levels, are presented in Table II. Cases were run for each aircraft to predict SEL and EPNL departure contours and areas within the contours in 5 dB increments from 80 dB to 100 dB for SEL and from 85 dB to 105 dB for EPNL. Areas within these contours are presented in Table III.

INM cases were also set up for each of the Stage 3 aircraft in Table I using the INM standard approach profile and landing weight, a straight approach track, and a single operation. The approach certification point under the flight track and 2000 m from threshold was specified to obtain the predicted approach certification noise levels. Cases were run for each aircraft to predict SEL approach contours and areas within the contours in 5 dB increments from 80 dB to 100 dB. These areas are presented in Table IV along with measured certification noise levels in EPNL and predicted levels in SEL at the approach certification point.

Table II. Measured and predicted noise levels at takeoff and sideline certification measurement locations.

INM aircraft designation	Certification noise level (EPNL), dB		INM calculated noise level (EPNL), dB		INM calculated noise level (SEL), dB	
	Takeoff	Sideline	Takeof	Sideline	Takeoff	Sideline
707QN	104.4	98.9	108.9	106.0	106.2	103.6
717200	82.2	91.5	85.8	87.8	84.0	85.7
720B	99.3	103.2	102.7	106.9	99.1	103.8
727D17	102.4	104.2	111.1	109.1	109.0	107.2
727EM2	97.7	97.6	105.9	102.4	102.8	99.5
737300	87.5	89.9	84.7	90.0	83.5	88.9
737800	85.9	94.3	93.1	94.9	90.6	92.5
737N17	89.7	97.5	95.1	101.5	93.2	99.8
74720B	103.2	103.5	106.3	104.0	102.0	100.4
747400	101.6	99.7	102.2	100.0	97.7	95.7
747SP	102.0	101.1	102.2	101.2	97.2	96.6
757300	88.4	94.8	95.0	95.4	92.3	92.9
757PW	86.2	94.0	90.0	94.1	84.0	89.3
757RR	81.3	94.4	88.4	95.6	85.8	93.1
767300	93.2	97.0	94.5	101.4	91.6	97.2
767400	91.2	96.8	93.4	97.0	89.7	94.5
777200	88.8	93.2	92.4	93.0	89.1	90.2
777300	94.2	96.9	96.1	97.0	92.7	94.5
A300	94.0	96.9	96.4	97.1	92.7	93.4
A30062	93.1	97.9	93.3	98.9	88.7	94.8
A310	92.9	96.1	90.5	93.6	87.4	90.6
A319	85.3	91.4	85.7	91.2	83.2	88.8
A320	87.8	94.3	91.2	95.1	86.9	90.8
A330	94.2	97.2	94.9	97.4	91.1	94.5
A340	96.1	95.4	98.9	94.5	95.3	91.8
BAE146	85.2	87.3	92.4	90.2	89.7	88.0
CL600	84.7	89.5	80.1	85.9	79.9	85.2
CNA55B	73.7	85.2	78.7	84.1	78.6	83.3
CNA750	72.3	83.0	78.8	79.5	77.6	77.9
EMB14L	79.4	84.6	81.4	84.3	80.1	83.0
F10065	81.8	91.7	86.8	91.1	84.1	89.8
FA20	90.0	92.3	91.8	92.4	91.0	91.5
GII	92.5	103.0	93.9	99.0	95.4	98.3
GIV	76.8	87.3	79.4	85.8	77.4	83.6
GV	80.3	89.1	83.3	88.1	82.0	85.4
IA1125	84.1	89.7	87.3	88.5	85.5	86.6
L10115	98.4	97.8	98.5	97.6	96.5	95.8
LEAR35	83.9	87.8	83.9	92.0	84.2	91.5
MD11GE	92.8	96.3	97.1	95.8	94.5	93.4
MD11PW	95.8	96.1	98.5	94.9	94.0	91.3
MD81	88.9	94.7	93.8	93.9	93.0	92.8
MD9028	82.6	91.0	85.3	90.2	85.1	89.5
SAB80	91.2	91.4	91.8	92.4	91.0	91.5

Table III. Area contained within EPNL and SEL contours for departure operations.

INM aircraft designation)	Area in EPNL contour, sq. km					Area in SEL contour, sq. km				
	85dB	90dB	95dB	100dB	105dB	80dB	95dB	90dB	95dB	100dB
707QN	199.4	77.2	34.5	17.0	7.3	296.7	153.1	55.8	24.9	12.2
717200	6.4	2.8	1.5	0.7	0.4	12.6	4.5	2.0	0.8	0.4
720B	80.4	40.7	19.8	9.3	4.5	107.0	51.9	25.9	12.6	6.2
727D17	179.8	89.0	40.6	18.1	9.0	266.9	148.1	71.2	32.4	14.3
727EM2	60.6	27.2	13.2	7.4	3.9	115.6	46.8	20.1	9.7	5.3
737300	6.8	2.9	1.0	0.5	0.3	14.2	5.5	2.2	0.8	0.3
737800	17.8	8.7	3.9	1.6	0.8	32.7	12.6	6.2	2.3	1.0
737N17	43.5	18.3	8.0	4.0	1.5	68.7	30.5	12.9	6.3	3.0
74720B	75.2	37.9	17.8	10.0	4.6	139.6	62.5	26.3	13.2	5.6
747400	57.9	26.1	12.5	5.3	2.2	82.6	34.8	15.2	6.2	2.4
747SP	56.8	27.9	12.4	5.9	2.6	81.3	36.1	14.9	6.3	2.4
757300	16.9	9.6	4.7	1.8	0.8	28.8	13.3	7.3	2.9	1.2
757PW	12.0	5.8	2.8	1.2	0.5	13.1	5.8	2.8	1.1	0.5
757RR	12.4	5.7	2.8	1.1	0.5	20.9	8.9	4.0	1.8	0.9
767300	33.7	15.7	7.6	4.2	1.8	51.1	22.0	9.8	4.8	1.8
767400	23.3	10.1	4.1	2.1	1.0	37.8	15.2	5.9	2.9	1.4
777200	15.6	6.9	2.8	1.3	0.7	23.5	10.2	3.8	1.7	0.8
777300	30.5	13.9	5.6	2.6	1.2	48.9	21.2	8.4	3.7	1.8
A300	25.7	12.8	5.8	2.4	1.1	41.0	18.3	8.2	2.9	1.1
A30062	23.8	10.9	6.0	3.1	1.3	32.5	13.3	6.6	3.4	1.3
A310	13.1	6.3	3.1	1.3	0.7	22.1	8.5	4.1	1.6	0.7
A319	7.6	4.0	1.6	0.7	0.3	11.4	5.7	2.4	0.9	0.3
A320	14.2	7.6	3.9	1.6	0.8	18.5	8.4	4.1	1.5	0.6
A330	24.3	10.9	5.7	2.5	1.1	39.5	15.5	7.3	3.5	1.3
A340	24.2	12.6	6.1	2.6	1.3	39.1	17.8	8.9	3.2	1.4
BAE146	12.6	5.7	2.1	0.8	0.3	20.7	9.5	3.3	1.1	0.4
CL600	4.3	2.0	0.9	0.4	0.2	8.2	3.9	1.5	0.6	0.3
CNA55B	3.0	1.6	0.8	0.3	0.2	5.8	2.7	1.2	0.4	0.2
CNA750	2.2	1.1	0.5	0.3	0.2	3.4	1.5	0.7	0.3	0.3
EMB14L	2.9	1.4	0.6	0.3	0.2	5.8	2.2	0.9	0.3	0.2
F10065	9.0	4.4	2.0	0.9	0.4	16.9	7.1	3.6	1.4	0.6
FA20	13.2	6.6	3.3	1.7	0.9	27.7	12.8	6.1	2.6	1.2
GII	69.2	29.3	9.2	2.5	1.3	138.8	70.7	30.4	10.0	2.7
GIV	3.4	1.5	0.8	0.4	0.2	5.8	2.4	1.1	0.6	0.3
GV	5.8	2.6	1.3	0.6	0.3	11.3	4.1	1.7	0.7	0.3
IA1125	7.5	3.8	1.7	0.8	0.4	12.5	6.2	2.5	1.0	0.5
L10115	27.9	13.5	6.9	3.3	1.7	61.2	27.0	11.8	5.3	2.2
LEAR35	7.6	4.3	2.3	1.3	0.7	16.4	7.8	4.2	2.0	1.0
MD11GE	19.4	9.3	5.0	2.5	1.2	40.2	15.4	6.9	3.5	1.4
MD11PW	21.2	10.0	5.4	2.5	1.3	36.2	14.2	6.5	2.8	1.3
MD81	19.6	8.6	3.8	1.4	0.6	43.8	18.4	7.4	3.0	1.0
MD9028	7.6	3.7	1.9	0.9	0.5	18.5	7.3	3.3	1.5	0.7
SAB80	13.2	6.5	3.2	1.7	0.9	27.6	12.7	6.1	2.6	1.2

Table IV. Area contained within SEL contours for approach operations and noise levels for the Stage 3 aircraft at the certification measurement location.

INM aircraft designation	Area in SEL contour, sq. km					Certification noise level (EPNL), dB	INM calculated noise level (SEL), dB
	80dB	95dB	90dB	95dB	100dB		
717200	3.6	1.2	0.5	0.3	0.2	92.1	88.3
727EM2	32.1	14.4	6.6	2.6	1.1	98.6	102.1
737-300	30.0	13.3	5.7	2.3	1.0	101.1	101.5
737800	14.2	4.4	1.3	0.5	0.3	96.8	93.4
737N17	9.1	3.7	1.1	0.5	0.3	96.0	92.6
74720B	45.0	19.0	7.6	2.7	1.0	106.6	101.1
747400	34.6	14.1	5.6	2.2	1.0	104.7	100.4
747SP	22.6	10.2	4.7	1.8	0.8	102.9	99.8
757300	9.7	3.0	1.0	0.5	0.3	97.7	91.8
757PW	10.0	3.8	1.3	0.6	0.3	95.0	93.2
757RR	9.4	3.1	1.0	0.5	0.3	95.4	92.0
767300	15.8	6.7	2.4	0.8	0.4	100.2	95.8
767400	19.2	7.0	2.4	1.0	0.6	98.7	95.1
777200	12.4	4.9	1.9	0.9	0.5	97.8	94.6
777300	19.3	7.6	2.7	1.2	0.7	100.4	96.1
A300	12.2	5.4	2.1	1.0	0.6	102.4	95.8
A30062	23.8	9.6	3.3	1.3	0.7	101.9	97.9
A310	14.5	5.9	2.2	0.9	0.6	98.8	95.0
A319	6.4	2.8	1.1	0.6	0.4	94.5	92.1
A320	9.5	3.1	1.1	0.5	0.3	96.4	92.2
A330	17.0	6.7	2.1	0.8	0.4	98.7	95.3
A340	14.8	5.6	2.0	1.0	0.6	97.2	94.5
BAE146	6.6	2.5	0.8	0.4	0.2	95.8	91.0
CL600	1.9	0.8	0.4	0.2	0.1	91.6	86.1
CNA55B	3.3	1.1	0.4	0.2	0.1	91.2	88.5
CNA750	3.7	1.3	0.6	0.2	0.1	90.2	90.5
EMB14L	3.5	1.1	0.5	0.3	0.2	92.5	88.0
F10065	5.1	1.6	0.6	0.3	0.3	93.0	89.2
GIV	2.6	0.8	0.3	0.1	0.1	91.0	87.1
GV	5.1	1.7	0.5	0.2	0.1	90.8	90.3
IA1125	1.3	0.5	0.3	0.2	0.2	89.8	83.4
L10115	17.2	8.8	3.9	1.6	0.9	101.5	98.8
LEAR35	2.3	0.8	0.4	0.2	0.2	91.4	86.7
MD11GE	14.8	5.5	1.6	0.7	0.4	103.6	93.8
MD11PW	20.1	7.3	2.5	0.9	0.4	104.4	96.6
MD81	5.5	1.7	0.6	0.4	0.3	92.8	88.7
MD9028	5.5	1.7	0.7	0.3	0.2	91.9	90.3

Relationship between Contour Area and Noise Levels at Certification Measurement Points

A number of different correlation analyses were run on the data presented in the previous section. First a comparison was made between measured certification noise levels and INM predictions at certification measurement points for typical airport flight operations. Second, the relationship between noise contour area and measured and predicted noise levels at the certification points was examined. Both of these types of analyses were conducted for departure and approach operations, however more emphasis was placed on the departure operations since it was particularly desired to investigate the nature of the relationship between TO and SL noise levels as they affect the area in the departure contour.

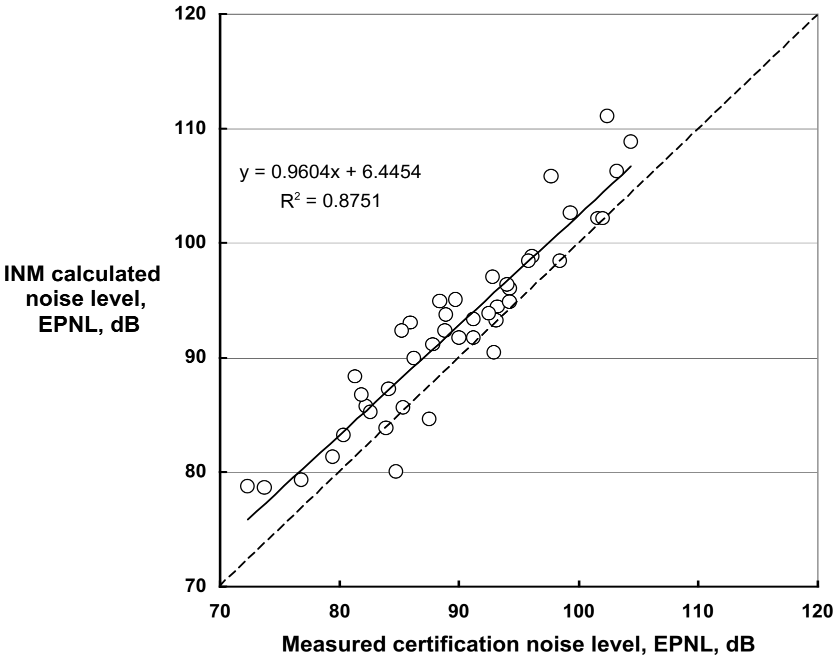
Departure Operations

Certification noise levels and predicted noise levels at certification points

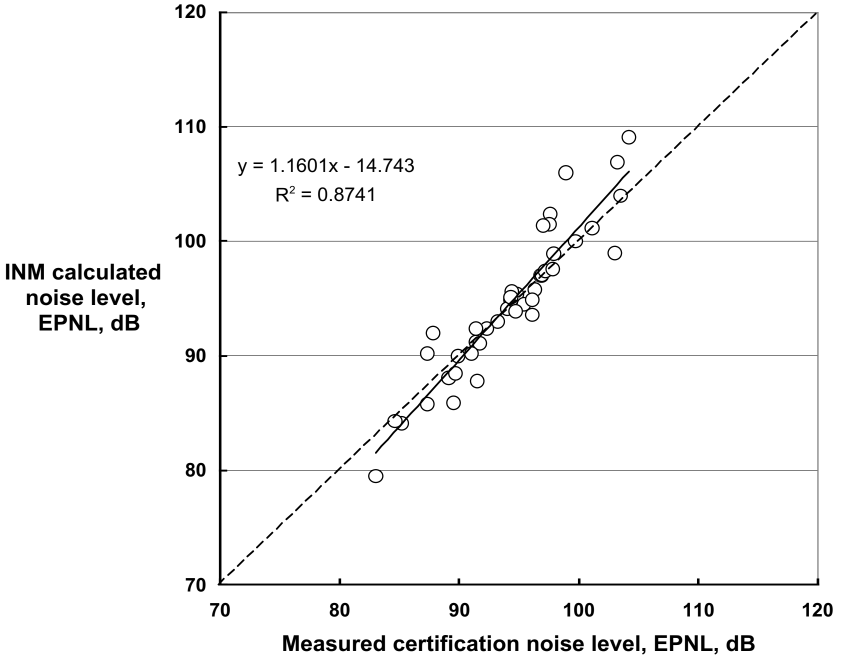
Comparisons of the reported certification noise levels and INM predictions of noise levels in terms of EPNL at the takeoff and sideline certification points for the full set of aircraft are presented in figures 2(a) and 2(b), respectively. Results of linear least square regression analyses are shown in the inset in each figure. Although the explained variance in the data (the square of the correlation coefficient, R) is very nearly the same for both points, there are some differences in the two relationships. At the takeoff measurement point the INM predictions are on average about 3 dB greater than the reported certification levels, whereas at the sideline measurement point the INM predictions are on average less than 0.5 dB greater. The difference at the takeoff point could be due to deeper cutbacks during certification than in normal airport operations, which would result in lower noise levels at certification. At the sideline point the noise level should be a result of full takeoff power for both certification and airport operations and the levels are in better agreement.

Contour areas

The calculated areas contained within EPNL and SEL contours for departure operations for the full set of aircraft examined are presented in Table III. Relationships between the sum of TO and SL certification noise levels with the logarithm of area within the SEL 80, 90, and 100 dB SEL contours are presented in figures 3, 4, and 5 for measured EPNL, INM predicted EPNL, and INM predicted SEL at the certification measurement points, respectively. The trends in each figure appear to be linear with high correlation for each set of contour levels and for each of the TO+SL metrics. In general, correlation was least for measured EPNL and greatest for predicted SEL. The contours for each aircraft were visually examined for anomalies and several contours were identified that were truncated because the INM calculations stopped when the aircraft reached 3048 m altitude. The SEL contours for these aircraft are shown in figures 6 (a), (b), and (c); each of theses cases was a Stage 2 aircraft. Since Stage 2 aircraft are not representative of commercial transports in current use, all further analyses to be presented will be limited to the Stage 3 aircraft.



(a) Takeoff measurement location



(b) Sideline measurement location

Figure 2. Comparison of INM predicted EPNL noise levels with measured EPNL certification noise levels for departure operations.

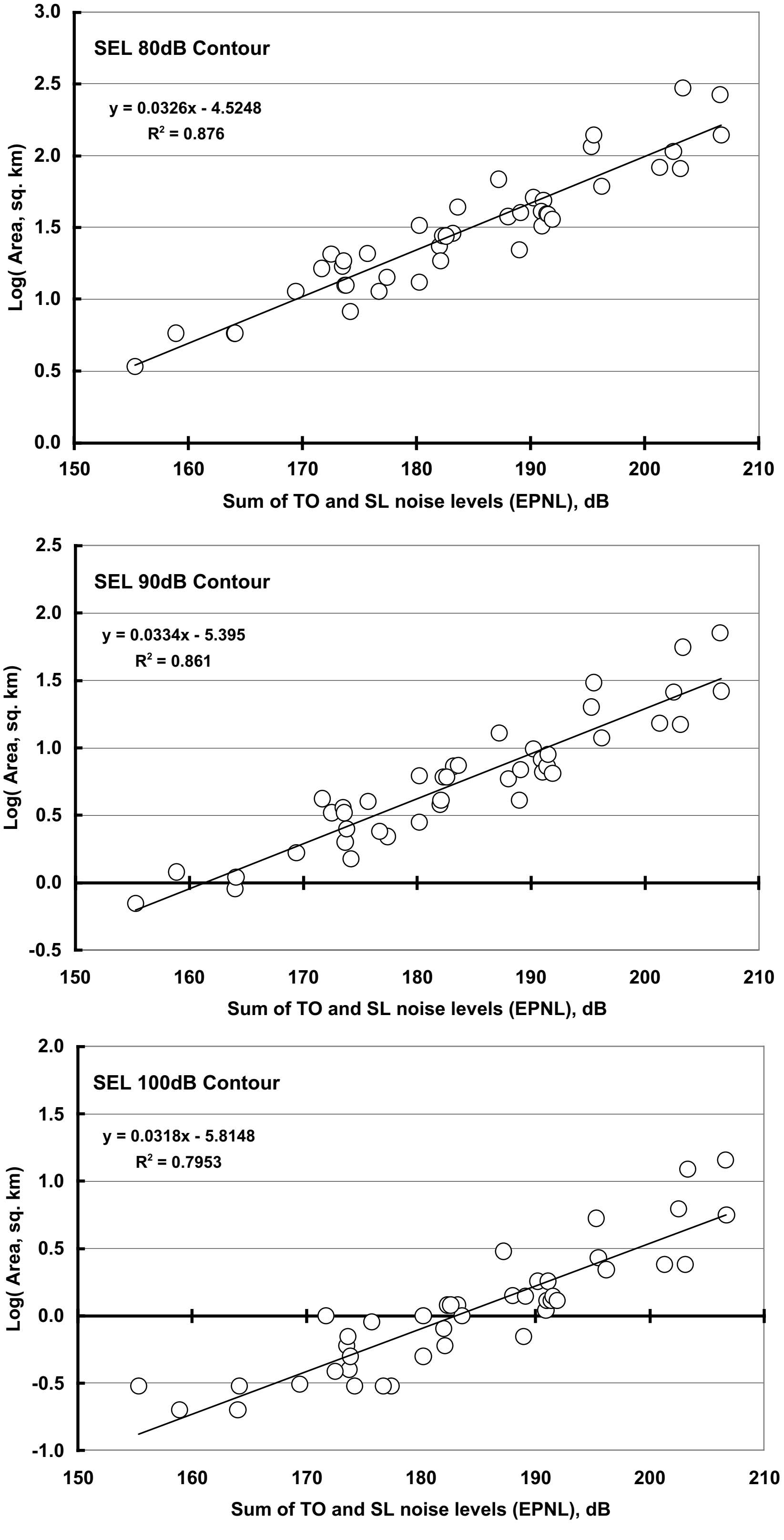
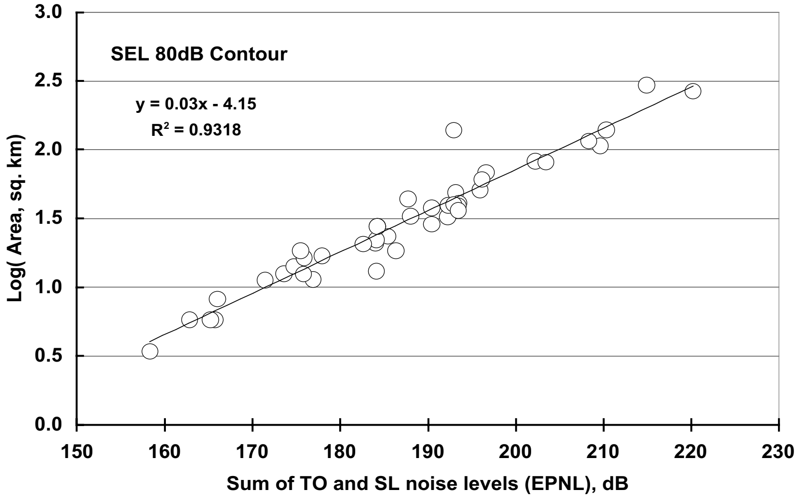
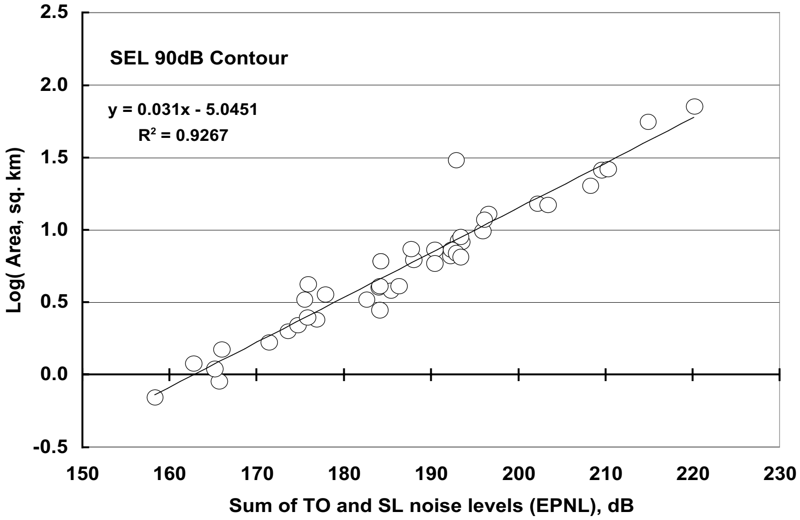


Figure 3. Relationship of area within 80 dB, 90 dB, and 100 dB SEL contours to sum of takeoff and sideline noise levels in certification measured EPNL.





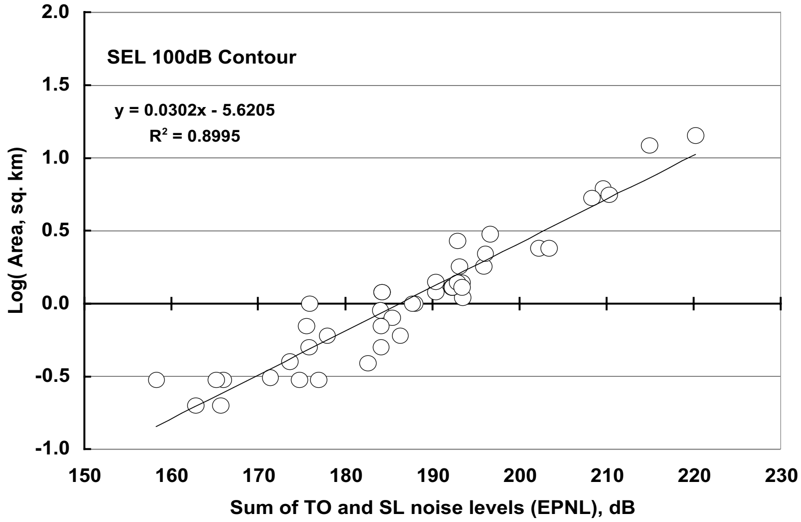


Figure 4. Relationship of area within 80 dB, 90 dB, and 100 dB SEL contours to sum of takeoff and sideline noise levels in INM predicted EPNL.

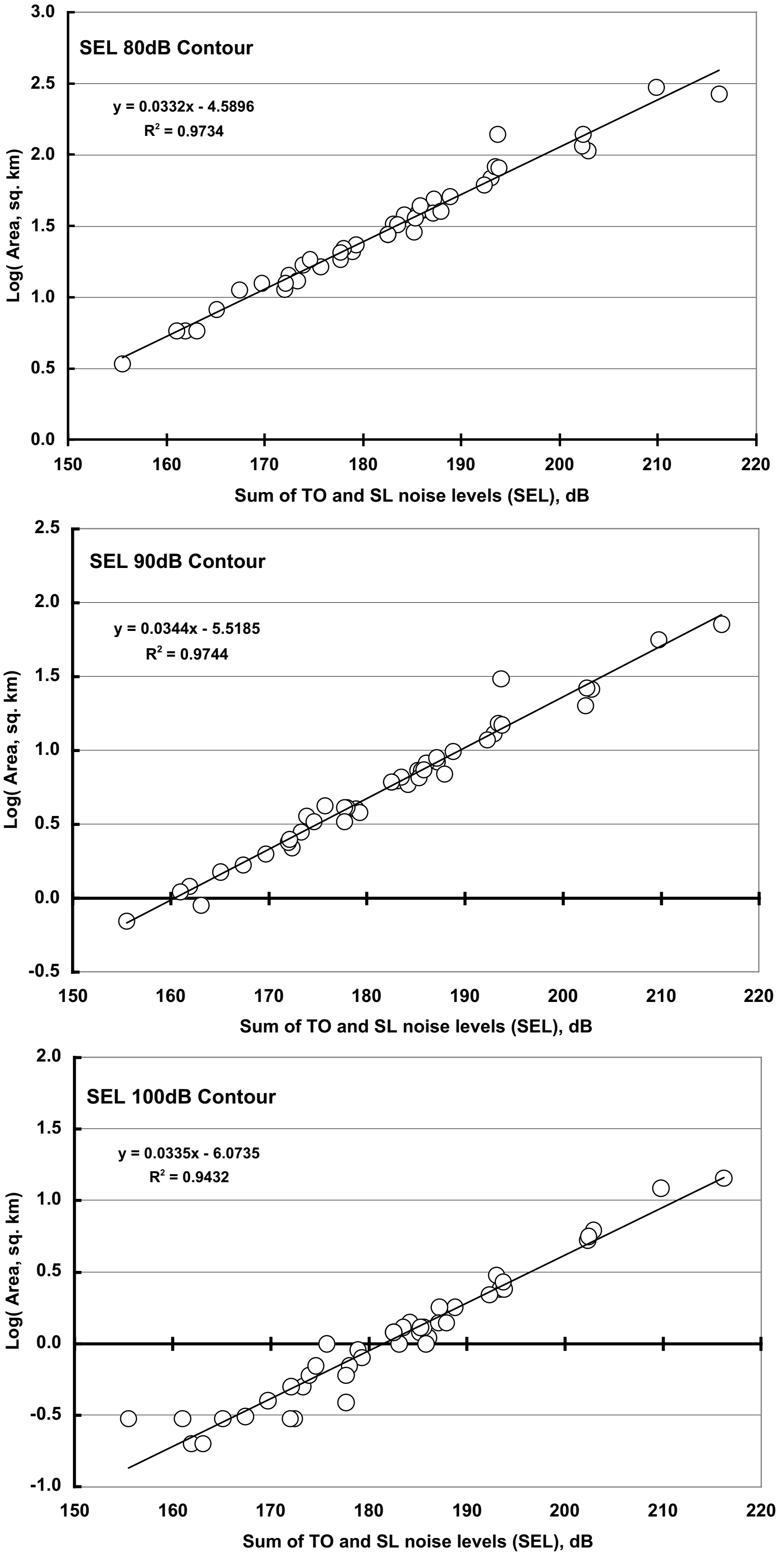
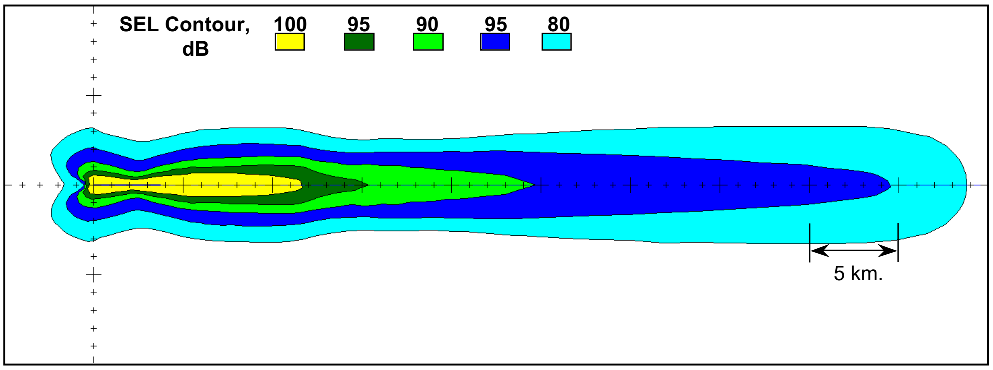
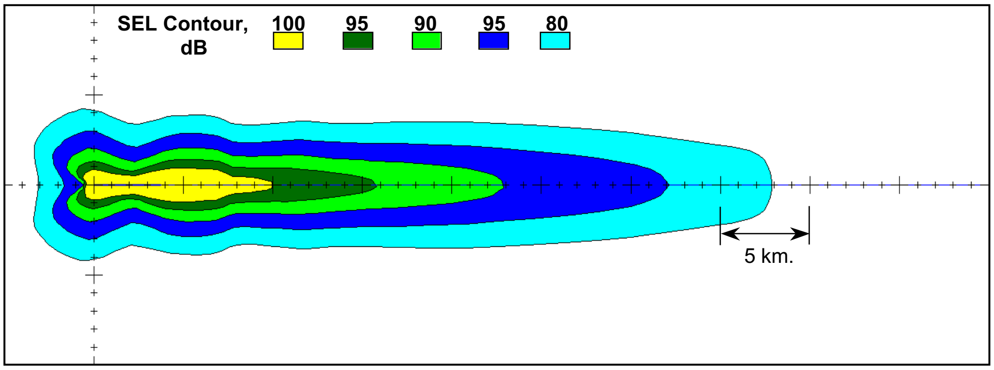


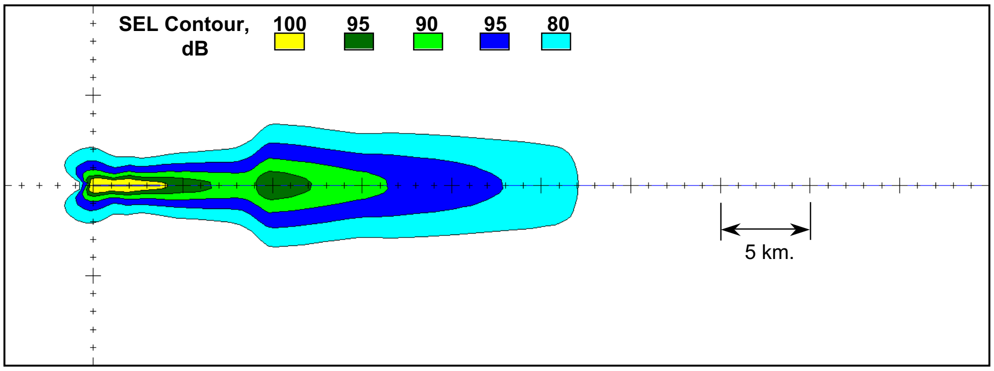
Figure 5. Relationship of area within 80 dB, 90 dB, and 100 dB SEL contours to sum of takeoff and sideline noise levels in INM predicted SEL.



(a). 707QN aircraft



(b). 727D17 aircraft



(c). GII aircraft

Figure 6. Noise contours for departure operations for Stage 2 aircraft, which exhibit truncation of the 80 dB SEL contour due to 3048 m altitude limit during INM calculations.

Correlation between contour area and noise levels at certification measurement points for Stage 3 aircraft

Linear least square regression analyses were conducted for the subset of Stage 3 aircraft using the logarithm (base 10) of the contour areas as the dependent variable with predicted and measured levels at the certification measurement points as independent variables. The independent variables included the TO and SL noise levels separately and the sum of the TO and SL noise levels. Results of the analyses are presented in Tables V, VI, and VII. Several general trends are noted.

The correlations for the SEL contours are generally greater when the noise levels at the certification measurement point are expressed in SEL. This is a very reasonable result since the same frequency weighting is used and tone corrections would have no influence. The correlations for the EPNL contours are generally greater when the noise levels at the certification measurement point are based on the INM predicted EPNL levels than when based on the INM SEL levels. The correlations for both the SEL contours and the EPNL contours are less when the levels at the certification points are based on measured certification EPNL levels than when based on EPNL or SEL levels predicted by INM.

For the cases where the independent variable is noise level at the TO measurement point (Table V) or the sum of the noise levels at the TO and SL measurement points (Table VII), correlation is generally greater for the more distant and lower contour levels than for the close in and higher contour levels. For the case where the independent variable is the noise level at the SL measurement point, the correlation is greatest for the 95 SEL and 95 EPNL contours.

For all cases, correlation is greater when the independent variable is the sum of the TO and SL noise levels at the certification points than either the TO or SL levels alone. From Table VII it is also apparent that the highest correlation is for the SEL contours with the sum of TO and SL from INM predicted SEL levels. However, very nearly as high correlation is found between the EPNL contours and sum of TO and SL from INM predicted EPNL levels.

Table VIII presents results of regression analyses between measurement point noise levels. The high correlation between the three metrics INM SEL, INM EPNL, and Cert. EPNL and between the SEL or EPNL contours and the three metrics when TO and SL levels are summed indicates that changes in the logarithm of contour area or changes in summed TO and SL levels are essentially equivalent measures of changes in airport community noise impact due to departure operations. The much lower correlation between levels at SL and TO points for all three metrics indicates that different characteristics are being measured or predicted at the two measurement points that would be missed if either point alone was used as a certification or noise impact surrogate.

Table V. Regression analyses of logarithm of noise contour area in square kilometers on noise level at TO measurement location.

Noise metric	R^2					Slope				
	SEL Contour									
	100 dB	95 dB	90 dB	85 dB	80 dB	100 dB	95 dB	90 dB	85 dB	80 dB
INM SEL	0.8520	0.8833	0.9188	0.9314	0.9338	0.0532	0.0586	0.0563	0.0565	0.0565
INM EPNL	0.8254	0.8637	0.9003	0.9006	0.9096	0.0460	0.0509	0.0489	0.0490	0.0490
Certification EPNL	0.7111	0.7854	0.8136	0.8272	0.8290	0.0417	0.0473	0.0454	0.0457	0.0457
	EPNL Contour									
	105 dB	100 dB	95 dB	90 dB	85 dB	105 dB	100 dB	95 dB	90 dB	85 dB
INM SEL	0.8769	0.8764	0.8926	0.9045	0.9004	0.0519	0.0571	0.0570	0.0570	0.0572
INM EPNL	0.8816	0.8996	0.9206	0.9317	0.9273	0.0458	0.0508	0.0509	0.0508	0.0510
Certification EPNL	0.8223	0.8213	0.8341	0.8447	0.8442	0.0431	0.0474	0.0473	0.0472	0.0474

Table VI. Regression analyses of logarithm of noise contour area in square kilometers on noise level at SL measurement location.

Noise metric	R^2					Slope				
	SEL Contour									
	100 dB	95 dB	90 dB	85 dB	80 dB	100 dB	95 dB	90 dB	85 dB	80 dB
INM SEL	0.8649	0.9364	0.9269	0.9183	0.9160	0.0692	0.0778	0.0729	0.0724	0.0723
INM EPNL	0.8430	0.9204	0.9151	0.9022	0.9015	0.0608	0.0687	0.0645	0.0639	0.0638
Certification EPNL	0.7739	0.8491	0.8463	0.8342	0.8468	0.0699	0.0791	0.0743	0.0737	0.0741
	EPNL Contour									
	105 dB	100 dB	95 dB	90 dB	85 dB	105 dB	100 dB	95 dB	90 dB	85 dB
INM SEL	0.8387	0.8868	0.8905	0.9003	0.9034	0.0656	0.0741	0.0735	0.0734	0.0739
INM EPNL	0.8670	0.9281	0.9355	0.9389	0.9395	0.0593	0.0675	0.0671	0.0667	0.0671
Certification EPNL	0.8219	0.8678	0.8928	0.8812	0.8859	0.0692	0.0782	0.0785	0.0774	0.0781

Table VII. Regression analyses of logarithm of noise contour area in square kilometers on the sum of noise levels at the TO and SL measurement locations.

Noise metric	R^2					Slope				
	SEL Contour									
	100 dB	95 dB	90 dB	85 dB	80 dB	100 dB	95 dB	90 dB	85 dB	80 dB
INM SEL	0.9130	0.9649	0.9819	0.9855	0.9858	0.0320	0.0356	0.0338	0.0338	0.0338
INM EPNL	0.8770	0.9350	0.9546	0.9526	0.9540	0.0276	0.0308	0.0293	0.0292	0.0292
Certification EPNL	0.7673	0.8453	0.8625	0.8665	0.8726	0.0273	0.0309	0.0294	0.0294	0.0295
	EPNL Contour									
	105 dB	100 dB	95 dB	90 dB	85 dB	105 dB	100 dB	95 dB	90 dB	85 dB
INM SEL	0.9157	0.9378	0.9493	0.9610	0.9599	0.0309	0.0343	0.0342	0.0341	0.0343
INM EPNL	0.9215	0.9601	0.9761	0.9842	0.9819	0.0272	0.0305	0.0305	0.0304	0.0305
Certification EPNL	0.8584	0.8760	0.8942	0.8965	0.8980	0.0277	0.0308	0.0308	0.0306	0.0308

Table VIII. Regression analysis results for relationships between noise levels using different metrics at departure certification noise measurement points.

Regression analysis			R^2	Slope	Intercept
INM EPNL(TO+SL)	on	INM SEL(TO+SL)	0.970	1.204	16.5
Cert. EPNL(TO+SL)	on	INM EPNL(TO+SL)	0.905	0.900	15.6
Cert. EPNL(TO+SL)	on	INM SEL(TO+SL)	0.862	0.995	2.3
INM SEL(SL)	on	INM SEL(TO)	0.769	0.679	30.9
INM EPNL(SL)	on	INM EPNL(TO)	0.806	0.687	30.9
Cert. EPNL(SL)	on	Cert. EPNL(TO)	0.829	0.567	43.4

Approach Operations

Certification noise levels and predicted noise levels at certification point

Measured EPNL and INM calculated SEL values at the certification measurement point for the data set of all of the Stage 3 aircraft in the present study are presented in Table IV along with SEL contour areas. Figure 7 shows the relationship of SEL values predicted by INM to the measured EPNL values at the approach certification measurement point. Although there is a strong correlation, considerable scatter is apparent in the data. The greatest deviation from the regression line is for the aircraft designated as 727EM2, a hushkit retrofit to an earlier Stage 2 aircraft

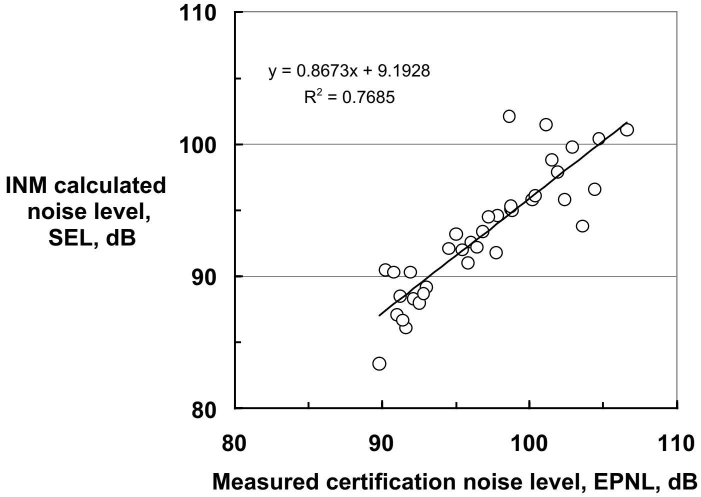


Figure 7. Comparison of INM predicted SEL noise levels with measured certification EPNL noise levels for approach operations.

Contour areas

The calculated areas contained within EPNL and SEL contours for approach operations for the Stage 3 aircraft are presented in Table IV. Relationships between the certification point noise levels in SEL with the logarithm of area within the 80 dB, 90dB, and 100 dB SEL contours are presented in figure 8. The trends in each figure appear to be linear with high correlation for each set of contour levels. The areas, averaged across the subset of Stage 3 aircraft, within the SEL 80 dB, 85 dB, 90 dB, 95 dB, and 100dB approach contours are respectively, 0.38, 0.35, 0.31, 0.29, and 0.35 times the area of the departure contours.

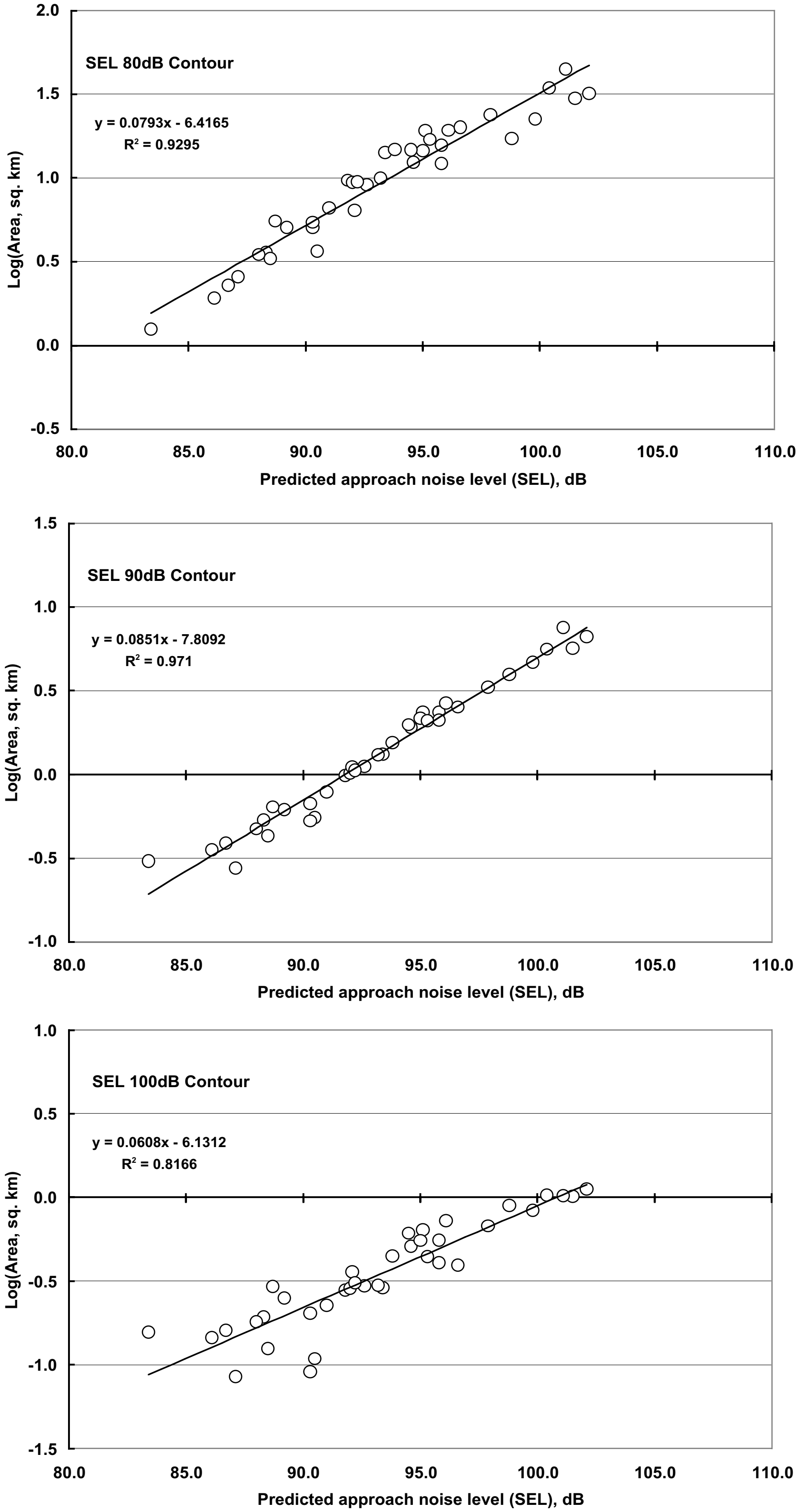


Figure 8. Relationships of area within 80 dB, 90 dB, and 100 dB SEL contours to approach noise levels in INM predicted SEL.

Correlation between contour area and noise level at the certification measurement points

Linear least square regression analyses were conducted for the subset of Stage 3 aircraft using the logarithm (base 10) of the contour areas as the dependent variable with predicted and measured levels at the approach certification measurement point as independent variables. Results of these analyses for the SEL contours are presented in Table IX. As was found for the departure cases, the correlations for the INM predicted SEL values are greater than for the measured certification EPNL values. The greatest correlations are noted for the SEL 90 dB and 85 dB contours and are nearly as great as for the departure cases where the TO and SL noise levels were summed. The slopes for both SEL and measured EPNL are somewhat greater than departure cases of TO and SL levels separately.

Table IX. Regression analyses of logarithm of noise contour area in square kilometers on the noise level at the approach measurement location.

Certification point noise metric	SEL Contour				
	100 dB	95 dB	90 dB	85 dB	80 dB
	R^2				
INM SEL	0.8166	0.9191	0.9710	0.9585	0.9295
Certification EPNL	0.7498	0.7885	0.8183	0.8328	0.8139
	Slope				
INM SEL	0.0608	0.0733	0.0851	0.0867	0.0793
Certification EPNL	0.0577	0.0672	0.0772	0.0801	0.0735

Relationships between Changes in Source Noise Level and Contour Areas

If a particular noise contour is selected, relationships can be established between changes in source noise reduction at noise certification measurement points and contour area by using the slopes of regression analyses presented in Tables V, VI, VII, and IX in the relationship

$$\Delta L = \frac{1}{s} \cdot \log\left(\frac{A - \Delta A}{A}\right) \qquad (11)$$

where s is the slope, A is the contour area, and ΔA is the reduction in area. A set of examples is presented in Table X for the SEL 90 dB contour. This particular contour was chosen because correlations are high for approach and departure operations and for both INM predicted SEL and measured EPNL at the certification points as well as being a representative community exposure condition for a typical medium sized airport. Fifty-four operations with SEL of 90 dB during the day and evening periods that have no nighttime penalty results in an equivalent continuous sound level, LEQ (15 hr)[ref.2] of 60 dB. Trading relationships are presented for both INM predicted SEL and for measured certification EPNL when the source noise is considered at the TO, SL, or AP points alone and at the TO and SL points combined. A one dB reduction in source noise level at any of the three-certification points could result in a reduction of 10% to 18% in the appropriate departure or approach 90 dB contour. A one dB reduction when TO and SL noise levels are summed could result in a reduction in the departure contour of 6.5% to 7.5%. Similarly, certification point noise levels reductions of 3.5 dB to 6.6 dB are required to reduce the area of the 90 dB SEL contour by one-half or combined TO and SL level reductions of about 9 dB to 10 dB are required to reduce the departure contour area by one-half.

Table X. Trading relationships between noise level changes at certification measurement locations and changes in area of SEL 90 dB contour area.

Certification measurement location	INM predicted SEL			Certification measured EPNL		
	log(area) slope	Contour area reduction per dB change in sound level, percent	Level change required to halve contour area, dB	log(area) slope	Contour area reduction per dB change in sound level, percent	Level change required to halve contour area, dB
Takeoff	0.0563	12.2	-5.3	0.0454	9.9	-6.6
Sideline	0.0729	15.5	-4.1	0.0743	15.7	-4.1
Takeoff+Sideline	0.0338	7.5	-8.9	0.0294	6.5	-10.2
Approach	0.0851	17.8	-3.5	0.0772	16.3	-3.9

It was shown in a previous section that for the aircraft investigated in the present analyses, the area within each of the approach contours is about one-third the area in the same departure contour. However, the results shown in Table X indicate that a given change in noise level at the approach measurement point is somewhat more effective than the same change in departure noise level in reducing the area of the respective contours. (This could be due, at least in part, to the contribution to a given contour area of the noise while the aircraft is on the runway is less for landings than for departures.) Therefore approach, sideline or takeoff noise reductions may be considered to be about equally effective in reducing community noise exposure. Thus a trading between noise level reductions at any of the certification measurement points can be considered to a reasonable basis for an effective metric for measuring the success of an aircraft noise reduction program such as QAT.

Reductions in airframe noise, which can be the dominant source on modern aircraft with high bypass ratio engines at the approach certification measurement point where the aircraft has flaps, slats and landing gear extended, may have little benefit at more remote points where the aircraft is in a cleaner configuration. Therefore noise reduction predicted only at the approach certification measurement point may not have the same effectiveness in reducing total approach noise exposure as the same reduction in fan or jet noise would have for departure noise exposure. A prediction method, which captures the effects of airframe noise and engine noise with more fidelity than INM could be used to predict the area within an appropriate contour. The SEL 85 dB or 90 dB contour may be a reasonable choice as being representative of levels important to airport communities for typical numbers of daily operations. Reductions in the area resulting from airframe and engine approach noise reduction technology developed in the QAT program could then be used to determine equivalent or effective approach source noise reduction. The equivalent approach noise reduction could be combined with takeoff and sideline reductions to provide an effective assessment of the program success.

Reduction in Contour Area for Low-Noise Approach Scenarios and Equivalent Reduction in Source Noise

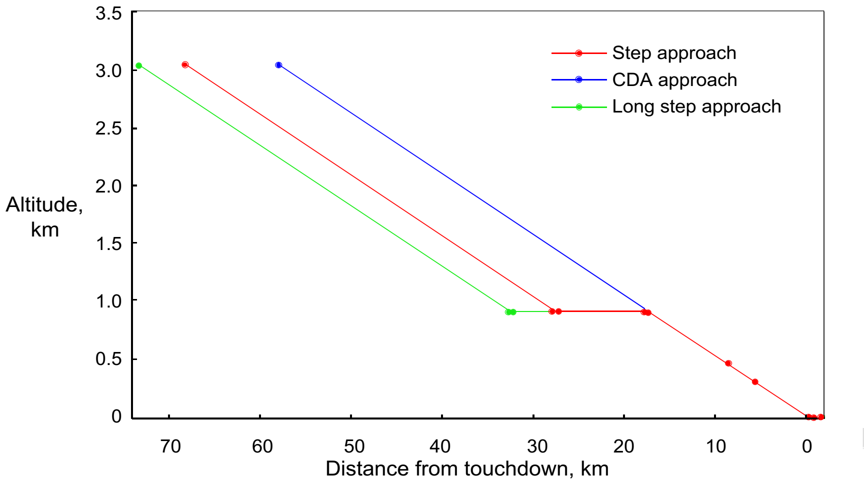
Approach Profile Data for INM Predictions

An additional set of INM cases were run for approach operations to examine potential effects of continuous descent approaches on noise contour areas. A set of six Stage 3 aircraft representing each of the Boeing product lines was selected and INM calculations were performed using 2 or 3 different approach profiles. In the INM, approach flight profiles are defined as procedural profiles or fixed–point profiles. For the procedural profiles, flap setting, start altitude, start speed, and descent angle define a descent flight segment. For fixed-point profiles, many points on the approach path are defined by distance from threshold, altitude, speed, and thrust setting. In the INM database, the standard approaches for the aircraft designated as 717200, 747400, and 757RR use the procedural profile method with continuous descent from 1828.8 m (6000 ft) to touchdown on a 3° glide-slope. The standard approaches for the aircraft designated as 737800, 767400, and 777300 are each defined by over 20 points between 1828.8 m altitude to touchdown with segments at a constant altitude of 914.4 m (3000 ft) from about 26.5 km to about 16.5 km (14.5 nm to 9.0 nm). For each aircraft the INM standard approach profile was used to define new continuous and stepped descent profiles.

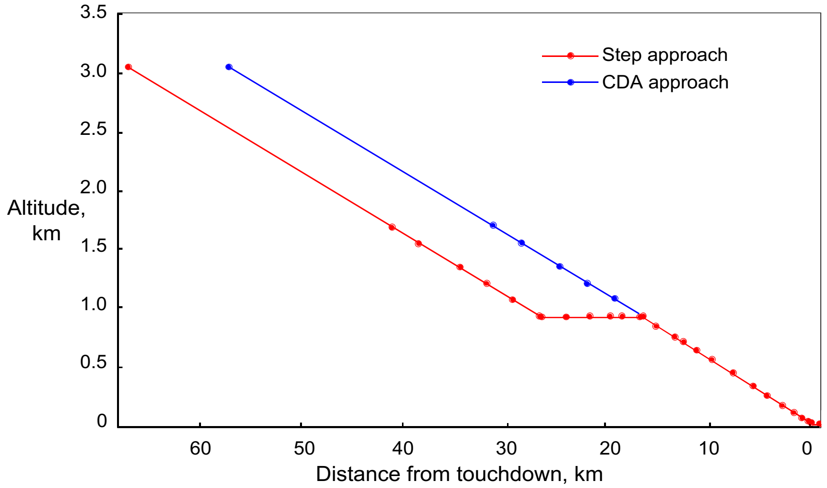
For each case the start of descent altitude was increased to 3048 m (10,000 ft). For the 717200, 747400, and 757RR aircraft the INM standard approach procedural profiles were used with only the change in start altitude and will be referred to in subsequent discussions as CDA, continuous descent approach, profiles. Also for each of these aircraft a “step” and a “long step” profile were defined by inserting constant altitude segments at 914.4 m with length 9.96 km and 15.0 km, respectively. Other than the constant altitude segments these procedures were the same as the CDA cases.

For the 737800, 767400, and 777300 aircraft the standard fixed-point profiles were used with only the change in start altitude and will be referred to as the “step” profiles. For each of these aircraft a CDA profile was defined by removing the constant altitude segments with some speed and thrust matching points before joining the same profiles as the step profiles at 914.4 m. Long-step profiles were not defined for these aircraft because it was not known exactly what thrust would be necessary to continue the longer constant altitude segments beyond the shorter step distances.

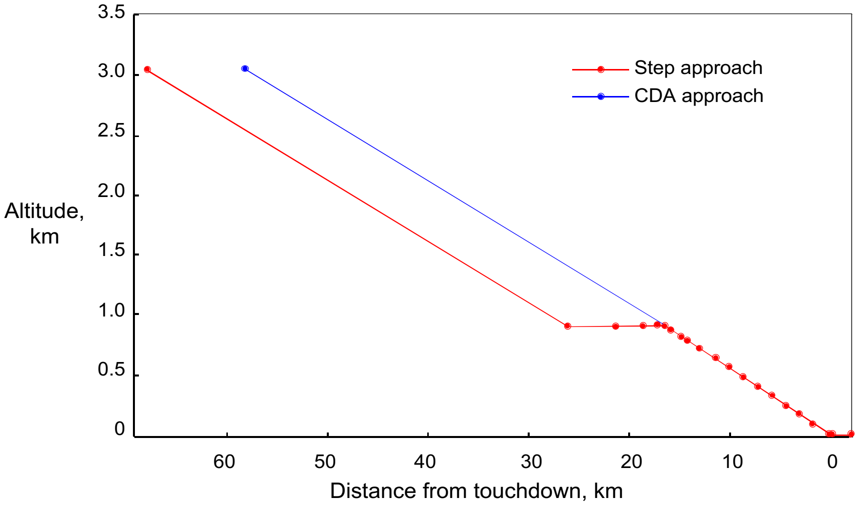
The altitude profile for the 747400 aircraft, for which INM uses the procedure profile method to define the standard approach, is shown in figures 9 (a). Altitude profiles for the 737800 and 777300, for which INM uses the fixed profile method to define standard approaches, are shown in figures (9b) and 9(c), respectively. Thrust profiles for the same aircraft are shown in figures 10 (a), (b), and (c). Although the modifications to the INM standard approach conditions to define the CDA and step profiles may create some additional errors in noise contours and noise levels at specific points, these data are only to be used as representative cases to demonstrate a process for assessing community noise impact reduction through low-noise approach procedures and not as being truly representative of the potential community noise impact reduction.



(a) 747400 aircraft

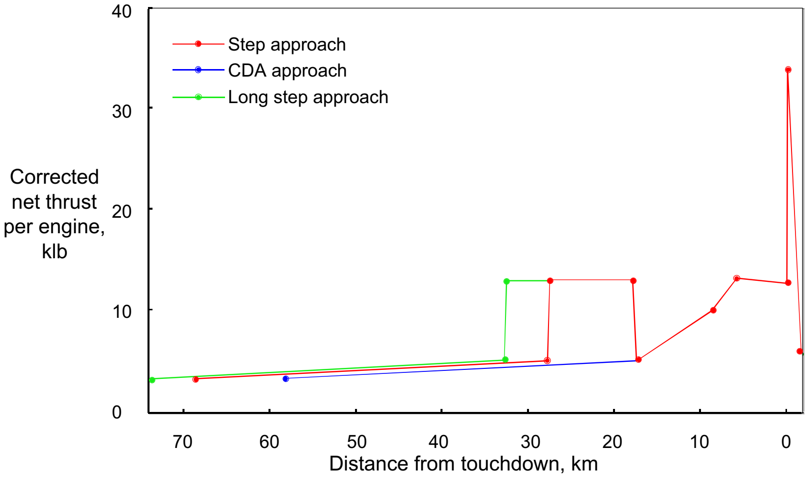


(b) 737800 aircraft

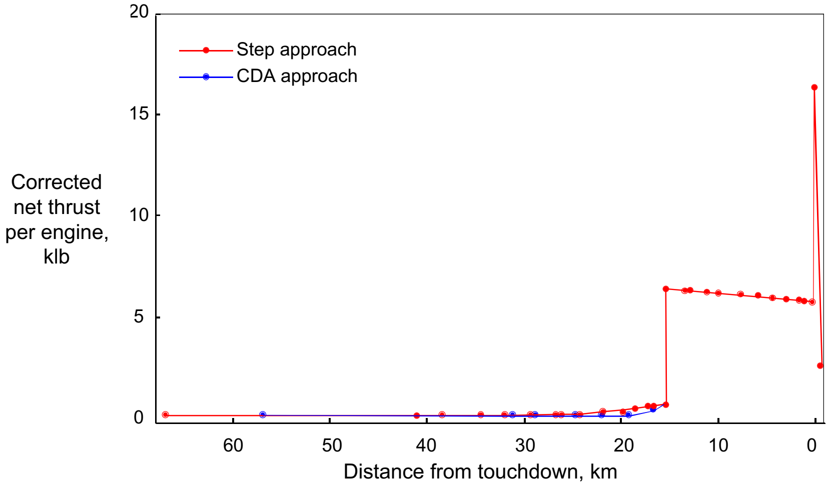


(c) 777300 aicarft

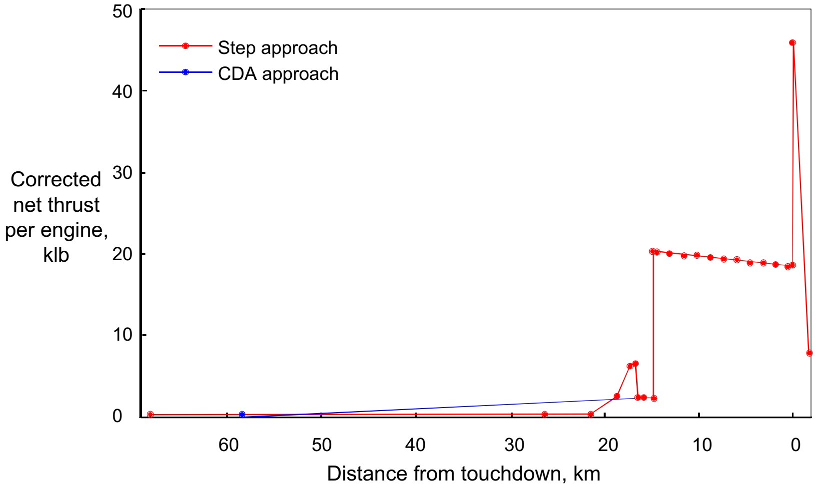
Figure 9. Altitude profiles used in INM predictions of approach noise of representative aircraft for continuous and stepped descents.



(a) 747400 aircraft



(b) 737800 aircraft



(c) 777300 aircraft

Figure 10. Thrust settings used in INM predictions of approach noise of representative aircraft for continuous and stepped descents.

INM Predictions for Low-Noise Approach Operations

Noise levels under the flight path

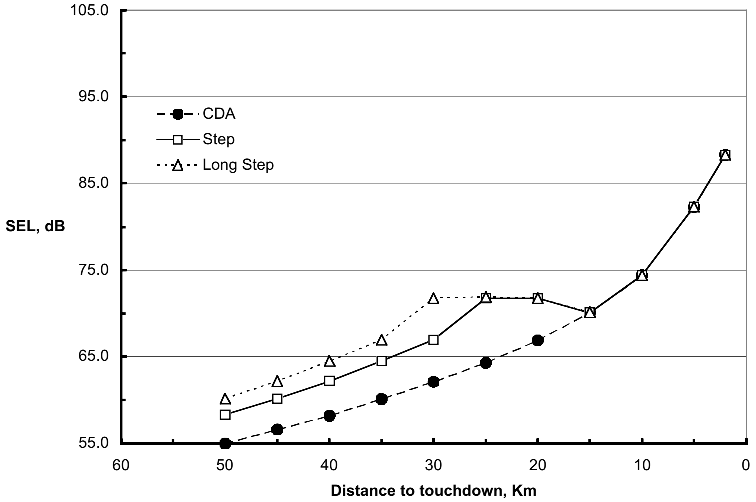
Noise levels were predicted using INM, in terms of SEL, for the CDA and stepped approach profiles at the approach certification measurement point and at a series of points under the flight path every 5 km from touchdown. Results of these calculations are shown in figures 11(a) through (f) for the six representative aircraft. The data point closest to touchdown indicates the noise for the approach certification point in each figure. Reductions in approach noise levels using CDA at points 20 km from touchdown range from about 3 dB to 5 dB for the cases using procedural profiles, i.e., the 717200, 747400, and 757RR aircraft. For the aircraft cases using fixed-point profiles, the reductions were on the order of 2 dB. Several reasons could be responsible for the differences between aircraft including; inaccuracies in the INM noise–distance-power data at low power settings, particularly airframe contributions, and improper setup of the fixed-point data inputs for the INM case setups.

Contour areas

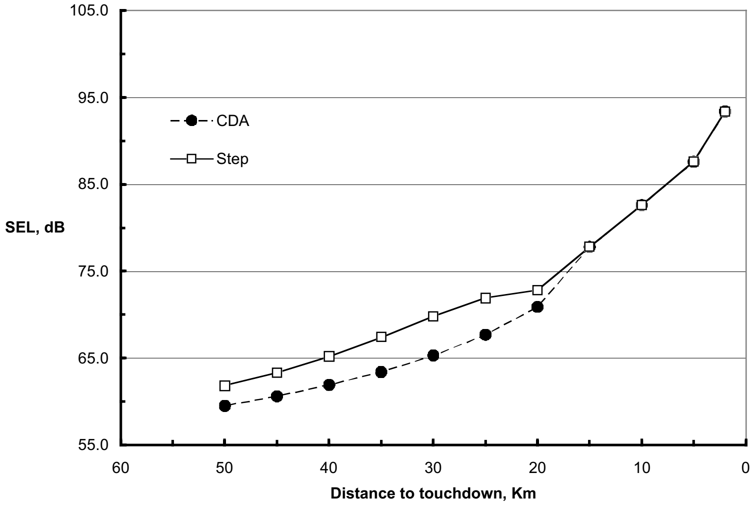
CDA procedures reduce airport noise impact only at locations where the distance to observer is greater and/or engine thrust is reduced relative to conventional stepped approaches. Therefore the greatest potential reduction in contour area is, in general, at lower noise contour levels. INM predictions for SEL contours down to 60 dB were made for the above-described CDA and stepped approaches. At the lowest levels the aircraft would still be quite audible out-of-doors but should not cause any appreciable adverse impact indoors. Noise contours for these cases are shown in figures 12 (a) through (f) in order of increasing aircraft size. It is noted in figures 12(d) through (f) that there is some distortion or truncation in the lower SEL contours for the three larger aircraft, particularly for the 767400 and 747400. This is due to the noise levels for these aircraft, even at distances greater than the altitude of the start point for the calculations, exceed SEL 60 dB and for the 747400, SEL 65 dB. Since the areas for these contours are underestimated, they are not as valid for comparing benefits of the low-noise approach procedure, as are the other contours.

Reduction in contour area and equivalent source noise reduction of low-noise operations

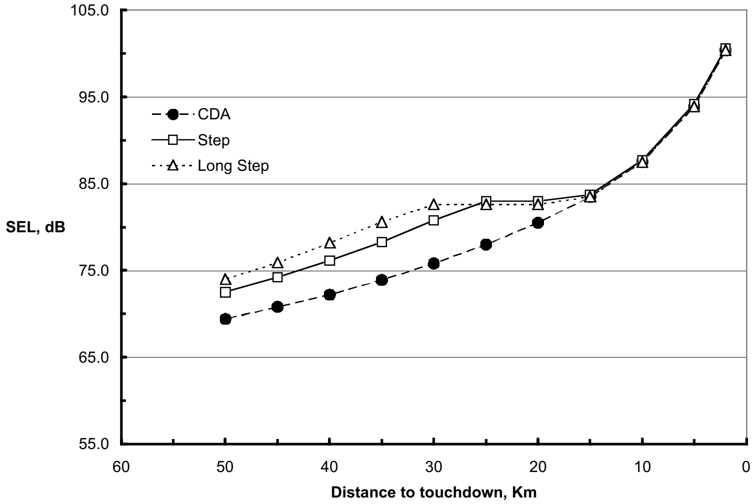
In figures 12 (a) through (f) it can be seen that CDA can reduce the area of approach noise contours. The reduction in area can be equated to a change in area of a stepped approach contour effected by a change in aircraft source noise. This equivalent change in source noise can be estimated from equation 11 using the slopes in the relationships, depicted in figure 8 and Table IX, between the logarithm of the area within a given contour and the noise level at the certification approach measurement point. The slopes in Table IX vary from about 0.06 to 0.09 depending on the particular contour and whether the noise level at the certification measurement point is expressed in INM predicted SEL or measured EPNL. For the lower value SEL contours, an approximate slope of 0.08 could be selected as being representative. Using this value, the changes in area between the CDA and stepped approach contours were converted to equivalent changes in source noise. The areas for the CDA and stepped approach contours and equivalent source noise reductions are given in Table XI. Values in areas and equivalent source noise reductions for contours that were distorted by the limited range of altitude used in the INM calculations are indicated in italics and bold font. For the cases examined, the maximum equivalent source noise reduction was 3.4 dB for the 717200 aircraft. Unless the contour noise level was on the order of 20 dB to 25 dB below the noise level at the certification measurement point, the CDA approach provided little or no benefit. Again it should be emphasized that the examples in these simple analyses do not necessarily represent the true potential benefit of CDA or other low-noise approach procedures, but rather illustrate a process to assess benefits in a manner equivalent to source noise reductions.



(a) 717200 aircraft

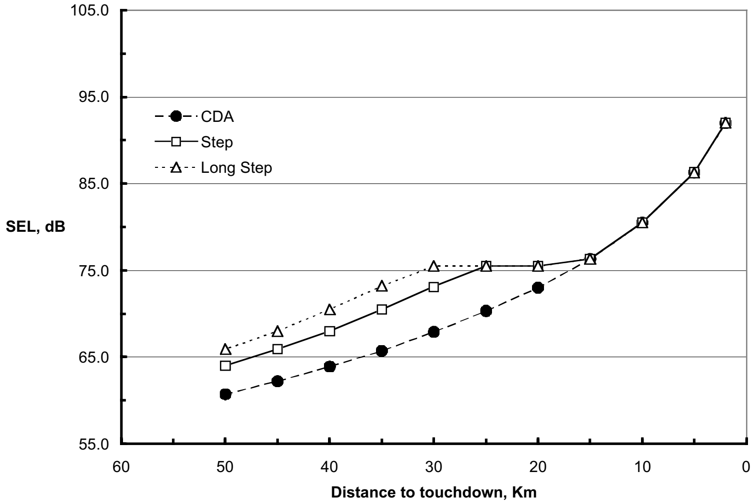


(b) 737800 aircraft

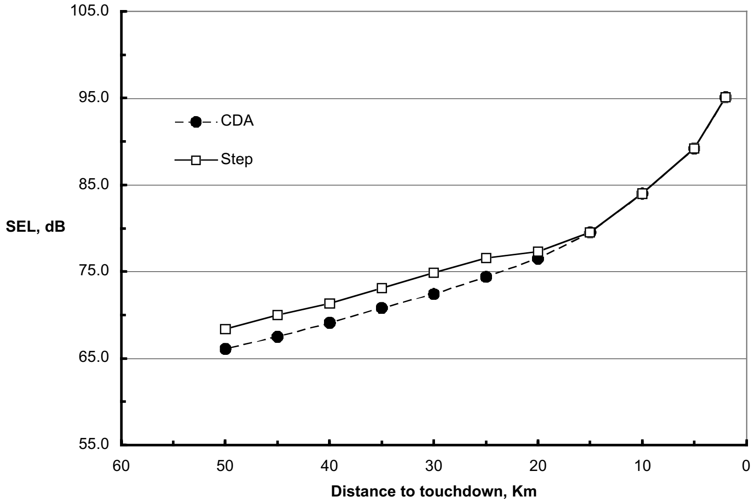


(c) 747400 aircraft

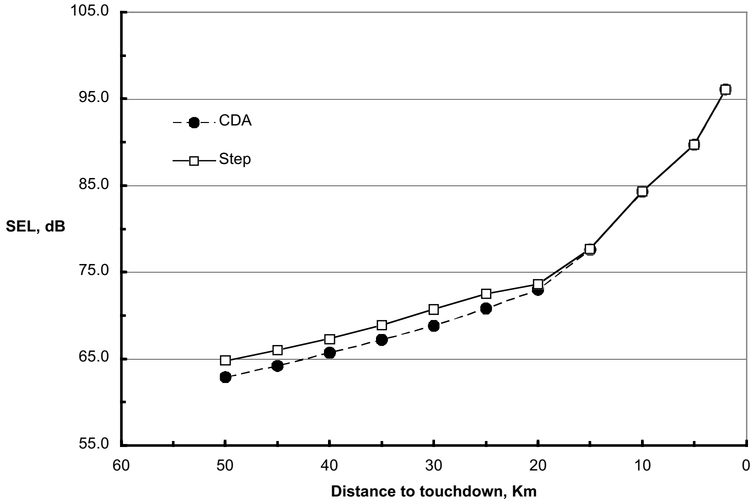
Figure 11. Noise levels under approach paths for continuous and stepped descents.



(d) 757RR aircraft

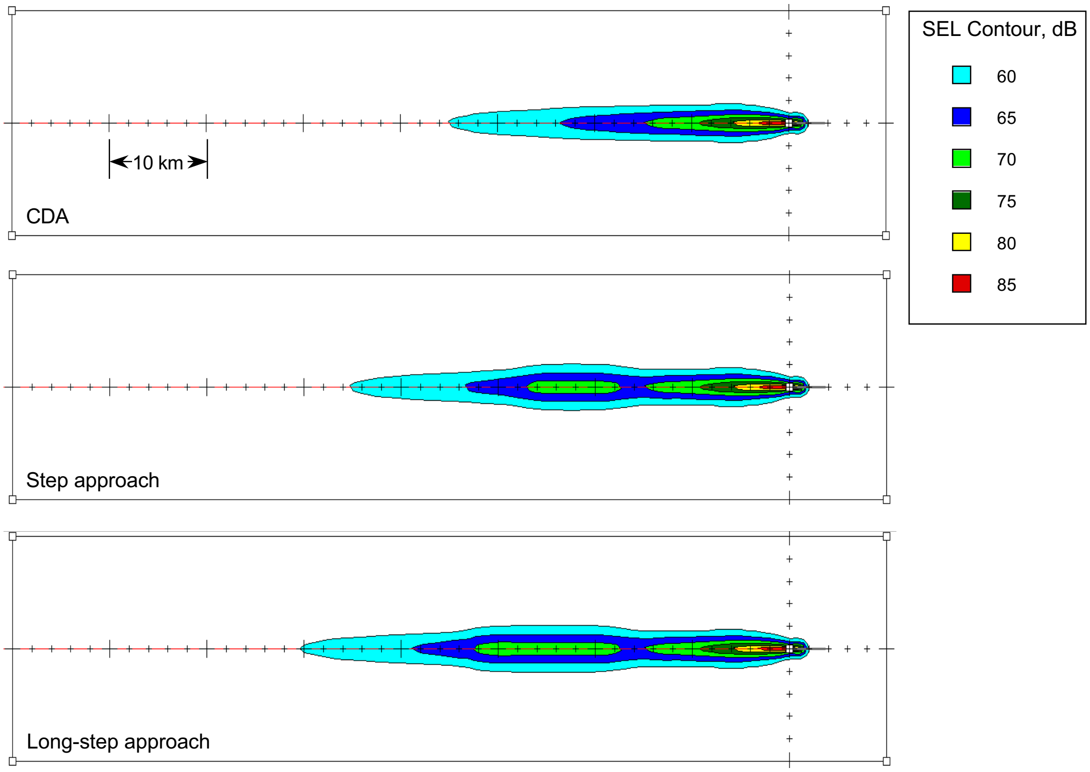


(e) 767400 aircraft

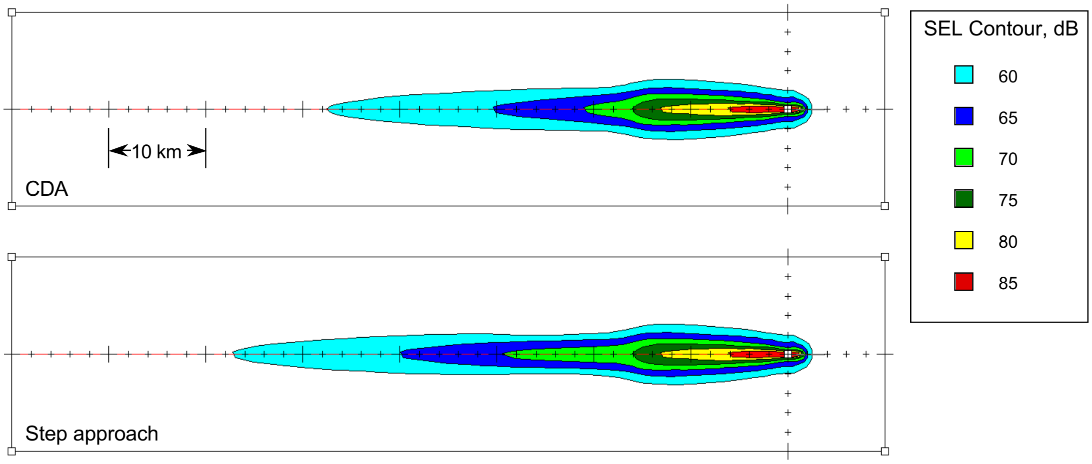


(f) 777300 aircraft

Figure 11. concluded

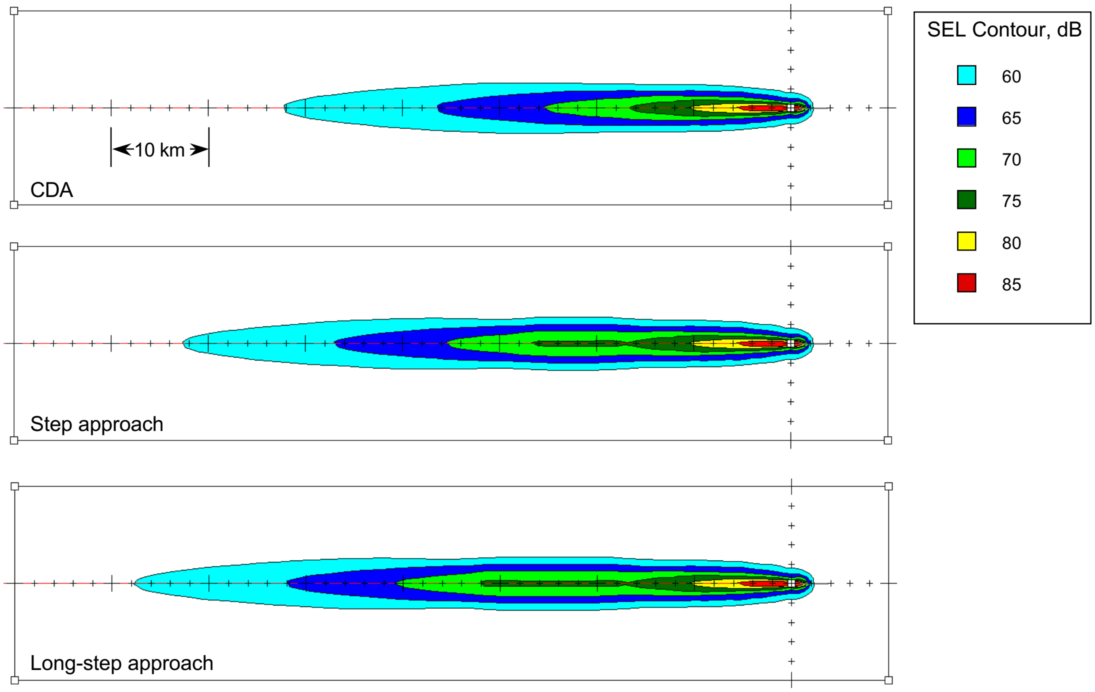


(a) 717200 aircraft

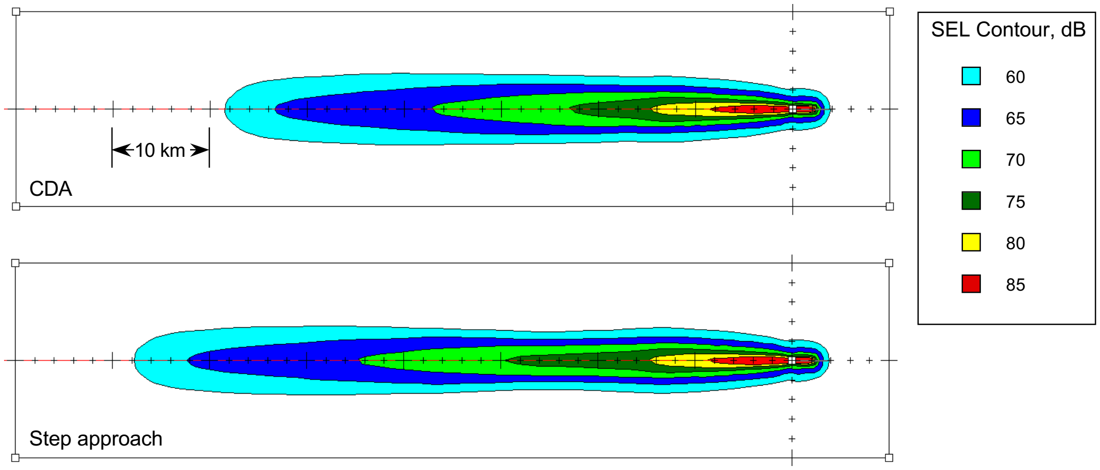


(b) 737800 aircraft

Figure 12. Noise contours for continuous descent approach (CDA) and step approach operations.

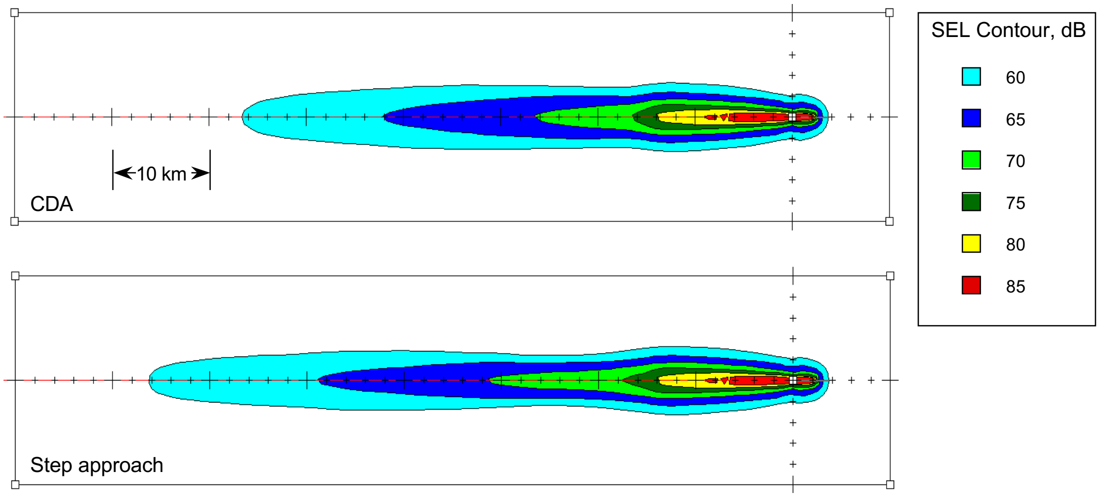


(c) 757RR aircraft

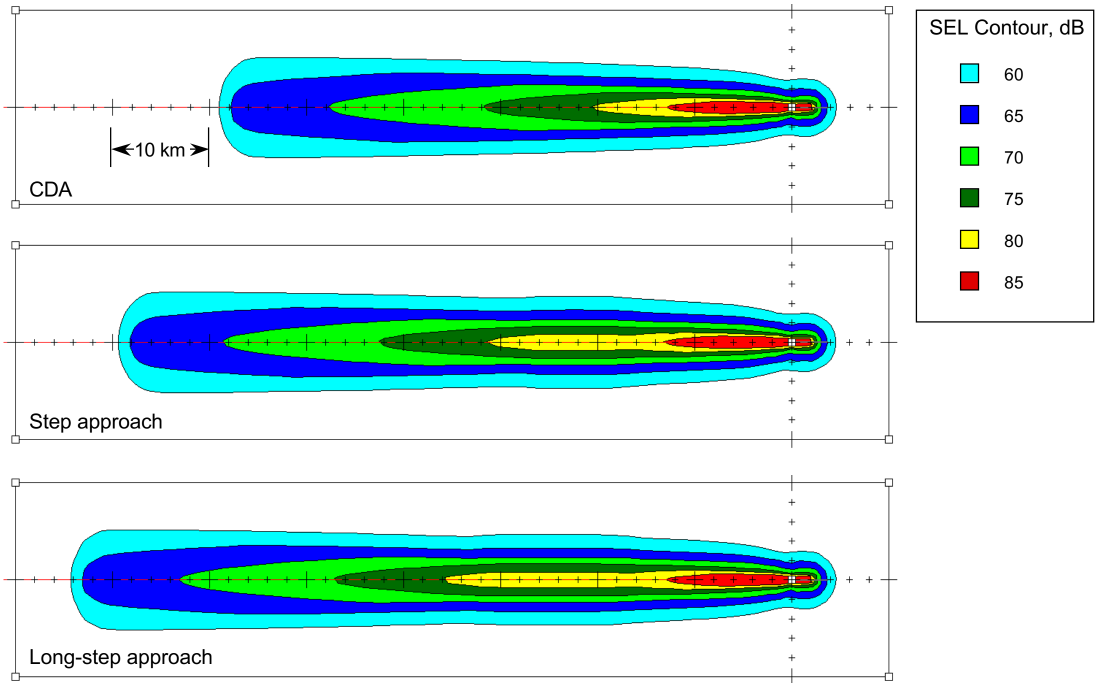


(d) 767400 aircraft

Figure 12. continued



(e) 777300 aircraft



(f) 747400 aircraft

Figure 12. concluded

Table XI. Approach noise contour areas and equivalent source noise reduction for CDA profiles relative to stepped profiles.

Aircraft	Profile	Calculated SEL at certification location, dB	SEL Contour Area, sq. km.						Equivalent source noise reduction of CDA relative to stepped approach, dB					
			60dB	65dB	70dB	75dB	80dB	85dB	60dB	65dB	70dB	75dB	80dB	85dB
717200	CDA	88.3	97.3	43.9	19.2	8.3	3.6	1.2						
	Step	88.3	139.6	69.8	29.3	8.3	3.6	1.2	-2.0	-2.5	-2.3	0.0	0.0	0.0
	Long Step	88.3	160.7	82.9	35.6	8.3	3.6	1.2	-2.7	-3.4	-3.4	0.0	0.0	0.0
737800	CDA	93.4	204.8	98.6	53	30	14.4	4.3						
	Step	93.4	242.5	124.2	64.6	30.0	14.4	4.3	-0.9	-1.3	-1.1	0.0	0.0	0.0
747400	CDA	100.4	***557.2***	***363.4***	184.4	81.0	34.9	14.4						
	Step	100.6	***661.9***	***437.1***	237.7	117.9	53.1	14.9	***-0.9***	***-1.0***	-1.4	-2.0	-2.3	-0.2
	Long Step	100.4	***699.0***	***462.8***	255.1	131.4	58.6	14.4	***-1.2***	***-1.3***	-1.8	-2.6	-2.8	0.0
757RR	CDA	92.0	231.9	112.5	52.7	23.3	9.4	3.2						
	Step	92.0	288.4	153.4	79.7	28.6	9.4	3.2	-1.2	-1.7	-2.2	-1.1	0.0	0.0
	Long Step	92.0	316.4	173.4	93.1	32.0	9.4	3.2	-1.7	-2.4	-3.1	-1.7	0.0	0.0
767400	CDA	95.1	***393.2***	232.7	110.1	45.5	19.4	6.9						
	Step	95.1	***436.6***	259.7	127.9	53.2	19.4	6.9	***-0.6***	-0.6	-0.8	-0.9	0.0	0.0
777300	CDA	96.1	***323.4***	158.8	70.5	34.6	19.3	7.2						
	Step	96.1	***354.7***	171.0	77.6	35.4	19.3	7.2	***-0.5***	-0.4	-0.5	-0.1	0.0	0.0

Concluding Remarks

This paper has addressed several topics related to alternative or supplemental metrics to the existing three-point noise reduction methodology for assessing the success of the QAT program. Of particular interest were methods that fairly represent airframe and operations noise reduction efforts.

First, an analytical basis for a tradeoff relationship between certification noise levels and noise contour areas was developed for departure operations. Through a simple analysis, the logarithm of the area within a given noise contour was found to linearly related to the sum or average of the noise level at the takeoff and sideline noise certification points. Based on this analysis, it appears reasonable that for a departure operation the combination of noise levels at the takeoff and sideline certification measurement locations and noise contour area are equally effective means for relating changes in aircraft noise level to changes in community noise impact.

Second, the paper determined and examined the relationship between noise contour areas predicted using the FAA's Integrated Noise Model and the noise levels measured or predicted at the certification points for a wide range of commercial and business aircraft. Based on strong correlation and the nature of the relationships between the logarithm of the area within a given single event contour and the noise levels at the certification measurement points, a trade between noise level changes at any of the certification measurement points can be considered to a reasonable basis for assessing changes in noise exposure around an airport due to a given type of aircraft. Therefore, trading between the noise reductions at the three certification measurement points is an effective metric for measuring the success of an aircraft noise reduction program such as QAT and is essentially equivalent to relative changes in noise exposure contour areas. Prediction methods, which capture the effects of airframe noise and engine noise better than INM, could be used to predict the area within an appropriate contour (perhaps the 85 dB or 90 dB SEL contour). Reductions in the area resulting from airframe and engine approach noise reduction technology developed in the QAT program could then be used to determine equivalent or effective approach source noise reduction. The equivalent approach noise reduction can be combined with takeoff and sideline reductions to provide an effective assessment of the program success.

Third, the paper examined predicted reduction in contour area for low-noise approach scenarios and determined equivalent reduction in approach source noise. Thus a process has been illustrated that can assess benefits of low-noise operations on reducing community noise impact in a manner equivalent to source noise reductions. However, low-noise approach procedures like the continuous descent approach (CDA) investigated in the current analyses have little or no benefit at locations near the airport. Therefore contour areas with noise levels less than considered appropriate for assessing jet, fan, and airframe noise should be used to assess low-noise approach procedures. Unless the contour noise level are on the order of 20 dB to 25 dB below the noise level at the certification measurement point, the CDA procedures may provide little or no benefit. For the 777 sized aircraft that is used assessing the success of the QAT program, SEL contours less than or equal to 70 dB may be appropriate to assess low-noise operations.

Although not specifically addressed in this paper, it should be recognized that many flight parameters have a direct effect on the noise sources of an aircraft and on the resultant noise levels at certification measurement points and in contour areas. Therefore the baseline parameters need to be defined that are representative of current operating practices. These include but may not be limited to aircraft weight, specific power settings and flight profiles, and flap, slat and landing gear positions.

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14. ABSTRACT

The use of sound exposure level contour area reduction has been proposed as an alternative or supplemental metric of progress and success for the NASA Quiet Aircraft Technology program, which currently uses the average of predicted noise reductions at three community locations. As the program has expanded to include reductions in airframe noise as well as reduction due to optimization of operating procedures for lower noise, there is concern that the three-point methodology may not represent a fair measure of benefit to airport communities. This paper addresses several topics related to this proposal: (1) an analytical basis for a relationship between certification noise levels and noise contour areas for departure operations is developed, (2) the relationship between predicted noise contour area and the noise levels measured or predicted at the certification measurement points is examined for a wide range of commercial and business aircraft, and (3) reductions in contour area for low-noise approach scenarios are predicted and equivalent reductions in source noise are determined.

15. SUBJECT TERMS
Aircraft noise certification; Aircraft noise reduction; Noise contour; Integrated Noise Model; INM; Quiet Aircraft Technology; QAT

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