Doc 9889
First Edition
Corrigendum No. 1
(English only)
16/1/12

AIRPORT AIR QUALITY MANUAL

FIRST EDITION — 2011

CORRIGENDUM NO. 1

1. Please replace existing pages (xiv), (xv), 3-A1-24, 3-A1-30, 3-A1-31, 3-A3-4, 3-A3-10, 4-8, 5-3 and 7-2 by the attached new pages dated 16/1/12.

2. Record the entry of this corrigendum on page (iii) of the manual.

ACRONYMS AND ABBREVIATIONS

AAL	Above aerodrome level
ACARE	Advisory Council for Aeronautics Research in Europe
ACU	Air climate unit
ADAECAM	Advanced aircraft emission calculation method
AFR	Air-fuel ratio
AGL	Above ground level
AMSL	Above mean sea level
ANSP	Air navigation service provider
APMA	Air pollution in the megacities of Asia
APU	Auxiliary power unit
ARFF	Airport rescue and fire fighting
ARP	Aerodrome reference point
ASQP	Airline service quality performance
ASU	Air starter unit
ATA	Air Transport Association
ATOW	Actual take-off weight
Avgas	Aviation gasoline
BADA	Base of aircraft data
BFFM2	Boeing fuel flow method 2
bhp	Brake horsepower
BPR	Bypass ratio
BTS	Bureau of Transportation Statistics (U.S.)
CAEP	Committee on Aviation Environmental Protection
CDO	Continuous descent operations
CERC	Cambridge Environmental Research Consultants (U.K.)
CH_4	Methane
CI	Carbon index
CNG	Compressed natural gas (carburant)
CO	Carbon monoxide
CO_2	Carbon dioxide
DAC	Double annular combustor
DEFRA	Department for Environment, Food and Rural Affairs (U.K.)
DfT	Department for Transport (U.K.)
DOAS	Differential optical absorption spectroscopy
DOT	Department of Transportation (U.S.)
ECS	Environmental control system
EDMS	Emission and Dispersion Modelling System (U.S. FAA)
EEDB	Engine Emissions Data Bank (ICAO)
EGT	Exhaust gas temperature
EI	Emission index
EPA	Environmental Protection Agency (U.S.)
ETFMS	Enhanced tactical flow management system (Eurocontrol)
ETMS	Enhanced traffic management system (U.S.)
EU	European Union
FAA	Federal Aviation Administration (U.S.)
FAF	Final approach fix

FBO	Fixed-based operator
FDR	Flight data recorder
FES	Fixed energy system
FESG	ICAO CAEP Forecasting and Economics Sub-group
FIRE	Factor Information Retrieval Data System (U.S. EPA)
FOA	First Order Approximation
FOCA	Federal Office for Civil Aviation (Switzerland)
FOD	Foreign object damage
FOI	Swedish Defence Research Agency
FSC	Fuel sulphur contents
g	Gram
GE	General Electric
GIS	Geographical information system
GPU	Ground power unit
GSE	Ground support equipment
GUI	Graphical user interface
h	Hour
HAP	Hazardous air pollutant
HC	Hydrocarbon
HDV	Heavy-duty vehicle (e.g. truck, bus)
hp	Horsepower
Hz	Hertz
IAE	International Aero Engines
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industry Associations
IOAG	International Official Airline Guide
IPCC	Intergovernmental Panel on Climate Change
ISA	International Standard Atmosphere
kg	Kilogram
km	Kilometre
kN	Kilonewton
kt	Knot
KVA	Kilovolt ampere
kW	Kilowatt
LASAT	Lagrangian simulation of aerosol — transport
LASPORT	LASAT for Airports (Europe)
LDV	Light-duty vehicle (e.g. delivery vans)
LPG	Liquefied petroleum gas
LTO	Landing and take-off
m	Metre
MCLT	Maximum climb-limited thrust
MES	Main engine start
min	Minute
MSDS	Material safety data sheet
NAAQS	National Ambient Air Quality Standards (U.S.)
NASA	National Aeronautics and Space Administration (U.S.)
NGGIP	National Greenhouse Gas Inventories Programme
NMHC	Non-methane hydrocarbons
NMVOC	Non-methane volatile organic compounds
NO	Nitrogen monoxide
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
NPR	Noise-preferential route

O_3	Ozone
OPR	Overall pressure ratio
Pb	Lead
PBL	Planetary boundary layer
PCA	Pre-conditioned air (for cooling/heating of parked aircraft)
PLTOW	Performance-limited take-off weight
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of 2.5 micrometres or less
PM_{10}	Particulate matter with an aerodynamic diameter of 10 micrometres or less
POV	Privately owned vehicle
PPM	Parts per million
P&W	Pratt & Whitney
RR	Rolls Royce
s	Second
SAE	Society of Automotive Engineers
SAEFL	Swiss Agency for Environment, Forests and Landscape
SHP	Shaft horsepower
SN	Smoke number
SO_x	Sulphur oxides
SO_2	Sulphur dioxide
TAF	Terminal area forecasts (U.S.)
TEOM	Tapered Element Oscillating Microbalance
TIM	Time-in-mode
TOW	Take-off weight
UID	Unique identifier
U.K.	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention for Climate Change
U.S.	United States
$\mu g/m^3$	Micrograms per cubic metre
V	Volt
VMT	Vehicle-miles travelled
VOC	Volatile organic compounds
WHO	World Health Organization

6.64 Similarly, data measured by operators may be made available, including:

a) typical or actual throttle settings used during reverse thrust operation;

b) actual aircraft/engine configuration data;

c) actual fuel flow data;

d) actual engine-type idle speeds;

e) typical or actual throttle settings for approach, take-off and climb-out (e.g. reduced thrust take-off procedures);

f) approach and climb profiles;

g) frequency of less than all-engines taxi operation.

These measured and actual operator data may supplement or replace elements of modelled data.

6.65 Using actual performance and operational data, engine emission factors can be calculated using programmes such as the Boeing fuel flow method 2 or the Deutsches Zentrum für Luft- und Raumfahrt method.

Sophisticated calculation methodology for NO_x, CO and THC

6.66 Once the actual fleet engine emissions factors, TIM and fuel flow are known, the LTO emissions are calculated using the same equation used in the advanced approach, however with the refined input values.

$$E_{ij} = \sum (TIM_{jk}*60) * f(FF_{jk}, Ei_{ijk} \text{ or } Thrust_{jk}, Cond_j, Ne_j) \quad \text{Eq. A1-7}$$

where:

E_{ij} = total emissions of pollutant i (e.g. NO_x, CO or HC), in grams, produced by a specific aircraft j for one LTO cycle;

Ei_{ijk} = the emission index for pollutant i (e.g. NO_x, CO or HC), in grams per pollutant per kilogram of fuel (g/kg of fuel), in mode k for each engine used on aircraft j;

FF_{jk} = fuel flow for mode k, in kilograms per second (kg/s), for each engine used on aircraft type j;

$Thrust_{jk}$ = thrust level for mode k for the aircraft type j;

TIM_{jk} = time-in-mode for mode k, in minutes, for aircraft j;

N_{ej} = number of engines used on aircraft j;

$Cond_j$ = ambient conditions (forward speed, altitude, p, t, h) for aircraft type j movement.

7. AUXILIARY POWER-UNIT EMISSIONS

7.1 An auxiliary power unit (APU) is a small gas-turbine engine coupled to an electrical generator and is used to provide electrical and pneumatic power to aircraft systems when required. It is normally mounted in the tail cone of the aircraft, behind the rear pressure bulkhead, and runs on kerosene fed from the main fuel tanks. Not all aircraft are fitted with an APU and, though their use on transport category jet aircraft is now almost universal, some turboprops and business jets do not have an APU fitted.

Emissions calculation methodology

7.2 Unlike aircraft main engines, APUs are not certificated for emissions, and the manufacturers generally consider information on APU emissions rates as proprietary. As a result, little data are publicly available to serve as a basis for calculating APU emissions.

7.3 Analysis performed to date on APUs has not been successful in developing advanced and sophisticated methodologies that more accurately predict APU particulate matter emissions. If more information is available to users then they are encouraged to use this information if this would be of benefit to the study. As a result, use of the simple approach for calculating particulate matter emissions is recommended at this time.

Simple approach

7.4 If very little information is known about the aircraft types operating at the study airport, then the simple approach for APU emissions may be used. However, the results are likely to have a large order of uncertainty associated with APU use and their emissions. Generalized emissions for APUs have been made public. This information is recommended for use because the simple approach uses averaged proprietary engine-specific values obtained from APU manufacturers.

7.5 When the level of detail about the aircraft fleet does not allow for this process to be used, the values in Table 3-A1-3 are considered representative of the APU emissions for each aircraft operation at the airport under study (other values may be used if deemed more appropriate).

Table 3-A1-3. Values representative of APU emissions for each aircraft operation

Aircraft group	Short-haul[9]	Long-haul
Duration of APU operation	45 min	75 min
Fuel burn	80 kg	300 kg
NO_x emissions	700 g	2400 g
HC emissions	30 g	160 g
CO emissions	310 g	210 g
PM_{10} emissions	25 g	40 g

7.6 The fuel burn and emissions values given in 7.5 are based on averaged APU-specific proprietary data from the manufacturer, though do not represent any specific APU type. The operational times noted are based on

9. Although there is no common definition of short-haul and long-haul, in the context of this document a "rule of thumb" is proposed that relates the term to aircraft type. The long-haul group would include aircraft capable of a maximum range of more than 8 000 km (e.g. A330, A340, A380, B747, B767-200ER, B763, B764, B777, IL96). Short-haul would include all other aircraft.

Attachment A to Appendix 1

ICAO ENGINE EXHAUST EMISSIONS DATA BANK

SUBSONIC ENGINES

ENGINE IDENTIFICATION:	Trent 895	BYPASS RATIO:	5.7
UNIQUE ID NUMBER:	5RR040	PRESSURE RATIO (π_{oo}):	41.52
ENGINE TYPE:	TF	RATED OUTPUT (F_{oo}) (kN):	413.05

REGULATORY DATA

CHARACTERISTIC VALUE:	HC	CO	NOx	SMOKE NUMBER
D_p/F_{oo} (g/kN) or SN	1.7	23.1	78.6	6.9
AS % OF ORIGINAL LIMIT	8.6 %	19.6 %	63.9 %	42.8 %
AS % OF CAEP/2 LIMIT (NOx)			79.9 %	
AS % OF CAEP/4 LIMIT (NOx)			87.3 %	

DATA STATUS

- \- PRE-REGULATION
- x CERTIFICATION
- \- REVISED (SEE REMARKS)

TEST ENGINE STATUS

- \- NEWLY MANUFACTURED ENGINES
- x DEDICATED ENGINES TO PRODUCTION STANDARD
- \- OTHER (SEE REMARKS)

EMISSIONS STATUS

- x DATA CORRECTED TO REFERENCE (ANNEX 16 VOLUME II)

CURRENT ENGINE STATUS

(IN PRODUCTION, IN SERVICE UNLESS OTHERWISE NOTED)

- \- OUT OF PRODUCTION
- \- OUT OF SERVICE

MEASURED DATA

MODE	POWER SETTING (%F_{oo})	TIME minutes	FUEL FLOW kg/s	EMISSIONS INDICES (g/kg) HC	CO	NOx	SMOKE NUMBER
TAKE-OFF	100	0.7	4.03	0.02	0.27	47.79	-
CLIMB OUT	85	2.2	3.19	0	0.19	34.29	-
APPROACH	30	4.0	1.05	0	0.54	11.39	-
IDLE	7	26.0	0.33	0.89	14.71	5.11	-
LTO TOTAL FUEL (kg) or EMISSIONS (g)			1357	462	7834	28029	-
NUMBER OF ENGINES				1	1	1	1
NUMBER OF TESTS				3	3	3	3
AVERAGE D_p/F_{oo} (g/kN) or AVERAGE SN (MAX)				1.1	18.8	67.81	5.34
SIGMA (D_p/F_{oo} in g/kN, or SN)				-	-	-	-
RANGE (D_p/F_{oo} in g/kN, or SN)				0.95 - 1.24	17.71 - 19.67	65.76 - 69.5	4.7 - 6.0

ACCESSORY LOADS

POWER EXTRACTION	0	(kW)	AT	-	POWER SETTINGS
STAGE BLEED	0	% CORE FLOW	AT	-	POWER SETTINGS

ATMOSPHERIC CONDITIONS

BAROMETER (kPa)	100.2
TEMPERATURE (K)	287
ABS HUMIDITY (kg/kg)	.0053 - .0089

FUEL

SPEC	AVTUR
H/C	1.95
AROM (%)	16

MANUFACTURER: Rolls-Royce plc
TEST ORGANIZATION: Rolls-Royce plc
TEST LOCATION: SINFIN, Derby
TEST DATES: FROM Sep 94 TO -

REMARKS

1. Data from certification report DNS59304

This document was prepared on 1 October 2004. Check website for latest version.

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Attachment B to Appendix 1

SIMPLIFIED AIRCRAFT EMISSION INDICES

Table B-1. LTO emission factor by aircraft

Aircraft[1]		LTO emission factors/aeroplane (kg/LTO/aircraft)[2]					Fuel consumption (kg/LTO/aircraft)
		CO_2[3]	*HC*	*NO_x*	*CO*	*SO_2*[4]	
Large commercial aircraft[5] Source: ICAO (2004)[6]	A300	5 450	1.25	25.86	14.80	1.72	1 720
	A310	4 760	6.30	19.46	28.30	1.51	1 510
	A319	2 310	0.59	8.73	6.35	0.73	730
	A320	2 440	0.57	9.01	6.19	0.77	770
	A321	3 020	1.42	16.72	7.55	0.96	960
	A330-200/300	7 050	1.28	35.57	16.20	2.23	2 230
	A340-200	5 890	4.20	28.31	26.19	1.86	1 860
	A340-300	6 380	3.90	34.81	25.23	2.02	2 020
	A340-500/600	10 660	0.14	64.45	15.31	3.37	3 370
	707	5 890	97.45	10.96	92.37	1.86	1 860
	717	2 140	0.05	6.68	6.78	0.68	680
	727-100	3 970	6.94	9.23	24.44	1.26	1 260
	727-200	4 610	8.14	11.97	27.16	1.46	1460
	737-100/200	2 740	4.51	6.74	16.04	0.87	870
	737-300/400/500	2 480	0.84	7.19	13.03	0.78	780
	737-600	2 280	1.01	7.66	8.65	0.72	720
	737-700	2 460	0.86	9.12	8.00	0.78	780
	737-800/900	2 780	0.72	12.30	7.07	0.88	880
	747-100	10 140	48.43	49.17	114.59	3.21	3 210
	747-200	11 370	18.24	49.52	79.78	3.60	3 600
	747-300	11 080	2.73	65.00	17.84	3.51	3 510
	747-400	10 240	2.25	42.88	26.72	3.24	3 240
	757-200	4 320	0.22	23.43	8.08	1.37	1 370
	757-300	4630	0.11	17.85	11.62	1.46	1 460
	767-200	4 620	3.32	23.76	14.80	1.46	1 460
	767-300	5 610	1.19	28.19	14.47	1.77	1 780
	767-400	5 520	0.98	24.80	12.37	1.75	1 750
	777-200/300	8 100	0.66	52.81	12.76	2.56	2 560
	DC-10	7 290	2.37	35.65	20.59	2.31	2 310
	DC-8-50/60/70	5 360	1.51	15.62	26.31	1.70	1 700
	DC-9	2 650	4.63	6.16	16.29	0.84	840
	L-1011	7 300	73.96	31.64	103.33	2.31	2 310

Aircraft[1]		LTO emission factors/aeroplane (kg/LTO/aircraft)[2]					Fuel consumption (kg/LTO/aircraft)
		CO_2[3]	*HC*	*NO_x*	*CO*	*SO_2*[4]	
Large commercial aircraft[5] Source: ICAO (2004)[6]	MD-11	7 290	2.37	35.65	20.59	2.31	2 310
	MD-80	3 180	1.87	11.97	6.46	1.01	1 010
	MD-90	2 760	0.06	10.76	5.53	0.87	870
	TU-134	5 860	35.97	17.35	55.96	1.86	1 860
	TU-154-M	7 040	17.56	16.00	110.51	2.51	2 510
	TU-154-B	9 370	158.71	19.11	190.74	2.97	2 970
Regional jets/business jets > 26.7 kN thrust	RJ-RJ85	950	0.67	2.17	5.61	0.30	300
	BAE 146	900	0.70	2.03	5.59	0.29	290
	CRJ-100ER	1 060	0.63	2.27	6.70	0.33	330
	ERJ-145	990	0.56	2.69	6.18	0.31	310
	Fokker 100/70/28	2 390	1.43	5.75	13.84	0.76	760
	BAC111	2 520	1.52	7.40	13.07	0.80	800
	Dornier 328 Jet	870	0.57	2.99	5.35	0.27	280
	Gulfstream IV	2 160	1.37	5.63	8.88	0.68	680
	Gulfstream V	1 890	0.31	5.58	8.42	0.60	600
	Yak-42M	1 920	1.68	7.11	6.81	0.61	610
Low thrust jets (Fn < 26.7 kN) Source: FAEED222[7]	Cessna 525/560	1 060	3.35	0.74	34.07	0.34	340
Turboprops Source: FOI[8]	Beech King Air[9]	230	0.64	0.30	2.97	0.07	70
	DHC8-100[10]	640	0.00	1.51	2.24	0.20	200
	ATR72-500[11]	620	0.29	1.82	2.33	0.20	200

Notes.—

1. Equivalent aircraft are contained in Table B-3.

2. Information regarding the uncertainties associated with the data can be found in the following references:

   — QinetiQ/FST/CR030440 "EC-NEPAir: Work Package 1 Aircraft engine emissions certification — a review of the development of ICAO Annex 16, Volume II," by D.H. Lister and P.D. Norman.
   — ICAO Annex 16, Volume II, 2nd edition (1993).

3. CO_2 for each aircraft based on 3.16 kg CO_2 produced for each kg of fuel used, then rounded to the nearest 10 kg.

4. The sulphur content of the fuel is assumed to be 0.05 per cent (same assumption as in the 1996 IPCC NGGIP revision).

5. Engine types for each aircraft were selected on the basis of the engine with the most LTOs as of 30 July 2004 (except 747-300 — see text). This approach, for some engine types, may underestimate (or overestimate) fleet emissions which are not directly related to fuel consumption (e.g. NO_x, CO, HC).

6. ICAO (International Civil Aviation Organization) Engine Exhaust Emissions Data Bank (2004) based on average measured certification data**.** Emission factors apply to the LTO cycle only. Total emissions and fuel consumption are calculated based on ICAO standard time-in-mode and thrust levels.

7. U.S. Federal Aviation Administration (FAA) Emissions and Dispersion Modelling System (EDMS) non-certified data.

8. FOI (The Swedish Defence Research Agency) turboprop LTO emissions database non-certified data.

9. Representative of turboprop aircraft with shaft horsepower (SHP) of up to 1 000 SHP/engine.

10. Representative of turboprop aircraft with shaft horsepower of 1 000 to 2 000 SHP/engine.

11. Representative of turboprop aircraft with shaft horsepower of more than 2 000 SHP/engine.

Table B-2. Engine designation by aircraft

Aircraft	ICAO engine	Engine UID
A300	PW4158	1PW048
A310	CF6-80C2A2	1GE016
A319	CFM56-5A5	4CM036
A320	CFM56-5A1	1CM008
A321	CFM56-5B3/P	3CM025
A330-200/300	Trent 772B-60	3RR030
A340-200	CFM56-5C2	1CM010
A340-300	CFM56-5C4	2CM015
A340-500/600	TRENT 556-61	6RR041
707	JT3D-3B	1PW001
717	BR700-715A1-30	4BR005
727-100	JT8D-7B	1PW004
727-200	JT8D-15	1PW009
737-100/200	JT8D-9A	1PW006
737-300/400/500	CFM56-3B-1	1CM004
737-600	CFM56-7B20	3CM030
737-700	CFM56-7B22	3CM031
737-800/900	CFM56-7B26	3CM033
747-100	JT9D-7A	1PW021
747-200	JT9D-7Q	1PW025
747-300	JT9D-7R4G2(66%) RB211-524D4(34%)	1PW029(66%) 1RR008(34%)
747-400	CF6-80C2B1F	2GE041
757-200	RB211-535E4	3RR028
757-300	RB211-535E4B	5RR039
767-200	CF6-80A2	1GE012
767-300	PW4060	1PW043
767-400	CF6-80C2B8F	3GE058
777-200/300	Trent 892	2RR027
DC-10	CF6-50C2	3GE074
DC-8-50/60/70	CFM56-2C1	1CM003
DC-9	JT8D-7B	1PW004
L-1011	RB211-22B	1RR003
MD-11	CF6-80C2D1F	3GE074

Table 3-A3-2. Sources of emission rate data — emergency generators

Fuel	Methodology	Source
Diesel fuel	U.S. EPA	AP-42, Vol. 1, Table 3.1-1
	USAF (distillate oil)	FAA's *Air Quality Handbook*, Table H-2 1985 National Acid Precipitation Program
Gasoline	USAF	FAA's *Air Quality Handbook*, Table H-2 NONROAD
	U.S. EPA	AP-42, Vol. 1, Table 3.1-1
Kerosene/naphtha (jet fuel)	USAF	FAA's *Air Quality Handbook*, Table H-2
LPG (propane or butane)	USAF	FAA's *Air Quality Handbook*, Table H-2 NONROAD
Natural gas	USAF	FAA's *Air Quality Handbook*, Table H-2
Residual/crude oil	USAF	FAA's *Air Quality Handbook*, Table H-2

2.4 For demonstration purposes, estimates of emissions from power/heating plants, boilers and generators are calculated using the following general equation:

$$E = A \times EF \times (1–ER/100) \qquad \text{Eq. A3-1}$$

where:

E = emissions (e.g. kilograms/day);

A = activity rate (e.g. horsepower-hour or litres/day);

EF = emission factor (e.g. kilograms/litre specific to fuel type and pollutant);

ER = control equipment emissions reduction efficiency (%).

2.5 In cases where fuel sulphur content is important, an alternative formula may be more appropriate. Using this formula, the following example is given for an airport emergency generator. Assume an airport has a 335 horsepower diesel engine emergency generator with an emissions reduction efficiency of 75 per cent. If the emission factor for NO_x is 14.0 grams/horsepower-hour and the airport operates the generator 1 000 hours annually, total NO_x emissions would be:

1 000 hours × 14.0 grams/horsepower-hour × 335 horsepower × (1–75/100) =
1 172 500 grams of NO_x.

3. INCINERATORS

3.1 When located at airports, incinerators are typically used to destroy or sterilize refuse and other regulated waste products produced and transported on international aircraft. An airport may also have food preparation facilities that use incinerators to dispose of solid wastes (i.e. paper, wood, plastics and other rubbish).

3.2 Combustible waste incinerators have a variety of furnace types and configurations (in-line, retort, etc.), include single or multiple combustion chambers and are typically fuelled by natural gas, oil or LPG. Control equipment and technologies are used in both the burning process and at the stack to help reduce excess emissions.

3.3 For existing incinerators that have operating permits, estimates of air pollutant emissions can be obtained from the appropriate regulatory agency files and/or the operating permit itself. In the absence of a permit, emissions estimates are often based on the fuel type, the content and amount of refuse incinerated and appropriate emission factors for the fuel, refuse and combustion chamber design. For new and expanding facilities, the forecasted amounts of incinerated refuse can be based on the projected increase in international flights and/or increase in food service providers, if applicable.

3.4 Commonly-used sources of emission rate data for combustible waste incinerators are provided in Table 3-A3-3.

Table 3-A3-3. Sources of emission rate data — combustible waste incinerators

Number of chambers	*Source*
Single and multiple	AP-42, Vol. 1, Table 2.1-12
	EPA's Factor Information Retrieval (FIRE) software *CORINAIR Emission Inventory Guidebook — 2005* (Group 9)

3.5 For demonstration purposes, estimates of emissions from a combustible waste incinerator are calculated using the following general equation:

$$E = A \times EF \times (1 - ER/100) \qquad \text{Eq. A3-2}$$

where:

E = emissions (e.g. kilograms/year, grams/day);

A = amount of refuse incinerated (e.g. metric tonnes or kilograms/day);

EF = emission factor (e.g. kilograms or grams/metric tonne);

ER = control equipment emissions reduction efficiency (%).

3.6 Using this formula, the following example is given for an incinerator. Assume an airport has a single chamber incinerator with an emissions reduction efficiency of 80 per cent. If the emission factor for CO is 1.0 kilograms/metric tonne of waste and the airport incinerates 2 500 metric tonnes of waste, the total CO emissions would be:

1.0 kilograms × 2 500 metric tonnes × (1–80/100) = 500 kilograms of CO (i.e. 0.5 metric tonnes).

4. AIRCRAFT/AIRPORT MAINTENANCE FACILITIES

4.1 At most large airports, aircraft maintenance facilities are typically operated by commercial airlines or other service providers and perform scheduled aircraft inspections and repairs on the aircraft fuselage, engines and other apparatus. A variety of surface treatment, coating and painting operations may also occur. At smaller airports, these maintenance services are typically offered by privately-owned fixed-based operators (FBO).

8.2 Common U.S. sources of emission rate data for construction activities are provided in Table 3-A3-9.

Table 3-A3-9. Source of emission rate data — construction activities

Activity/vehicle type	Source
Land clearing/demolition	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources
Construction equipment/vehicles (off-road)	U.S. EPA NONROAD model
Construction vehicles (on-road)	U.S. EPA MOBILE model
Material storage piles (standing and working)	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources
Asphalt paving	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 4: Evaporation Loss Sources
Batch mix plants	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 11: Mineral Products Industry
Concrete batching	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 11: Mineral Products Industry
Open burning	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 2: Solid Waste Disposal
Vehicle travel on unpaved roads	U.S. EPA AP-42, Fifth Edition, Volume 1, Chapter 13: Miscellaneous Sources

8.3 For Europe, emission factors for these activities can be found in the *CORINAIR Emission Inventory Guidebook*[1].

8.4 For demonstration purposes, estimates of PM emissions from the working of a storage pile can be obtained using the following general equation that considers the throughput of the operation (i.e. the quantity of material used over a given time and the number of drops the material undergoes (once during loading and once during unloading)). Notably, the emission factors for various materials vary depending on the type, particle size, silt content and moisture content of the material.

$$E_{PM} = 2 \times TH \times EF \qquad \text{Eq. A3-7}$$

where:

E_{PM} = emissions of PM (e.g. kilograms);

2 = number of drops material undergoes;

TH = total throughput;

EF = emission factor (e.g. grams).

1. The name of the *Corinair Emission Inventory Guidebook* has been changed to the *EMEP/EEA Air Pollutant Emission Inventory Guidebook*.

8.5 Using this formula, the following example is given for construction operations at an airport. Assume a construction operation involves the movement of 100 metric tonnes of limestone. Given a moisture content of approximately 0.2 per cent, an aerodynamic particle size of 0.45 micrometres and an average wind speed of 20 kilometres per hour, the amount of PM generated would be as follows based on an emission factor of 54 grams/metric tonne:

2 x 100 metric tonnes x 54 grams/metric tonne = 10 800 grams (i.e. 0.01 metric tonnes).

8.6 Another common example of construction emissions involves the use of an off-road vehicle. The equation used to obtain pollutant estimates from this type of construction activity considers the type of equipment (i.e. bulldozer, articulated truck), the size of the equipment (i.e. horsepower), the load factor placed on the equipment (i.e. the ratio of the load over a designated period of time to the peak load) and the period (i.e. hours) of operation.

8.7 For demonstration purposes, estimates of exhaust emissions from construction vehicles and equipment can be derived from the following formula.

$$E = H \times EF \times LF \times T \qquad \text{Eq. A3-8}$$

where:

E = emissions (e.g. grams/day);

H = horsepower of the equipment;

EF = emission factor (e.g. grams/horsepower-hour);

LF = load factor (per cent);

T = total period of operation (hours).

8.8 Using this formula, the following example is given for the use of a bulldozer. Assume an airport contractor uses a 400 horsepower bulldozer 3 hours each day, 15 days a month, for a period of one year and the average load factor for the equipment is 59 per cent. If the emission factor for the bulldozer is 9.6 grams per horsepower-hour, the amount of NO_x would be:

400 hp x 9.6 grams/hp-h x 0.59 x 540 hours = 1 223 424 grams (i.e. 1.2 metric tonnes).

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4.5.2 During the input data development for these models, the process previously described will often be needed since the models may not have algorithms for all sources to allow spatial and temporal determination. A GIS-based model should facilitate the spatial distribution process through its highly visual interface; an example is shown in Figure 4-1 taken from the Arcview-based ALAQS-AV. LASPORT and EDMS also have GIS capabilities. It should be noted that any graphical user interface-based programme will support the spatial determination more easily and, with proper input, assist in the temporal distribution. The user should consult the appropriate model user's guide for further information.

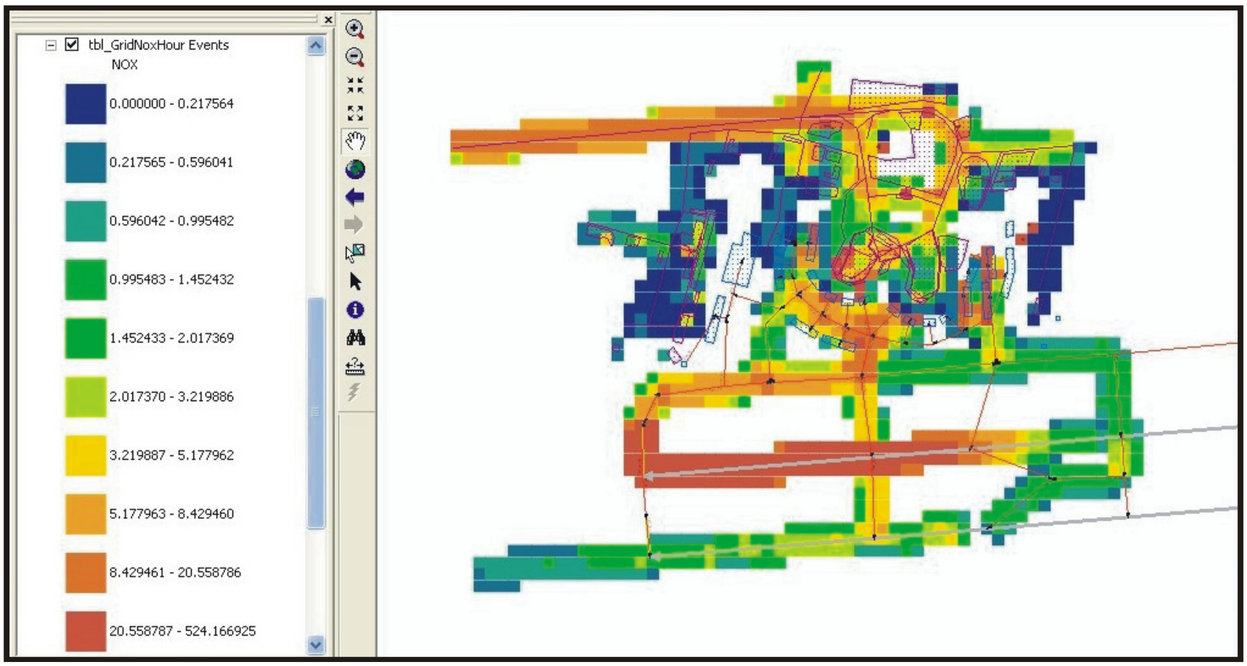

Figure 4-1. Example of 2-D geospatial emissions inventory

4.6 DATA FORMATTING AND REPORTING

4.6.1 It is often essential to use a matrix-type approach when reporting spatial and temporal emissions results. Figure 4-2 shows an example (U.S. EPA). In this figure, it can be seen that sources 23 and 24 are continuous emitting sources while source 25 represents a source with temporal emissions variability. From this type of analysis, emissions for any hour can be easily determined. For example, source 24 emits 417 pounds from 2:00 to 3:00 p.m. This same matrix approach may also be used for spatial reporting or for each individual source in a single table, a combination of spatial and temporal data. In some models such matrixes can be obtained as an output.

4.6.2 Once the data are in this format, graphics can also be used to display the results and more easily identify trends. For example, Figure 4-3 is the plot of source 25 that was shown in Figure 4-2. It can be seen that the source is utilized in the afternoon but much less at other times of day. This could be used for spatial distribution and with 3-D graphics as well, resulting in much easier comprehension by the reviewer.

4.6.3 Graphical displays may be used to show the geo-spatial distribution, usually in 2-D density grids, but careful use of 3-D techniques could also be envisaged for sources such as aircraft as illustrated in Figure 4-4.

Hour	**…**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**…**	**Total**
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
23	…	435	435	435	435	435	435	435	435	435	435	435	435	435	435	…	10005
24	…	417	417	417	417	417	417	**417**	417	417	417	417	417	417	417	…	**10008**
25	…	508	763	847	847	847	847	847	847	847	847	763	508	254	85	…	9996
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Sources

Pounds per hour released

Figure 4-2. Diurnal profile file

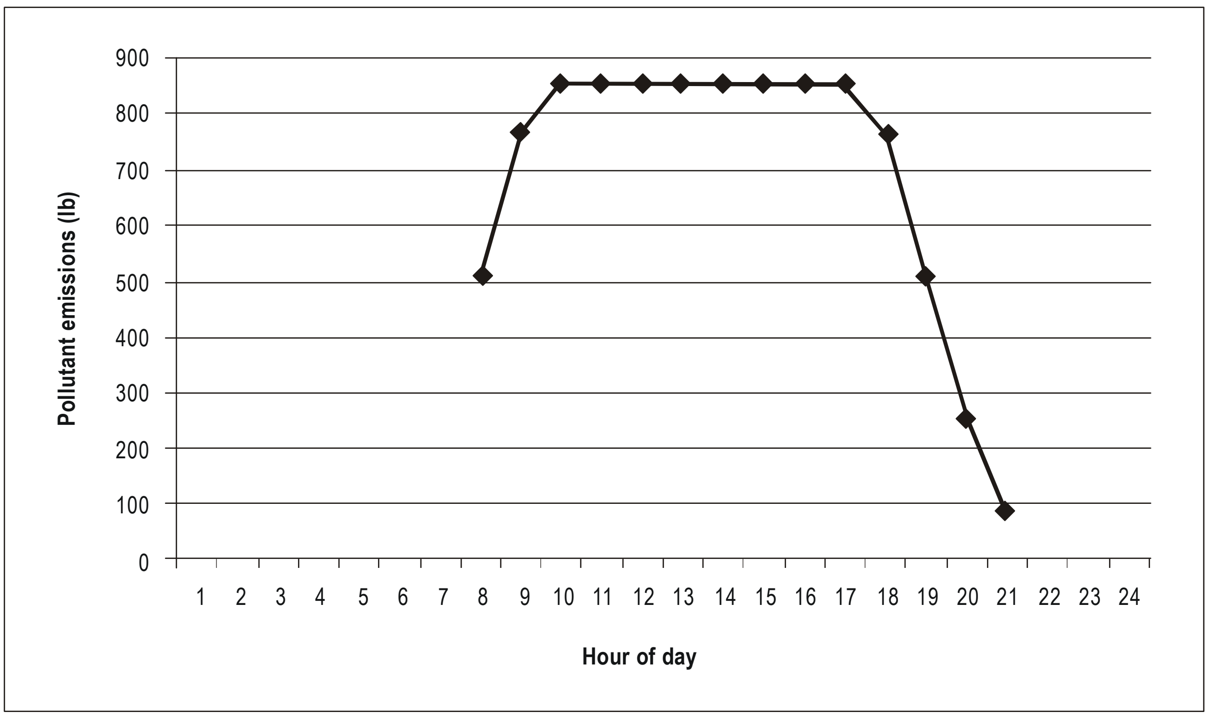

Figure 4-3. Diurnal profile plot

b) Q2 emissions parameters (emissions strength of each trace substance for each source);

c) Q3 substance parameters (e.g. conversion or deposition properties);

d) Q4 atmospheric parameters (e.g. wind speed, wind direction, turbulence properties and temperature); and

e) Q5 terrain parameters (e.g. surface roughness, terrain profile, obstacles).

5.3.5 Not all of the above parameters are independent and most of the parameters are time-dependent. It is evident that the parameter set includes additional information than is required for emissions calculations, even when emissions allocation has been conducted as described in Chapter 4.

5.3.6 At airports, the relevant sources can be grouped as follows:

a) S1 aircraft, including auxiliary power units (APUs);

b) S2 aircraft handling sources (e.g. ground support equipment (GSE), aircraft fuelling, airside vehicles);

c) S3 stationary and area sources (e.g. power plants, fire training); and

d) S4 airport access traffic (e.g. landside motor vehicles).

5.3.7 The dispersion methodologies used are of course only for those sources directly included in the model. Regional or background contributions also add to the total local concentration to produce the total concentration. The total concentration is needed to compare to the applicable criteria or standards. These background sources can be substantial and come from sources at varying distances from the airport. How background sources and the resulting concentrations are accounted for needs to be considered based on the spatial resolution of the modelling area and data sources to be used, such as long-term ambient monitoring stations. This stands in contrast to noise assessments, where the airport contribution is usually by far the dominating component. To account for the overall concentration the background concentration must be added to the concentration predicted by the models. This results in:

$$c_t = c_s + c_b \qquad \text{Eq. 5-1}$$

where:

c = concentration with the subscripts t, s and b representing total, source and background, respectively.

5.3.8 The summation in Equation 5-1 represents the concentration at a point in space from all sources and is the value that is compared to applicable ambient air quality standards. Of note is that concentration, c, is pollutant-specific, that is, pollutants of different species cannot be added.

5.3.9 Figure 5-1 shows an overview of the modelling process (A) and the detailed steps required (B).

5.3.10 Several approaches to dispersion modelling have been applied at various airports around the world to predict local concentrations. As the science continues to evolve, so will the airport models. As such, this chapter will concentrate on the common methodologies currently used rather than on specific models.

5.3.11 The actual formulation for these models may vary. To assist the reader in a more comprehensive understanding of dispersion model methodologies, model formulations are briefly discussed in Appendix 1. Computer models in common use for airport dispersion modelling are listed in Appendix 2.

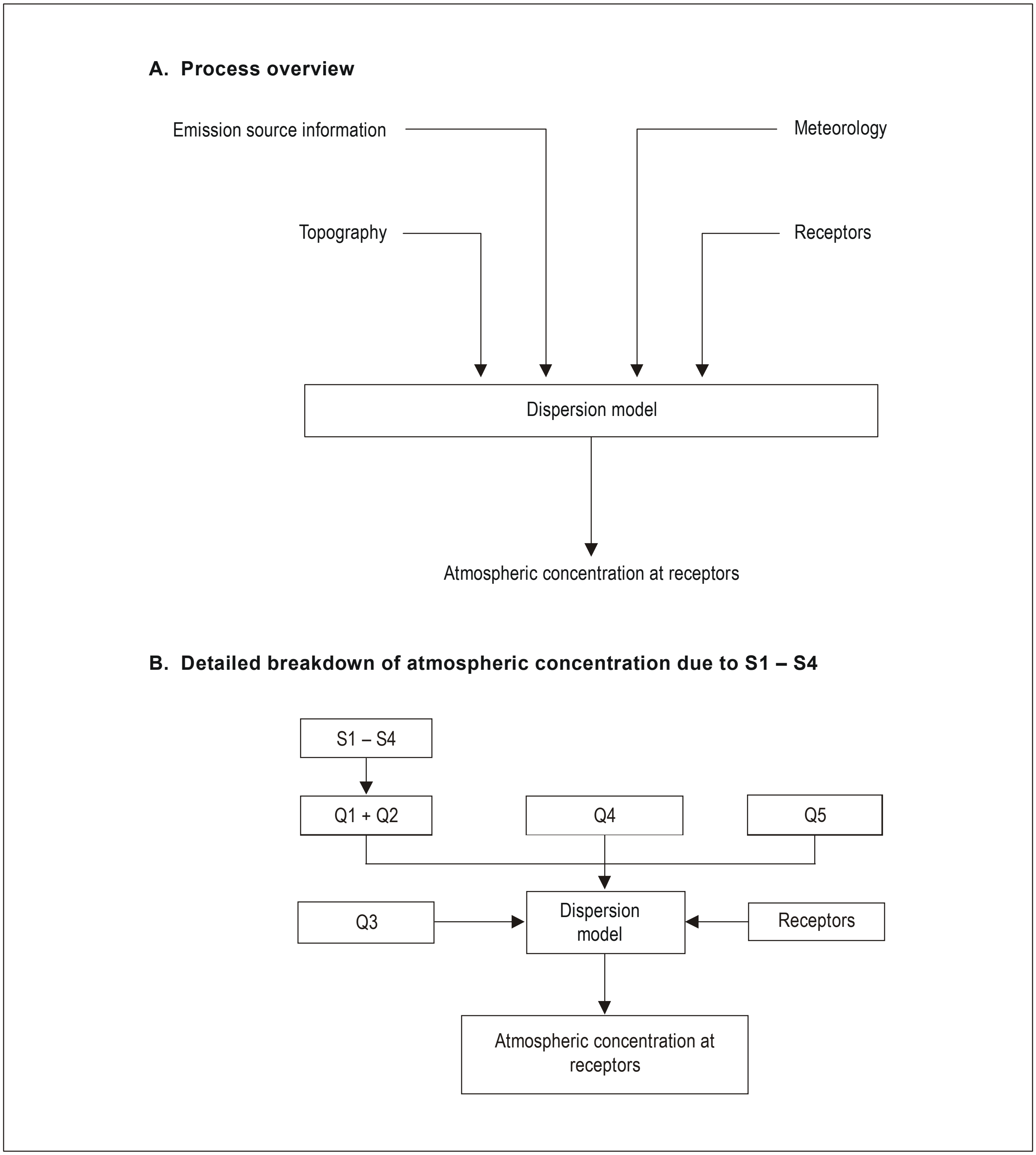

Figure 5-1. Inputs and outputs of dispersion modelling[2]

2. J. Draper et al., *Air Quality Procedures for Civilian Airports and Air Force Bases, Appendix I: Dispersion Methodology*, FAA-AEE-97-03, Arlington, VA., April 1997.

Chapter 7

MITIGATION OPTIONS

7.1 INTRODUCTION

7.1.1 The need to set up mitigation plans with specific measures can be triggered by existing regulatory requirements for ambient air quality, particularly when standards are exceeded, or by regulations or conditions set forth in permits for airport operation and/or expansion.

7.1.2 Measures to reduce emissions from airport sources should be based upon information provided from emissions inventories and/or concentration information. As such, it is a requirement to have such information available prior to planning measures.

7.1.3 This chapter does not discuss specific contents of measures or their appropriateness. Rather, the local circumstances have to be considered when designing a mitigation plan.

7.2 MITIGATION PLANNING METHODOLOGY

Framework for emissions reduction measures

7.2.1 Emissions reduction measures typically fall into four different strategic categories: regulatory, technical, operational and economic, as described more fully in 7.3. Examples of each type of strategy are provided in Table 7-1. It is important to note that the value of these measures when applied to a specific problem has to be evaluated on a case-by-case basis, and a combination of measures may prove to be the best way forward. All measures aim at reducing, directly or indirectly, the emissions at source.

7.2.2 "Regulatory measures" refer to mandatory requirements stated in the laws and regulations of the relevant jurisdiction setting emissions standards and/or operation of emissions sources.

7.2.3 "Technical measures" refer to changes in the technology associated with the emissions characteristics of certain sources. These can be measures related to the reduction of emissions at the direct source of emissions (e.g. vehicle) or it can also include infrastructure measures (e.g. insulation, road layout).

7.2.4 "Operational measures" refer to those measures that would be implemented by the operator of the equipment in question, whether the airline, the airport authority, tenants or any other entity.

7.2.5 "Economic (market-based) measures"[1] can include a number of different instruments to incorporate the environmental external costs of activity. A basic differentiation must be made under ICAO policy between taxes which raise revenues for general governmental use, and charges, which are designed and applied to recover the costs of providing facilities and services for civil aviation.[2] Economic measures can also take the form of subsidies or allowances.

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1. The economic measures category does not include fines assessed to violators of traditional regulatory requirements.

2. *ICAO's Policies on Charges for Airports and Air Navigation Services* (Doc 9082); Assembly Resolution A37-18, Appendix H.

Table 7-1. Overview of emissions reduction measures (examples)

Source group	Measures			
	Regulatory	Technical (Infrastructure)	Operational[1]	Economic
Aircraft	• ICAO engine emissions standards, as adopted into States' national law • APU operating restrictions	• General airport layout • High-speed runway turn-offs • Parallel taxiways • Flow management • 400Hz/PCA at aircraft gates/stands	• Engine start-up • Scheduling improvement • Single/reduced engine taxiing • Reduced engine idling time • Aircraft towing • Reduced APU use • De-rated/reduced thrust • Engine washing • Use of alternative jet fuel • Airport-specific ATM measures, including RNAV, RNP and continuous descent operations (CDOs)	• See *Guidance on Aircraft Emissions Charges Related to Local Air Quality* (Doc 9884)[2]
Aircraft handling and support	• Motor-vehicle emissions standards for GSE (as applicable)	• Alternative-fuel GSE (CNG/LNG, LPG, electric) • Alternative-fuel fleet vehicles (CNG/LNG, LPG, electric) • Emissions reduction devices (PM filter traps, etc.) • Fuel fumes capturing systems	• Reduction of vehicle operational characteristics • Use of generators, GPUs, airstarts • Reduced intensity of hot fire practices.	• Emissions-related licensing fees
Infrastructure and stationary sources	• Emissions standards for facilities (e.g. power plants, emergency generators)	• Low emissions energy plant, incinerator (perhaps filters) • Energy conservation measures in new construction and building maintenance • Change of fuel use • Change in stack heights and location	• Low emissions procedures for maintenance operations (painting, engine testing, cleaning)	
Landside access traffic	• Motor-vehicle emissions standards • Idling restrictions	• Enhanced public transit and intermodal connections • Road structure layout • Alternative fuels • Dedicated public traffic lanes	• Off-airport check-in • Preferential parking for alternative-fuel vehicles • Preferential queues for "green" taxis	• Employee rideshare/ carpooling incentives • Parking pricing and subsidies • Public transit incentives

1. Certain operational measures set forth in this table may be done on either a voluntary or regulatory basis. The laws of various States differ regarding the right of authorities at the regional and local level to require or regulate operational practices. In circumstances where an authority has legal jurisdiction, it may require an operational practice by regulation (e.g. APU operating restrictions, vehicle idling restrictions). When regulation is not permitted, emissions management efforts may consist of informal consultations, voluntary agreements, etc., encouraging the use of such practices and ascertaining the extent and environmental effect of their use. When the airport authority is the owner or operator of the emissions source of interest, it is empowered, within its legal mandates, to select and implement viable options.

2. This chapter does not address market-based measures, such as charges and taxes, related to aircraft engine emissions affecting local air quality. Such measures are addressed in Doc 9884.