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Air Quality at UK Regional Airports in 2005 and 2010

A report produced for DETR

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Executive Summary

AEA Technology was commissioned by the Airports Policy Division of the DETR to assess the impact on air quality of postulated growth scenarios at UK regional airports in the years 2015 and 2030. This air quality assessment was part of the Regional Air Services Co-ordination (RASCO) exercise, undertaken to support the development of an airports policy White Paper.

The AEQ Division of the DETR separately commissioned AEA Technology to extend the study to the years 2005 and 2010, since these are key years in relation to the National Air Quality Strategy and the EC Daughter Directives. The results of the extension work are reported here in a similar format to that used in the 2015/2030 report. An outline of the methodology used in the 2015/2030 study is repeated here, together with a description of the extensions to the methodology for the 2005/2010 work

The objective of the study was to determine the impacts of postulated airport growth scenarios on the air quality in the vicinity of 23 UK regional airports, as judged against the objectives in the Air Quality Regulations 2000, focusing on the pollutants NO_2 and PM_{10}.

To ensure an efficient use of resources, the assessment was carried out in two stages, labelled Stage A and Stage B. Stage A is a screening analysis, which provides a way of identifying - without using dispersion modelling - airport/scenario combinations that will not generate exceedences of air quality objectives. Airport/scenario combinations that do not satisfy the screening criteria in Stage A will not necessarily lead to air quality exceedences, but need to be considered further in Stage B.

For 2005, movement data were supplied by the CAA in the same format as for 2015 and 2030, taking account of anticipated changes in the airframe and aircraft engine mix between 1999 and 2005. For 2010, the estimates of aircraft emissions were based on linear interpolation between the emissions estimates for 2005 and 2015, using passenger throughput as the interpolation variable.

For Stage A, the concentration contributions in 2005 and 2010 from aircraft-related (ie, aircraft and airside vehicle) emissions were derived using the same methodology as for 2015 and 2030. In Stage B, the results for 2005 and 2010 were based on scaling from the results for 2015 using the ratio of total aircraft emissions as the scaling factor.

For non-roadside receptors, the contribution from road-vehicle emissions was calculated using the mapping methodology developed by AEA Technology for the DETR, based on estimates of the vehicle-km travelled in 5-km squares, together with vehicle emission factors from the National Atmospheric Emissions Inventory (NAEI). For the 2005/2010 extension, the vehicle-km estimates were derived from values provided for 1999 and 2015, using linear interpolation by year.

For the key links analysis, the road traffic on the individual links was scaled from the data supplied for 2015 (since none was supplied for 1999).

At Stage A, NO_2 concentrations at non-roadside receptors failed to meet the screening criteria in 15 airport/case combinations out of a total of 138, compared to 40 for the future cases in 2015/2030. The failures arise at only 3 airports (Birmingham, East Midlands and Manchester), with 6 failures in 2005 and 9 failures in 2010. Thus, despite a greater contribution from sources other than aircraft-related in 2005 and 2010 compared to 2015, the lower forecast throughput of the airports more than compensates, leading to lower concentrations in 2005/2010 than in 2015. Considering the criterion based on the 99.8th percentile of 1-hourly mean NO_2 concentrations at representative airport terminal locations, 6 cases (all at Manchester) fail to meet this screening criterion, compared to 13 in 2015/2030.

For PM_{10}, six cases fail to meet the Stage A screening criterion, all at Manchester International airport, compared to 8 in 2015/2030 (2 at Birmingham and 6 at Manchester).

The Stage A screening criteria for NO_2 were not met at 14 key road links distributed amongst 7 airports (Birmingham, Edinburgh, Glasgow, Leeds Bradford, Liverpool, Manchester and Newcastle). Of the total number of year/cases considered, a greater fraction fail in 2005/2010 than in 2015/2030, reflecting the larger contribution from road-vehicle emissions.
No failures of the Stage A screening criteria were found in the 'key links' analysis for PM_{10}.

At Stage B, for non-roadside receptors, no off-airport exceedences of the current objectives for NO_2 and PM_{10} are predicted around any of the airports investigated for any of the future cases considered in 2005 and 2010. Similarly there are no predicted exceedences of the current objective for the 99.8th percentile of 1-hour mean NO_2 concentrations ($200\mu g/m^3$) at representative terminal locations at any of the study airports in any of the future cases considered in 2005 and 2010. These conclusions are likely to stand even after taking account of the uncertainties in the calculations (other than those associated with forecasting the levels of activity at the airports), but are made on the assumption that the spatial layout of the airport, surrounding roads and housing does not change from the current situation (apart from the operation of a second runway at Manchester airport).

Considering key road links (those carrying more than 10% airport-related traffic and having properties within 200m of the roadside), it is likely that for a few links around Birmingham, Edinburgh, Glasgow and Manchester airports there will be exceedences of the current objective for annual-mean NO_2 concentration at the nearest receptor to the road in at least some of the future cases. Further work would be required to quantify the level of exceedence and the number of future cases affected.

Abbreviations

ADMS	Atmospheric Dispersion Modelling System
APU	Auxiliary Power Unit
AQS	Air Quality Strategy
atms	air transport movements (landing and take-off counted as separate movements)
B	Base case
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environmental Protection
DETR	Department of the Environment, Transport and the Regions
DMRB	Design Manual for Roads and Bridges
DORA	Department of Operations Research and Analysis, CAA
E	Environmental case
FAA	Federal Aviation Administration (US)
FEGP	Fixed Electrical Ground Power
H	High-growth case
HC	Hydrocarbon
HDV	Heavy Duty Vehicles
HGV	Heavy Goods Vehicles
ICAO	International Civil Aviation Organisation
LA	Local Authority
LDV	Light Duty Vehicles
LPAM	Long Period Average Model
LTO	Landing and Take-Off
mppa	millions of passengers per annum
NAEI	National Atmospheric Emissions Inventory
NETCEN	National Environmental Technology Centre
NO_x	Nitrogen oxides (comprising NO and NO_2)
NTP	Normal Temperature and Pressure
OS	Ordnance Survey
PM_{10}	Particulate matter with an aerodynamic diameter less than 10 microns
R2	Runway 2 (Manchester International Airport)
RAS	Regional Air Services
SN	Smoke Number
T5	Terminal 5 (Heathrow)

Glossary (Main Text)

Dp	Total amount of pollutant emitted in a standard ICAO LTO cycle (g)
F_{00}	Rated output (maximum sea level thrust) (N)
NO	Nitric oxide
NO_2	Nitrogen dioxide

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1 Introduction

1.1 BACKGROUND

AEA Technology was commissioned by the Airports Policy Division of the Department of the Environment, Transport and the Regions (DETR) to assess the impact on air quality of postulated growth scenarios at UK regional airports in the years 2015 and 2030. This air quality assessment was part of the Regional Air Services Co-ordination (RASCO) exercise, undertaken to support the development of an airports policy White Paper. The results for 2015 and 2030 have been reported elsewhere[1].

The AEQ Division of DETR separately commissioned AEA Technology to extend the study to the years 2005 and 2010, since these are key years in relation to the National Air Quality Strategy and the EC Daughter Directives. The results of the extension work are reported here in a similar format to that used in the 2015/2030 report.

1.2 OBJECTIVE OF THE STUDY

The objective of the study is to determine the impacts of postulated airport growth scenarios on the air quality in the vicinity of 23 UK regional airports, as judged against the objectives in the Air Quality Regulations 2000[2], focusing on the pollutants NO_2 and PM_{10}.

1.3 SCOPE

1.3.1 Airports

The study considers the air quality at 23 UK regional airports, as listed in Table 1.

1.3.2 Cases

Three future cases are considered for each airport are briefly characterised as follows:

- ‘Base Case’ (B): mid-point demand, with constraints applied to airports in the south east;
- ‘High Growth’ (H): growth according to demand (high demand), with constraints applied to airports in the SE;
- ‘Environmental’ (E): assumes no infrastructure development other than what is already in the planning system.

The study evaluates the air quality implications of the growth scenarios under the assumption that the airport infrastructure and surface access network remain the same as at present. Manchester International Airport is the only instance where the study considered a change to the airport infrastructure, in that the Stage B analysis for the future cases takes account of the operation of Runway 2.

Furthermore, the study takes no account of any specific measures that might be taken by the airports to mitigate the effects of airport-related emissions on local air quality.

1.3.3 Pollutants

The pollutants included are

- NO_x (nitrogen oxides, comprising NO and NO_2) and
- PM_{10} (broadly speaking, particulate matter with an aerodynamic diameter less than 10µm).

Although other airborne pollutants are emitted at airports and are included in the Air Quality Regulations 2000, NO_2 and PM_{10} are currently of particular concern in a number of areas of the UK, including areas around some airports. Neither of these pollutants is unique to airports, being emitted by a variety of sources, in particular road vehicles and power stations. On an airport, the chief emitters of these pollutants are aircraft, road vehicles and airside support vehicles/plant.

1.3.4 Air Quality Criteria

For ease of reference, the Air Quality Regulations 2000, as they apply to NO_2 and PM_{10}, are reproduced in Table 1.2. It has been borne in mind that the objectives apply in non-occupational near-ground level outdoor locations where a person might reasonably be expected to be exposed over the relevant averaging period. In the case of the annual-mean objective, this is taken to mean locations where individuals may be exposed for a substantial part of the day, thus including the vicinity of housing, schools and hospitals. In this study, therefore, the annual-mean NO_2 objective and the 24-hour PM_{10} objective are applied only at appropriate off-airport locations. In the following, the term ‘residence’ will be used as a shorthand to include housing, schools and hospitals.

At a given location, the annual-mean NO_2 objective is recognised as being more onerous than the 1-hour NO_2 objective. However, the 1-hour objective may need to be considered separately if there are receptors that lie closer to sources than do the nearest residential receptors and at which members of the public may be exposed (outdoors at ground level) for periods of an hour. This is the rationale for applying the 1-hour objective in the vicinity of the airport terminal. Similarly, the 24-hour PM_{10} objective is recognised as being more onerous than the annual-mean objective at the same location; neither of the PM_{10} objectives is considered applicable at on-airport locations.

2 Methodology

2.1 STAGES

To ensure an efficient use of resources, the assessment was carried out in two stages, labelled Stage A and Stage B. Stage A is a screening analysis, which provides a way of identifying - without using dispersion modelling - airport/scenario combinations that will not generate exceedences of air quality objectives. Airport/scenario combinations that do not satisfy the screening criteria in Stage A will not necessarily lead to air quality exceedences, but need to be considered further in Stage B. Given the nature of the analysis in Stage A, the concentration estimates may be significant overestimates in some instances.

2.2 RECEPTORS

Two classes of receptors are differentiated:

- 'background' receptors – these are far enough from roads that they do not receive a significant above-background contribution from the nearby road links;
- 'near-road' receptors – these are close enough to the nearest road links that they receive a significant above-background contribution from those links.

For screening purposes, properties out to a maximum of 200m from a road are considered potentially at risk of receiving a significant contribution from the road, but in practice the distance within which there is a significant contribution might be much smaller, depending on traffic volume, vehicle fleet mix, meteorology etc.

In addition, on-airport receptors are distinguished from off-airport receptors, in that only the air quality objective relating to the 1-hour mean NO_2 concentration is applied on the airport, for the reasons explained earlier.

2.3 CONTRIBUTIONS

From a methodology viewpoint, the total annual-mean concentration of a specified pollutant at background receptors is considered as having two components:

- the contribution from 'aircraft-related' sources, defined as aircraft exhaust emissions, APU (Auxiliary Power Unit) emissions and emissions from airside support vehicles;
- the contribution from all other sources, including landside road vehicles and sources that contribute to general background levels in the region of the airport.

For near-road receptors, in addition, the contribution from the nearby road link(s) is considered separately.

2.3.1 Aircraft-Related Sources

For this contribution, the concentration estimate is based on an evaluation of the emissions and the calculation of concentrations arising from those emissions using conventional atmospheric dispersion modelling, although the second step is carried out differently in Stages A and B. An outline of techniques used to evaluate aircraft emissions is given in Section 2.4.

2.3.2 Other Sources

The contribution to annual-mean concentrations from all other sources was estimated using the 'mapping' methodology previously developed by AEA Technology for the DETR[3],[4]. For NO_x, this represents the concentration at any point in the UK as arising from two components, the first related to local emissions (ie emissions in a 5km x 5 km square surrounding the point) and the second a background contribution taking into account more distant sources, obtained by interpolating rural monitoring data. The coefficient relating concentration to local emissions is empirically derived from analysis of national monitoring data. A similar procedure is used for PM_{10}, although the analysis is more complex in this case and the results more approximate.

To implement this approach here, first the base map (1999) has to be modified to remove any contribution from airports (to avoid double counting). Then, both the rural background contribution and the contribution relating to local emissions have to be projected forward to the future years. Further details on the projection are given in Section 2.7.

2.3.3 Near-Road Receptors

Further description of how this contribution is evaluated is given in later sections describing details of Stages A and B methodologies.

2.4 AIRCRAFT-RELATED EMISSIONS

The emissions (kg) from a given aircraft engine during a particular phase (mode) of the Landing and Take-Off (LTO) cycle are given by the product of the time-in-mode (s), the fuel flow rate (kg/s) and the emission factor (also called emission index) (kg pollutant per kg of fuel burned) for the particular engine thrust setting engaged during the mode. The total annual LTO-cycle emissions at an airport is then the sum over all engines on a particular aircraft, summed over all aircraft movements in a year at the airport (with landing and take-off parts of the LTO cycle counting as separate movements).

2.4.1 Aircraft Movement Data/Engine Assignment

Aircraft emission estimates were derived from movement data supplied by the DETR and the CAA. For 1999, the CAA provided actual data for the year, broken down by aircraft type. AEA Technology assigned engines to aircraft types, using standard fleet data sources, principally JP Airline-Fleets International[5]. For 2015 and 2030, the DETR provided movement forecasts broken down by aircraft seat-capacity band/tonnage band. The CAA[6] devised an aircraft fleet mix for each of the future years for each scenario, taking account of the introduction of new aircraft types/variants and the retirement of older aircraft; in addition they assigned engine types and variants to particular aircraft using current fleet data and taking account of current information on potential engine developments. The CAA then distributed the aircraft movements within a specific size band amongst particular aircraft types, for each airport in each scenario. The movement data based on passenger demand was supplemented by data on freight movements and business aviation. AEA Technology calculated the emissions from the resulting movement data broken down by aircraft type.

A limited set of aircraft was considered adequate for representing the future aircraft fleets, as listed in Table 2.1. As a check, the actual 1999 movements at each airport were assigned to a similar set of representative aircraft types as that used in the future years, and the emissions re-calculated. This was found to give total aircraft emissions close to those calculated using the full range of aircraft types (within 3% on average for NO_x and 10% on average for PM_{10}), indicating that the use of representative aircraft types was not likely to contribute large inaccuracies in calculating future emissions.

Where a number of possible engine types can be fitted to the same airframe, engines were assigned in proportion to their current usage at major UK airports. For airframes not yet in service, an approximate market share for the various potential engines was estimated by the CAA based on current information.

2.4.2 Times-in-Mode

It was outside the scope of the study to obtain detailed airport-specific time-in-mode data for aircraft at each airport separately (even presuming such data are available). However, algorithms were devised to give the times in the various phases (modes) of the LTO cycle, based on data obtained from Heathrow, Gatwick and Stansted airports, modified to take account of, for example, differing lengths of runway and differing levels of activity at the airport.

2.4.3 Aircraft Exhaust Emission Factors and Fuel Flow Data

Civil aircraft engines are certificated with respect to emissions of NO_x, CO, HC (total hydrocarbons) and Smoke Number (SN, related to the blackening of a filter paper after passing a known volume of exhaust gas under controlled conditions). Emissions standards are set by the International Civil Aviation Organisation (ICAO), a special body of the UN, which publishes a databank[7] of emission indices and fuel-flow data obtained from certification tests. This provided the chief source of NO_x emissions, SN data and fuel-flow information for current engines used in this study; it was supplemented by data in the FAA (Federal Aviation Administration) databank[8] for a small number of engines (principally turboprops) not found in the ICAO databank. In the (relatively few) cases that a current engine could not be found in either databank, a surrogate engine of similar thrust was assigned.

PM_{10} emissions are not measured specifically as part of the certification process, and a methodology has been devised by AEA Technology[9], using the Champagne curve[10], to derive approximate PM_{10} emission factors from SN data.

For those engines not yet in service and for which emissions data are not available, AEA Technology derived an estimate of the NO_x emission factor based on the estimated rated output (maximum sea-level thrust) required of the engine on a particular airframe together with whatever data could be gleaned about the manufacturer's design targets for engine pressure ratio. The assumption was made that these engines would just meet the CAEP4[11] NO_x standard for the target thrust and pressure ratio. Where the variables were known only to within a range, the maximum emission factor over the range was used.

Applying the CAEP4 standard provides an estimate only of Dp (NO_x), the total mass of NO_x emitted during a reference LTO cycle. To complete the specification of the emission indices, therefore, the procedure adopted was to choose a certificated engine with rated output in the appropriate range (and from the same manufacturer if possible) then re-normalise the emission factors of the chosen engine in each mode by the ratio of the calculated limit Dp value to the tabulated Dp for the chosen engine. Thus, the chosen engine is used only to provide plausible ratios of the emission indices across the four standard ICAO modes of the LTO cycle. Although the resulting emission factors will vary with the engine chosen, the sensitivity of total emissions to this variation is not great, given that Dp for NO_x is dominated by the take-off and climb-out modes, for which the ratio in emission indices does not vary strongly from engine to engine. The chosen engine was also used to give an estimate of SN. Table 2.2 shows the thrust and pressure ratio assumed for the 'new' engine, together with the calculated limit value of Dp/F_{00} (where F_{00} is the rated output) calculated from the CAEP4 line. In some cases, the 'new' engine was only one of several to be assigned to the airframe in the future fleet: the assumed fractional usage of the new engines is also shown in Table 2.2.

It was assumed in the analysis that aircraft in various modes of the LTO cycle engage one of the standard thrust settings referred to in the ICAO databank. Thus 100% thrust was assumed for take-off, 85% for climb-out, 30% for approach and 7% for taxiing. It is well known that large commercial jet aircraft often take off at less than 100% thrust, depending on, *inter alia*, take-off weight, air temperature, operational constraints and airline policy. In the absence of statistical data on the extent of reduced-thrust take-off at the regional airports, it was assumed in this study that all aircraft take off at full thrust, even though the statistical data on take-off runway occupancy times used may have been influenced implicitly by reduced thrust take-off. This will lead to a potential overestimation of the aircraft NO_x emissions by an fraction between zero and about 20%.

2.4.4 APU Emissions

NO_x emissions from an individual Auxiliary Power Unit (APU), per aircraft movement, (kg) were estimated from the product of the APU running time (s), the fuel consumption (kg/s) and the emission factor (kg pollutant per kg fuel consumed). No PM_{10} emission factors are available for APUs.

Airport/aircraft-specific data on APU usage were not available for the regional airports, and an approximate estimate of emissions was made on the assumption of 17.5 minutes running time on arrival and 30 minutes before pushback, on average, data specific to Heathrow provided for the T5 Public Inquiry. This is more likely to overestimate than underestimate APU emissions, particularly for the future cases, given the moves to reduce emissions from this source through increasing use of Fixed Electrical Ground Power and pre-conditioned air.

Published emission factors are available for only a limited number of APU models, with the data taken from old sources, leading to significant additional uncertainties in the emissions estimates. Every aircraft type was assigned one of the APU models for which emissions data are available, based on the size of aircraft.

Even on this conservative[*] estimate, APU emissions amount to typically around 5% of the total LTO-cycle NO_x emissions (around 15% of the ground-level aircraft emissions).

2.4.5 Fugitive PM_{10} Emissions from Aircraft

In the past there has been little information available on which to base an assessment of the contribution to PM_{10} emissions at airports from aircraft brake and tyre wear. Some limited information has recently become available relating to the operation of the Fokker100/BAe146 aircraft at Stansted, leading to an estimate of 0.07kg eroded material from (carbon) brakes and tyres per landing. In using this information, it has been assumed that all eroded material ends up as suspended particulate matter in the PM_{10} size range. The resulting value of emitted PM_{10} per landing was applied to all aircraft landings at the regional airports, irrespective of aircraft size and nature of brake material (which is steel rather than carbon for some aircraft types). This is

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[*] Here and in the following text, a 'conservative' estimate is one that is more likely to lead to an overestimate than an underestimate of the associated concentration contribution.

clearly a coarse assumption, and further work is needed in the future if these estimates are to be refined. The estimates are likely to be overestimates, given that all eroded material has been taken as PM_{10}, unless large aircraft turn out to have a disproportionately high impact on the total fugitive emissions.

Typically, the estimated contribution from brake and tyre wear is around 25%-40% of the total PM_{10} emissions from aircraft in the LTO cycle, so uncertainties in the estimate contribute significantly to the overall uncertainties in the aircraft contribution to ground-level PM_{10} concentrations.

2.4.6 Airside Vehicles

Estimates of the emissions from airside support vehicles and plant in a given year were based on the simple assumption of a fixed amount of pollutant per passenger throughput, on the grounds that the level of information available on this source at most airports would not support a more sophisticated methodology. At first sight it might appear that scaling emissions by the number of aircraft movements rather than passengers might be preferable, but the approach adopted is based on the assumption that larger aircraft will generate more airside activity.

The quantities of emissions per passenger in the current year were based on past analyses carried out for Stansted and Gatwick airports. Even at these airports, the emissions from airside support activities were derived from information on total amounts of fuel consumed (of various types), rather than detailed logs of activity for each type of plant, with consequent uncertainty over how the fuel usage is distributed over various types of plant with differing emissions characteristics. A composite emission factor, taking account of all fuel types, was worked out as 9 tonne/mppa for NO_x and 0.8 tonne/mppa for PM_{10}.

A dominant contributor to the above emissions arises from the diesel used in off-road vehicles and plant. Corresponding emission factors were taken from the European Environment Agency database[12], but such emissions are subject to EC Directive 97/68/EC which will lead to a reduction in the maximum allowed emissions per kW-hr (in two Stages). It is judged that by 2015 all vehicles in the fleet are likely to comply with limits in Stage 2 of this Directive. Accordingly a scaling factor of 0.41 has been applied to the NO_x emissions per passenger and a factor of 0.27 to the PM_{10} emissions, which are appropriate to the range of power ratings of typical airside vehicles/plant.

The mppa values used in calculating airside vehicle emissions were actually ‘effective mppa’ values, enhanced to include a passenger equivalent for freight aircraft. These ‘effective mppa’ values were derived from the processed aircraft movement data (which includes freight movements) broken down by aircraft size band by assigning the mean number of seats in the band to every aircraft and assuming 70% of the available seats are occupied.

2.4.7 Extensions to the Aircraft Emissions Methodology for 2005/2010

For 2005, movement data were supplied by the CAA in the same format as for 2015 and 2030, taking account of anticipated changes in the airframe and aircraft engine mix between 1999 and 2005 in response to the requirements of noise regulations. Aircraft emissions were thus calculated by the same methodology used for 2015 and 2030. For 2010, the estimates of aircraft emissions were based on linear interpolation between the emissions estimates for 2005 and 2015, using passenger throughput as the interpolation variable.

2.5 STAGE A CONCENTRATIONS

The estimates of aircraft-related emissions obtained as described above are used in both Stages A and B. Where the stages differ is in the derivation of the contribution to ground-level annual-mean concentrations resulting from those emissions.

This section describes the Stage A methodology for calculating the concentration contribution from aircraft-related sources and from key road links. The Stage A methodology described below was used for 2005, 2010, 2015 and 2030.

2.5.1 Screening Rationale

The extent to which the contour (ie, the curve joining points of equal ground-level annual-mean concentration) at a particular concentration level of interest extends out from the airport into the surrounding area depends firstly on the total emissions on the airport. But the precise shape of the contour is sensitive to the spatial distribution of sources over the airport and to the statistical distribution of weather conditions (in particular the wind rose[†]). In principle, therefore, to determine whether particular nearby residential properties may or may not experience concentration levels above a particular set objective requires detailed dispersion modelling to account fully for spatial and meteorological features. However, in view of the large number of cases to be investigated, devising a way of identifying, without having to carry out dispersion modelling, airports/scenarios that will definitely not generate any exceedences of objectives was considered worthwhile, provided the effort required to carry out the screening was less than the dispersion modelling effort saved.

For this study, a screening methodology was based on the results of past dispersion modelling studies, principally at Gatwick airport, but also taking account of results at Stansted and Heathrow airports. The method recognises two principal features of the contours of the contribution from aircraft-related sources. First, they reflect the large quantities of ground-level emissions on the runway, associated with take-off roll (particularly important for NO_x) and landing roll, which causes contours to enclose all or some of the runway. Secondly, they show the influence of the sources on the terminal aprons, resulting from stand-related aircraft emissions (such as APU emissions) and airside support-vehicle emissions, in terms of a ‘bulge’ in close-in contours around the terminal area.

The first stage in the methodology, therefore, was to devise a relationship giving the maximum annual-mean concentration contribution as a function of distances from the runway per unit total annual aircraft emissions, as derived from studies at Gatwick airport. In applying this relationship at other airports, the use of the maximum value will account for the fact that it is not known *a priori* what are the worst locations at any given distance from the runway at a particular airport. Thus, the calculated aircraft contributions are likely to be overestimates for a selected receptor at a specified distance from the runway, unless it happens to lie at the worst location with respect to sources for that particular distance. In addition, even if it was at the worst location for its distance, the contribution would still be overestimated if the airport under

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[†] wind rose: the relative frequency with which the wind blows in various directions

consideration had a more favourable disposition of key sources in relation to the prominent wind direction and the bearing of the receptor than does Gatwick. Inspection of the spatial and meteorological information at Gatwick, and comparison against equivalent (normalised) Stansted results, suggests that Gatwick will lead to a curve of maximum normalised concentration as a function of distance that lies in the upper part of the range of such curves over all airports.

Thus the degree of overestimation in applying the derived relationship varies from receptor to receptor and, potentially, from airport to airport. The analysis at Gatwick suggests that for off-airport locations the overestimation in the contribution from aircraft to annual average NO_x or PM_{10} may be as high as a factor of 10, although it is expected to be less in the vicinity of the terminal. Nevertheless, the resulting screening process is effective if it eliminates a significant fraction of the airport/scenarios from needing further analysis in Stage B. The overestimation in the Stage A results may be particularly marked for Manchester International Airport in the future cases, in that the analysis does not take account of the sharing of emissions between the two runways.

The Stage A analysis also makes specific provision for off-airport receptors that are much closer to the terminal complex than to the runway, in that they may receive a significant contribution from sources on the terminal aprons. Also, an estimate of concentrations in the vicinity of the terminal itself is required for application of the 1-hour NO_2 objective to passengers. A concentration contribution is added, therefore, which is related to the total emissions in the terminal area.

2.5.2 Receptors for Stage A

For each airport, the relevant shortest distance of interest was found by inspecting the map for the residence with the shortest distance to any point on the runway and the residence with the shortest distance to the terminal. Where there was uncertainty over whether an off-airport property is residential or not, the assumption was made that it is residential.

Table 2.3 shows the distances of the selected representative properties.

In addition, the Stage A methodology also requires the distance between terminal and runway be specified, in the context of applying the 1-hour NO_2 objective at the terminal, and this is also given in Table 2.3.

2.5.3 ‘Key Links’ Methodology for Stage A

The following methodology was developed for Stage A in relation to receptors close to key road links around the airports.

First, W S Atkins supplied traffic volumes, for the years 2015 ande 2030, on a set of links which satisfied both of the following criteria:

- more than 10% of the flow on the link was airport-related (in at least one of the scenarios considered), a typical criterion when assessing scheme impacts, and
- there are properties currently less than 200m from the road.

For 2005 and 2010, the road traffic on the individual links was scaled from the data supplied for 2015, taking account of airport-related and non-airport traffic separately.

For the identified links, a further stage of screening was applied using the tools provided for Local Authority Stage 1 Review and Assessment[13]. These give estimates of the traffic volume – for a specified background air quality in the vicinity of the road - below which there is little risk of exceeding the AQS annual-mean NO_2 and 24-hour PM_{10} objectives, given an estimate of the speed on the link and whether or not the link is single or dual carriageway. Although the curves are applicable to 2005, they will be conservative (ie, tend to overestimate) when applied to 2010, 2015 or 2030, given the decrease in emissions per vehicle with time.

For those links emerging from the above screening process as requiring further attention, the screening methodology provided by the Design Manual for Roads and Bridges - as modified by Stanger for use in the LA Review and Assessment process[14] - was applied at the nearest property to the road link. Again, where there was uncertainty over whether the property was residential or not it was assumed to be residential. The representative vehicle speeds used were judged from the road class.

2.5.4 Screening Criteria

In summary, the following screening criteria were used to determine if an airport/scenario needed to be considered in more detail in Stage B.

Considering receptors not influenced appreciably by a nearby road,

- if the calculated annual mean concentration of NO_2 at the selected nearest residence to the airport is greater than 40 µg m^{-3} or
- if the calculated 99.8th percentile of the one-hour mean concentration of NO_2 at the airport terminal is greater than 200 µg m^{-3} or
- if the calculated 90th percentile of the 24-hour mean concentration of PM_{10} at the selected nearest residence to the airport is greater than 50 µg m^{-3}

then the airport/scenario will have to be considered further in Stage B.

(NB: The current annual-mean PM_{10} objective is less onerous than the 24-hour objective applied at the same location.)

In addition, considering receptors close to roads carrying significant airport-related traffic:

- if the calculated annual mean concentration of NO_2 at the residence nearest to the road is greater than 40 µg m^{-3} or
- if the calculated 90th percentile of the 24-hour mean concentration of PM_{10} at the residence nearest to the road is greater than 50 µg m^{-3}

then the airport/scenario will have to be considered further in Stage B.

2.6 STAGE B CONCENTRATIONS

This section describes the Stage B dispersion-modelling methodology for obtaining the concentration contribution from aircraft-related sources in 2015 and 2030.

The results for 2005 and 2010 were based on scaling from the results for 2015 using the ratio of total aircraft emissions as the scaling factor. This is a good approximation, given that the spatial layout of the airport was assumed to be the same in all years and that the relative fraction of emissions in each LTO-cycle phase does not vary strongly from year to year.

2.6.1 Dispersion Model

The dispersion model used for the Stage B analysis was ADMS-3[15], one of the new generation of dispersion models that exploit advances made over the last few decades in understanding the transport-diffusion of pollutants in the lower levels of the atmosphere. By contrast, the relationships used in the Stage A analysis were derived from results obtained with an earlier dispersion model (LPAM[16]), a typical representative of the earlier generation of Gaussian dispersion models. A sufficient number of comparisons between ADMS and the older models have been carried out to indicate that, for the predominantly low-level sources on an airport, large systematic differences in calculated annual-mean concentrations are not to be expected, provided meteorological conditions are parameterised in equivalent ways.

ADMS has been compared against experimental data in a wide variety of situations[15], sufficient to justify its applicability to the sources on an airport, provided adequate consideration is given to near-source effects that are not automatically dealt with by the model. These will be discussed further below.

ADMS was applied to the large number of sources on the airport by using a ‘dispersion kernel’ approach, a highly efficient way of handling the complex spatial distribution of emissions on an airport. This exploits the fact that the annual-mean concentration arising from a number of sources is the simple sum of the annual-mean concentration from each taken individually, provided the sources behave passively (ie, provided one source does not change the environment within which another source is dispersing, as can happen for example if there are overlapping plume-rise effects). Thus, for example, all ground-level sources of the same initial dispersion can be handled by performing a single run for one such source and translating the origin to apply the results to any other such source. To account for aircraft emissions above the ground, a series of ADMS runs (each for a single source) was carried out spanning the range of heights of interest, and interpolation used for sources at intermediate heights.

2.6.2 Dispersion Parameters

No specific coastal or topographical effects on dispersion are included other than through their influence, if any, on the statistical meteorological data used for each airport. Although fumigation[‡] of elevated aircraft emissions is feasible in particular weather conditions for an airport located at the coast, this phenomenon will not have a significant impact on annual mean ground-level concentrations around the airport. Similarly, it is assumed that there are no hills of

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[‡] fumigation: rapid mixing down to ground level of material emitted into a stable atmospheric layer above an unstable layer once the material reaches the interface between the two layers

sufficient elevation close to the airports of interest to significantly affect dispersion in the immediate vicinity of the airport.

Each airport has been assigned a roughness length (related to the heights of projections from the surface in so far as they affect the wind flow over the surface) representative of the airport and surrounding terrain. This will influence the passive dispersion of pollutants once they escape from the near-field influences of aircraft, vehicles and buildings. Near-field effects have been represented by assuming sources have a minimum initial horizontal and vertical extent. Clearly this will not provide the details of the concentration pattern in the immediate vicinity of sources, but the initial size parameters are chosen to give a representative amount of dilution in the near field.

For aircraft exhaust emissions, near-field effects are complex, governed by the heat and momentum of the exhaust gases, and there are fundamental uncertainties over how much additional dispersion these create beyond that generated by ambient atmospheric turbulence. In this study, initial dispersion parameters have been chosen, therefore, that are more likely to underestimate than overestimate the near-field dilution, and thus more likely to overestimate than underestimate near-field concentrations. At further distances from the aircraft (beyond a few hundred metres, typically) uncertainties in initial dispersion become less important as ambient turbulence takes over. In general, concentration information is not sought so close to aircraft that there is large sensitivity to initial dispersion. Some sensitivity may remain, however, at the terminal locations included in the study and, for some airports, at the nearest off-airport residences when these lie within a few hundred metres of runways or terminal aprons. In the ‘key road links’ analysis, predictions may be sought very close to individual road links, and concentrations there will be sensitive to the choice of initial dispersion.

The way in which the heat and momentum combine to produce dispersion and, possibly, bodily rise of the plume is not well understood for plumes in close proximity to the ground such as from aircraft on the airport; the empirical data on aircraft exhaust plume rise - what little exists - is difficult to interpret. Thus, no specific representation of the potential plume rise of aircraft engine exhaust gases has been included in the modelling. Again, this could lead to overestimation of the near-field concentration contribution from aircraft.

2.6.3 Meteorological Data

It is not possible to forecast the detailed weather patterns in the future years, and the analysis here is based on the assumption that there are no significant climatological shifts between now and then. In terms of annual-mean concentrations, the variations from year to year currently are not large, but it was considered preferable to use long-period meteorological data to avoid the forecast concentrations being dominated by a single, possibly untypical, year’s meteorology. ADMS can be operated either with a set of hour-by-hour sequential meteorological data or with a ‘statistical’ set of data in which the hourly data have been assigned to a number of discrete meteorological categories spanning the ranges of the pertinent variable. The use of statistical datasets is considered adequate for calculating annual-mean concentrations, and involves shorter computational times when the data span several years.

Thus, statistical datasets based on a 10-year run of meteorological data were obtained from the UK Meteorological Office for each of sites of interest in Stage B (Birmingham, East Midlands and Manchester). For Birmingham and Manchester, weather data obtained on the airport itself were available; for East Midlands airport data were obtained from Watnall (Nottingham), the latter considered sufficiently close to the airport to provide representative statistical data. ADMS allows for the possibility that the roughness length of the terrain around the site of interest may be different from that around the met. station.

For some of the stations, data were not available right up to the current year because the station had stopped operating. It was considered preferable to use data from the nearest site for an earlier 10-year period rather than more recent data from a site further away. Table 2.5 lists the data sets used.

2.6.4 Spatial Representation of Sources

The spatial distribution of emissions on the airport is complex. On the runway during take-off or landing roll, the emissions arise from an accelerating or decelerating source, which may focus emissions towards the ends of the runway. The orientation of the runway and the airport wind rose will generally lead to an asymmetric split of annual emissions between the two ends of the runway, as aircraft usually take-off and land into the prevailing wind. Different aircraft weight classes may require different lengths of roll. For taxiing emissions, some taxiways may be used more frequently than others; some may be used predominantly by some types of aircraft rather than others. Emissions on the aprons may be focused on some aprons or parts of aprons more than others. It is a formidable task to construct the fine detail in the spatial distribution of emissions, beyond the scope of the current study covering 23 airports. However, the sensitivity of the resulting overall concentrations to the spatial detail of a particular source category depends on how close to sources concentration information is sought and what contribution the particular source category makes to the total.

For the current study, an intermediate level of spatial detail was chosen, to capture broad features of the spatial distribution of diffuse sources or sources of lower emission intensity, with somewhat more detail used for intense sources localised in particular regions. In line with this philosophy, emissions from taxiing emissions were spread uniformly within two rectangles stretching to either side of the runway, running the full length of the runway, with widths judged from the detailed map of the airport. APU and airside-vehicle/plant emissions were distributed uniformly within a rectangle (of selected orientation) chosen by inspection to represent the area where such emissions are expected principally to arise. Emissions associated with take-off and landing roll were represented in more spatial detail - taking account of different characteristics for different categories of aircraft – as were the emissions arising from the near-ground portions of the initial climb and approach trajectories. ‘Holding’ emissions were represented as point sources at the ends of the runway.

All sources on the airport - whether configured in the horizontal plane as lines, points or areas - were represented as arrays of small volume sources of cuboid shape, with the horizontal area chosen to be a square of side 10m and the depth chosen to reflect initial vertical dispersion (8.7m for aircraft-related sources), in order to apply the dispersion kernel approach outlined earlier. This effectively limits the smallest (horizontal) distance between receptor and source to 5m. If concentration information were required very close to sources, the individual sources could be spaced every 10m horizontally (thereby giving contiguous volumes). However, where concentration information is required only at greater distances from the source, a more ‘grainy’ representation of the source is possible (for example with sources of correspondingly greater intensity every 20m), without introducing artefacts into the concentration pattern caused by the discretised nature of the source representation. For all aircraft emissions at ground level in this study, line sources were discretised at 20m spacing and area sources on a 20m square grid.

The key road links identified in Stage A as needing further attention were modelled as straight-line sections of road of the appropriate orientation, with recognition given to the variation of road width with road class. An appropriate length of road was obtained by drawing a 200m radius circle centred on the nearest receptor and choosing the stretch of road within the circle, on the grounds that concentrations are expected to relax to the background value by 200m from the road at most. In calculating the 'background' concentration near the road (from all other sources, including the aircraft-related emissions and all other road-vehicle emissions), no attempt was made to subtract out the contribution from the stretch of road modelled in detail. However, this represents a very minor amount of double-counting given that the background is modelled as arising from the total road-vehicle emissions within a 5km square around the point of interest (Section 2.7). Given the small number of road links to be investigated, each road link was modelled in ADMS as a single volume source, taking advantage of the internal ADMS procedures for integrating over the volume.

2.6.5 Diurnal Profiles

Aircraft-related emissions do not arise uniformly throughout the day; in particular, there are usually comparatively few aircraft movements at night. This will influence annual-mean concentrations, given that atmospheric conditions leading to slower dispersion – and hence higher concentrations for low-level sources – are more likely to occur at night.

The statistical meteorological data supplied by the UK Met. Office for use with ADMS fortunately provides separate information on the relative frequency of various weather classes for different periods of the day and night, each of several hours duration. This enables some representation - albeit at a temporal resolution of a few hours - to be made of the diurnal profile of emissions: the weather-category probabilities in the various periods of the day were weighted by the relative intensity of emissions during that part of the day (and the resulting probabilities re-normalised). For this purpose, a single, stylised, representative diurnal profile was constructed to apply to all airports in all years, as shown in Fig 2.1. This mirrors the diurnal emissions profile typically found at a large airport.

2.6.6 Receptors

Concentrations were calculated on a regular grid of receptors spaced at 100m throughout a 7.5km square area centred on the airport. Also, a representative terminal location was chosen for each airport studied in Stage B. In addition, the road-link contribution to concentrations was calculated at the nearest receptor for each of the key links treated in Stage B (with the contribution from all other sources at the nearest receptor interpolated from the 100m grid results).

Results on the 100m grid were interpolated using a standard kriging algorithm to obtain the concentration contours referred to in Section 3.

2.7 CONTRIBUTION FROM OTHER SOURCES

The previous two sections have shown how the contribution to annual-mean NO_x and PM_{10} concentrations from aircraft-related emissions were obtained in Stages A and B respectively. In both analyses, this contribution has to be added to the contribution from all other sources, obtained using the mapping methodology described earlier. This contribution itself was considered as two components:

- the contribution from (landside) road-vehicle emissions local to the area of interest and
- the contribution from the remaining sources.

2.7.1 Contribution from Remaining Sources

$\underline{NO_x}$

In applying the 'mapping' methodology for NO_x to a current year, the contribution to annual-mean concentration at a given point from 'other' sources, omitting local road-vehicle emissions, is itself considered as two contributions:

- a 'background' contribution derived by interpolation of rural monitoring data and
- a contribution from emissions (excluding road-vehicle emissions) in a 5km square around the point.

In projecting these contributions to the future years, the first was obtained by scaling from the 1999 values using a spatially-independent factor equal to the ratio of forecast to current values of the total UK NO_x emissions (all source categories), with the tacit assumption that any non-UK contributions will also scale approximately with UK total emissions. Projections of total UK emissions are available only up to 2020[17], but the trend is fairly flat towards the end of this range, so the values in 2030 are taken to be the same as in 2020. This procedure is approximate in that it will not account for regional differences in the way NO_x emissions over the whole country (and beyond) influence rural concentrations.

For the second contribution, spatially-disaggregated emissions forecasts for 2015 and 2030 were not available, so 1997 emissions within the 5km square were obtained from the NAEI $1km^2$ disaggregated emissions database, this being the most recent source of data at the time. These data were scaled in accordance with forecast changes in the total UK NO_x emissions in the particular source categories included in the NO_x mapping methodology (but excluding road vehicle emissions). The mapping methodology includes low-level sources, with the principal categories (after leaving aside road vehicle emissions) being domestic, industry services and other transport (apart from aircraft and shipping).

$\underline{PM_{10}}$

Given the absence of data from a network of rural PM_{10} monitors, the mapping methodology for PM_{10} identifies more separate contributions to the annual-mean concentration, namely

1. a coarse PM_{10} contribution ($7\mu g/m^3$), uniform across the UK,
2. contribution from secondary particulate, obtained by scaling from rural sulphate concentrations,

3. a UK regional primary PM_{10} contribution,
4. a European regional primary PM_{10} contribution, obtained from European-scale modelling studies,
5. a contribution from urban activities to coarse PM_{10} (a small contribution ranging up to about $2\mu g/m^3$),

in addition to the contribution related to local emissions in the 5km square surrounding the point of interest. In forecasting the total contribution in 2015 and 2030, the following assumptions were made for the various components respectively.

1. The coarse contribution is assumed to remain constant in time.
2. The contribution from secondary particulate matter in 2005 (2010) has been forecast by the NAEI to be 0.953 (0.73) times that in 1999; the values in 2015 and 2030 are assumed to be the same as in 2010, which is more likely to overestimate than underestimate the value for those years.
3. The UK regional primary contribution is scaled (uniformly over the UK) using the ratio forecast to current values of total UK primary PM_{10} emissions, excluding the contribution from quarries, construction and road-vehicle brake and tyre wear.
4. The European regional primary contribution is scaled in line with UK total primary emissions (ie, as for contribution 3.), in the absence of European-scale emissions projections.
5. The urban coarse contribution is held fixed at current levels.

In the absence of spatially-disaggregated emissions forecasts for the future years, the 1997 emissions within the 5km square obtained from the NAEI $1km^2$ disaggregated emissions database were scaled in accordance with the ratio of forecast to current values of the total UK PM_{10} emissions in those source categories included in the PM_{10} mapping methodology (but excluding road vehicle emissions). The mapping methodology includes low-level source categories, with the principal categories (after leaving aside road vehicle emissions) being domestic, industry services and other transport (apart from aircraft).

2.7.2 Contribution from Road-Vehicle Emissions

In applying the mapping methodology, separate consideration was given to road traffic emissions in view of their potential importance to NO_x and PM_{10} concentrations, with a distinction drawn between airport-related trips and non-airport traffic (since the former varies with airport scenario). W S Atkins were responsible for estimating the traffic volumes around each airport for each airport/scenario in each year, with AEA Technology responsible for converting traffic data into emissions, using factors provided by the NAEI.

As a first step, Atkins calculated the total vehicle-km arising from airport-related trips in a set of 5km squares lying within a 10km square centred on each airport in the study, for 1997, 2015 and 2030, based on total (non-transfer) passenger numbers, modal splits and estimated vehicle occupancies. (NB: These estimates took account of airport staff journeys and secondary activity created by the operation of the airport). The vehicle-km were partitioned according to road type, the latter being used as a surrogate for speed, given that emissions per vehicle are speed dependent. This enabled an estimate to be made of the airport-related road-vehicle emissions per km within the 10km square. (Although this procedure generates emissions information only at a spatial resolution of 5km, it should be borne in mind that it is used to calculate concentrations by aggregating emissions into 5km x 5km squares.) For 2005 and 2010, the vehicle-km estimates were derived from values provided for 1999 and 2015, using linear interpolation by year.

In addition, the extra contribution from engines starting from cold was also included by assuming that all trips (passenger and staff) originating from the airport, together with all taxi and staff trips in to the airport, involve a cold start. Cold-start emission factors (in g/trip) were obtained from the NAEI, as a function of vehicle type and year of interest.

Atkins also estimated the ratio between the non-airport vehicle-km in a future year to the value in 1997, separately for each airport and each future year, based on regional traffic growth forecasts (TEMPRO[18]), which go as far as 2031. The absolute values of non-airport road-vehicle emissions in each 1km square in a 10km square around each airport for 1997 were obtained by subtraction of the calculated airport-related road vehicle emissions from the total road-vehicle emissions contained in the NAEI disaggregated database for 1997. Non-airport road vehicle emissions for future years were thence obtained by multiplying the 1997 emissions by the vehicle-km ratio supplied by Atkins, after making allowance for the differences in emissions per unit vehicle between years. In the latter context, Atkins supplied the ratio of HDV (Heavy Duty Vehicles, including HGV and buses) vehicle-km to LDV (Light Duty Vehicle, including Light Goods Vehicles and passenger cars) vehicle-km, since the changes in emission factors differ from one vehicle type to another. Within the two broad categories of HDV and LDV, the vehicle fleet mix was assumed to reflect the national average, for which forecasts are available in the NAEI. It should be noted that projected road-vehicle emissions factors were available from the NAEI only up to 2025; the values were held constant thereafter.

The forecast road-vehicle emissions on a 1km basis around each airport were then converted into concentration contributions using the mapping methodology described earlier. This provided the contribution from sources other than airport-related on a 1km basis within a 7.5 km square study area centred on each airport investigated.

The transport modelling undertaken by W S Atkins was completed before the 10-year transport plan and associated modelling were published. It is possible that the traffic projections produced by W S Atkins are therefore now a little pessimistic in relation to the non-airport traffic component, which may not now grow as fast as assumed. The potential overestimation from this effect, however, is not expected to have a major impact on the results.

2.7.3 Major Point Sources

The ‘mapping’ methodology described above does not include explicitly the contribution from major ‘point’ sources such as power stations. These have tall stacks and significant plume rise, so that their impact on ground-level concentrations extends well beyond the local scale. The influence of distant, major sources may be included to some extent in the ‘rural’ contribution to the mapping estimates, but it is considered prudent in air quality assessments to take account of the possibility that a particular major point source may be situated so as to have a significant above-background impact at the location of interest.

For the present study, the NAEI database was interrogated to identify major point sources (of NO_x and PM_{10}) within 15km of any of the study airports, this distance having been judged on the basis of past experience to be a suitable limit for identifying major local impacts[13]. A number of sources were identified as being of potential significance, principally the large power stations within 15km of Cardiff airport (Aberthaw B), Liverpool airport (Fiddler's Ferry) and East Midlands airport (Ratcliffe on Soar).

These sources were further investigated using the screening tools recommended for Stage 2 LA Review and Assessment[13], which are based principally on a set of results obtained using the ADMS dispersion model[19]. This screening analysis demonstrated that the identified sources make a small contribution to the annual-mean NO_x and PM_{10} concentrations in the vicinity of the corresponding airports. In addition, the screening tools demonstrated, that the identified point sources were likely to lead to less than one exceedence of the 200 $\mu g/m^3$ level at the corresponding airports, even after taking account of the airport-related contribution.

2.7.4 Key Links Analysis

No Stage B key links analysis was carried out for 2005 and 2010.

2.8 CONVERSION OF ANNUAL-MEAN TO OTHER STATISTICS

The above sections outline how annual-mean NO_x and PM_{10} concentrations were obtained. The Air Quality Regulations 2000, however, relate to NO_2 rather than NO_x (the total of NO and NO_2) and refer to the 99.8th percentile of 1-hourly NO_2 means in addition to the annual mean. It has become common practice to derive these metrics from the annual-mean NO_x concentration using empirical relationships based on UK monitoring data. In this study, the relationships given in the Technical Guidance Note disseminated by the DETR[13] to assist the LA Review and Assessment process were used. Similarly, for PM_{10}, the 90th percentile of 24-hourly means is required; this was derived from the annual mean using the relationship in the same Guidance document.

For easy reference, the conversion relationships used are summarised in Table 2.4. It should be borne in mind that there is some scatter about the fitted relationship, which translates into an uncertainty in derived short-period statistics at a particular location. Similarly, there is some variability in the relationship from year to year at a given location.

For the key links analysis, the NO_x to NO_2 relationship was taken from the Stanger version of the DMRB[14], which shows a dependence on the distance from the road. This uses the relationship for kerbside/roadside sites given in reference [13] for receptors immediately at the kerbside (see Table 2.4) and the relationship for background receptors in [13] for distances greater than 25 metres from the edge of the road, with interpolation for distances in between. The additional constraint is applied that if the total NO_x annual-mean concentration is less than $50\mu g/m^3$ the background relationship is used at all distances. This procedure derives from empirical evidence that there is lower conversion to of NO to NO_2 very close to roads due to the time required to mix sufficient ambient ozone into the released NO_x plume.

3 Results and Discussion

Only the results for 2005 and 2010 are given below. The results for 2015 and 2030 are given in Reference [1].

3.1 CONTRIBUTION FROM ‘OTHER SOURCES’

Table 3.1 shows the contribution at the off-airport location chosen for Stage A from all sources other than airport-related emissions. It should be borne in mind that this contribution is calculated at a 1-km resolution only and involves an averaging of local emissions over a 5km square, so will not generally have a large spatial variation over the airport.

Comparing to the results in Reference [1], the concentrations in both 2005 and 2010 lie between those for 1999 and 2015, so for equivalent cases the concentrations are higher than in 2015, with the 2005 values higher than those in 2010.

3.2 AIRCRAFT-RELATED EMISSIONS

3.2.1 NO_x

Table 3.2 shows the total aircraft NO_x emissions, including APU emissions (which contribute around 3%-8% of the total). As expected, the emission estimates lie between those for 1999 and 2015, with values in 2005 lower than in 2010.

Estimated emissions from airside support vehicles/plant are shown in Table 3.3.

3.2.2 PM_{10}

Table 3.4 shows the total aircraft PM_{10} emissions for each airport/scenario. As expected, the emission estimates lie between those for 1999 and 2015, with emissions in 2005 lower than in 2010.

Table 3.5 shows PM_{10} emissions from airside support vehicles/plant.

3.3 STAGE A RESULTS

3.3.1 Non-Roadside Receptors

<u>NO_2</u>

Table 3.6 shows the results of applying the annual-mean NO_2 screening criterion to each airport/scenario: a ✓ denotes that the objective value is not exceeded, whereas a ✗ denotes that it is exceeded. 15 airport/case combinations out of a total of 138 (6x23) fail to meet the criterion, compared to 40 out of 138 future cases for 2015/2030. The failures arise at only 3 airports (Birmingham, East Midlands and Manchester), with 6 failures in 2005 and 9 failures in 2010. Thus, despite a greater contribution from sources other than aircraft-related in 2005 and

2010 compared to 2015, the lower forecast throughput of the airports more than compensates for this, leading to lower total concentrations in 2005/2010 than in 2015.

Table 3.7 shows the results of applying the screening criterion based on the 99.8th percentile of 1-hourly mean NO_2 concentrations at representative airport terminal locations. 6 cases (all at Manchester) fail to meet this screening criterion, compared to 13 in 2015/2030.

PM_{10}

Table 3.8 shows the results of applying the screening criterion relating to 90th percentile of 24-hour mean PM_{10} concentrations. Six cases fail to meet this screening criterion, all at Manchester International airport, compared to 8 in 2015/2030 (2 at Birmingham and 6 at Manchester).

3.3.2 Key Links Analysis

Table 3.9 provides identifying information for the 14 links for which the screening criterion based on the DMRB analysis was not met for at least one of the scenarios considered; in the main, these are the same links that failed in 2015/2030, apart from one less link at Edinburgh for 2005/2010 and the addition of a link at Liverpool. Table 3.10 gives the actual results of the screening analysis for NO_2 (where a ✓indicates that the total concentration, including background, at the receptor nearest to the road links was below the objective value of 40 µg m^{-3}). Of the total number of year/cases considered, a greater fraction fail in 2005/2010 than in 2015/2030, reflecting the larger contribution from road-vehicle emissions.

There were no exceedences of the 24-hour PM_{10} objective at the residences closest to these key links.

3.3.3 Summary of Stage A Results

In summary, NO_2 concentrations at non-roadside receptors failed to meet the Stage A screening criteria for 3 airports (Birmingham, East Midlands and Manchester). For PM_{10}, only one airport had cases which failed to meet the Stage A screening criteria (Manchester). The Stage A screening criteria for NO_2 were not met at 14 key road links distributed amongst 7 airports (Birmingham, Edinburgh, Glasgow, Leeds Bradford, Liverpool, Manchester and Newcastle). No failures of the Stage A screening criteria were found in the ‘key links’ analysis for PM_{10}.

For those airport/cases *not* taken through to Stage B, the conclusion is that the proposed growth scenarios would not present a threat to the meeting of current objectives in the years 2005 and 2010, provided that changes are not made to the airport infrastructure and residential areas that bring airport emissions closer to population than at present.

3.4 STAGE B RESULTS

3.4.1 Contour Plots

Contour plots are shown for all the airport/cases failing the Stage A screening criteria for non-roadside receptors.

Annual-Mean NO_2

In the NO_2 plots, a contour is shown at 40 $\mu g/m^3$, termed the 'exceedence' contour below on the grounds that the current annual-mean objective would not be met for residential properties, if any, within the contour. Also, a contour at 30$\mu g/m^3$ is displayed in order to give an indication of the sensitivity of the spatial extent of the contour to uncertainties in the calculated concentrations.

Birmingham

Figs 1(a) – (f) show contours plots of annual-mean NO_2 concentrations at Birmingham International Airport for the 6 cases in 2005/2010.

In none of the these cases does the exceedence contour enclose any residential properties, as far as can be ascertained from the OS map.

East Midlands

Figs 2 (a) –(c) show contours of annual mean NO_2 concentrations at East Midlands Airport for the 3 cases in 2010. In none of these cases does the exceedence contour enclose any residential properties, as far as can be ascertained by inspection of the OS map.

Manchester

Figs 3(a) – (f) show contours plots of annual-mean NO_2 concentrations at Manchester International Airport for all 6 future cases in 2005/2010.

In none of the these cases does the exceedence contour enclose any residential properties, as far as can be ascertained from the OS map.

90th Percentile of 24-Hour Mean PM_{10} Concentrations

Cases requiring further investigation at Stage B for PM_{10} in 2005/2010 are confined to Manchester International airport.

Manchester

Figs 4 (a)- (f) show contours for the 90th percentile of 24-hour mean PM_{10} concentrations for all six future cases at Manchester International Airport. Concentrations at the exceedence level of 50$\mu g/m^3$ are not found at any receptor either on or off the airport, so no exceedence contour can be shown. The 30$\mu g/m^3$ contour is shown to indicate the calculated values found around the airport.

Although this conclusion was drawn from results obtained using a representative relationship between the 90th percentile of 24-hour mean PM_{10} concentrations and annual-mean PM_{10} concentrations, reflecting measured data over a number of years, it would not be overturned if the more extreme values of the ratio are used, such as those found in 1996, which was climatologically unusual from the viewpoint of UK PM_{10} concentrations.

3.4.2 Terminal Concentrations

Table 3.11 shows the predicted 99.8th percentile of 1-hour mean NO_2 concentrations at the representative terminal locations, for the 6 future cases at Manchester International Airport, which failed to satisfy the relevant Stage A screening criterion.

There are no predicted exceedences of the current objective (200 $\mu g/m^3$).

3.4.3 Key Links

No key links analysis was carried out at Stage B. The annual-mean NO_2 concentrations at the nearest receptor found at Stage A are shown in Table 3.12. An analysis carried out for 2015/2030 showed that the contribution to annual-mean NO_x concentrations from the individual links is overestimated by the DMRB analysis by a factor of at least 1.3 (typically 2). In view of this, and considering the relative contributions to total annual-mean NO_x concentrations leading to the NO_2 concentrations in Table 3.12, it appears unlikely that links 4, 5, 8, 9, 12, 13, 14 will experience concentrations above the objective values in any of the future cases. On the other hand, the remaining links (1, 2, 3, 6, 7, 10, 11) are likely to experience concentrations above the objective value for at least some of the future cases considered.

4 Conclusions

- For non-roadside receptors, no off-airport exceedences of the current objectives for NO_2 and PM_{10} are predicted around any of the airports investigated for any of the future cases considered in 2005 and 2010. Similarly there are no predicted exceedences of the current objective for the 99.8th percentile of 1-hour mean NO_2 concentrations (200μg/m^3) at representative terminal locations at any of the study airports in any of the future cases considered in 2005 and 2010. These conclusions are likely to stand even after taking account of the uncertainties in the calculations (other than those associated with forecasting the levels of activity at the airports), but are made on the assumption that the spatial layout of the airport, surrounding roads and housing does not change from the current situation (apart from the operation of a second runway at Manchester airport).

- Considering key road links (those carrying more than 10% airport-related traffic and having properties within 200m of the roadside), it is likely that for a few links around Birmingham, Edinburgh, Glasgow and Manchester airports there will be exceedences of the current objective for annual-mean NO_2 concentration at the nearest receptor to the road in at least some of the future cases. Further work would be required to quantify the level of exceedence and the number of future cases affected.

5 Acknowledgements

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Table 1.1 Airports Included in the Study

ABERDEEN
BELFAST CITY
BELFAST INT.
BIRMINGHAM
BOURNEMOUTH
BRISTOL
CARDIFF WALES
COVENTRY
EAST MIDLANDS
EDINBURGH
EXETER
GLASGOW
HUMBERSIDE
INVERNESS
LEEDS BRADFORD
LIVERPOOL
MANCHESTER
NEWCASTLE
NEWQUAY CORNWALL
PLYMOUTH
PRESTWICK
SHEFFIELD CITY
TEESSIDE

Table 1.2 Air Quality Strategy objectives relevant to this study

Substance	Air quality objective levels	Air quality objective dates
Nitrogen dioxide	200 micrograms per cubic metre, when expressed as an hourly mean not to be exceeded more than 18 times a year	31st December 2005
	40 micrograms per cubic metre or less, when expressed as an annual mean	31st December 2005
PM_{10}	50 micrograms per cubic metre or less, when expressed as a 24 hour mean, not to be exceeded more than 35 times per year	31st December 2004
	40 micrograms per cubic metre or less, when expressed as an annual mean	31st December 2004

Table 2.1 Aircraft types used for the future fleet mix (and assigned DORA class)

Aircraft	DORA class*	Aircraft	DORA class
Aerospatiale/BAe Concorde	3	Boeing 737-500	5
Airbus A300 replacement (200 seats)	2	Boeing 737-600	5
Airbus A300-600/R	2	Boeing 737-700	5
Airbus A310-200/300	2	Boeing 737-800	5
Airbus A318	5	Boeing 737-900	5
Airbus A319	5	Boeing 747-100	1
Airbus A319 re-engine	5	Boeing 747-200 Chapter 2	1
Airbus A320	5	Boeing 747-200 Chapter 3	1
Airbus A320 re-engine	5	Boeing 747-400	1
Airbus A321	5	Boeing 747-400 stretch	1
Airbus A321 re-engine	5	Boeing 747-400D	1
Airbus A330-100	2	Boeing 747SP	1
Airbus A330-200	2	Boeing 747SR	1
Airbus A330-300	2	Boeing 757-200	4
Airbus A340-200	2	Boeing 757-200 extended range	4
Airbus A340-300	2	Boeing 757-300	4
Airbus A340-500	2	Boeing 767-200/ER	2
Airbus A340-600	2	Boeing 767-300/ER	2
Airbus A3XX-100	1	Boeing 767-400	2
Airbus A3XX-200	1	Boeing 777-200/ER	1
Airbus A3XX-50R	1	Boeing 777-200LR	1
AVRO 146-RJ	7	Boeing 777-300	1
AVRO RJ-X re-engine	8	Boeing 777-300ER	1
BAC1-11 500 series	2	Canadair Regional Jet	8
Boeing (McDonnell Douglas) DC10-10/30/40	2	Canadair Regional Jet 700	8
Boeing (McDonnell Douglas) DC8-60	4	Chapter 2 Executive Jet	12
Boeing (McDonnell Douglas) DC8-70	4	Chapter 3 Executive Jet	12
Boeing (McDonnell Douglas) DC9-10/20/30/40	5	Dornier 328-300 JET	11
Boeing (McDonnell Douglas) MD11	2	Embraer EMB 135/145	12
Boeing (McDonnell Douglas) MD80) all series	5	Embraer EMB 170	12
Boeing 707-300B	4	Embraer EMB 190	12
Boeing 717-100	5	Fokker 70/100	7
Boeing 717-200	5	Fokker F.28	7
Boeing 717-300	5	Ilyushin IL62M/MK	4
Boeing 727-100	5	Large 4-propeller	6
Boeing 727-100 with hush kit	5	Large twin turboprop	8
Boeing 727-200	5	Lockheed L1011 TriStar all series	2
Boeing 727-200 with hush kit	5	Single piston-propeller	12
Boeing 737-200	5	Small twin piston-propellor	12
Boeing 737-200 with hush kit	5	Small twin turboprop	12
Boeing 737-300	5	Tupolev TU154/M	5
Boeing 737-400	5	Vickers VC10	2

[*] The DORA classes are used here to group aircraft approximately by their runway occupancy times. The categories are used by DORA in the context of runway capacity studies and thus relate also to wake vortex separation. The DORA classes were used in assigning times-in-mode.

Table 2.2 ‘New’ engines: assumed thrust, pressure ratio, calculated Dp/F_{00}

Airframe	% New engine	New engine ID	PR	Rated Output (F_{00})(kN)	Dp/F_{00} (g/kN)
Airbus A300 replacement (200 seats)	100	PW8000	40	240	87.0
Airbus A318	100	PW6124	33	107	73.0
Airbus A319 re-engine	100	PW6000/8000	40	121	87.0
Airbus A320 re-engine	100	PW8000	40	118	87.0
Airbus A321 re-engine	100	PW8000	40	142	87.0
Airbus A330-100	100	RR Trent 772B-60	37	230	80.7
Airbus A330-200	100	RR Trent 772B-60	37	230	80.7
Airbus A330-300	100	RR Trent 772B-60	37	230	80.7
Airbus A340-500	100	RR Trent 553	35	236	77.2
Airbus A340-600	100	RR Trent 556	37	249	80.4
Airbus A3XX-100	100	GP700/Trent 900	46	298	99.0
Airbus A3XX-200	100	GP700/Trent 900	46	333	99.0
AVRO RJ-X re-engine	100	AS977	15	34	54.5
BAC1-11 500 series	100	RR Spey 510	18	56	55.3
Boeing 747-400	50	RR RB211-524H2	33	256	73.0
Boeing 747-400 stretch	100	GP700/Trent 900	46	303	99.0
Boeing 747-400D	50	RR RB211-524H2	33	256	73.0
Boeing 777-200/ER	20	RR Trent 890/2	43	371	92.4
Boeing 777-200LR	100	GE90-115B	44	512	95.0
Boeing 777-300ER	100	GE90-115B	44	512	95.0
Canadair Regional Jet 700	100	GE CF34-8C	27	40	72.5
Dornier 328-300 JET	100	P&W 306B	14	27	54.4
Embraer EMB 170	100	GE CF34-8E	27	56	69.3
Embraer EMB 190	100	GE CF34-10E	32	69	74.9
Fokker F.28	100	RR RB183P	21	44	62.1
Vickers VC10	100	RR Conway Mk301	15	100	43.0

Table 2.3 Approximate distances used in Stage A analysis

	Runway to Receptor (m)	Terminal to Receptor (m)	Runway to Terminal (m)
ABERDEEN	200	100	250
BELFAST CITY	400	100	200
BELFAST INTER.	200	350	300
BIRMINGHAM	300	800	700
BOURNEMOUTH	200	700	150
BRISTOL	300	200	200
CARDIFF WALES	280	600	270
COVENTRY	400	100	150
EAST MIDLANDS	450	300	400
EDINBURGH	450	600	350
EXETER	300	200	200
GLASGOW	600	500	550
HUMBERSIDE	200	500	200
INVERNESS	550	250	500
LEEDS BRADFORD	250	600	200
LIVERPOOL	400	250	350
MANCHESTER	250	750	500
NEWCASTLE	600	600	400
NEWQUAY CORNWALL	500	400	200
PLYMOUTH	100	200	100
PRESTWICK	175	400	200
SHEFFIELD CITY	600	600	150
TEESSIDE	600	500	250

Table 2.4 Relationships between annual means and other metrics relevant to the AQS objectives (from ref. [13])

From	To	Relationship
Annual mean NO_x (C_{NOx}) (µg/m^3)	Annual mean NO_2 (C_{NO2}) (µg/m^3) – background receptors	$C_{NO2} = 1.5358 C_{NOx}^{0.7341}$
	Annual mean NO_2 (C_{NO2}) (µg/m^3) – kerbside receptors	$C_{NO2} = 3.3931 C_{NOx}^{0.5278}$
	99.8th percentile of 1-hour mean NO_2 ($C_{99.8}$) (µg/m^3)	$C_{99.8} = 12.6 C_{NO2}^{0.6457}$
Annual mean PM_{10} (C_{PM}) (µg/m^3)	90th percentile of 24-hour mean PM_{10} (C_{90}) (µg/m^3)	$C_{90} = 1.68 C_{PM}$

Table 2.5 Meteorological data sets used in Stage B

Airport	Met. Station	Dataset years
Birmingham	Birmingham Elmdon	1987-96
East Midlands	Nottingham Watnall	1985-94
Manchester	Manchester Ringway	1988-97

Table 3.1 Contribution from 'other' sources at the 'Stage A' off-airport receptor

NO_x

Airport	Concentration ($\mu g/m^3$)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	13.5	13.5	13.5	11.7	11.7	11.7
BELFAST CITY	18.2	18.2	18.2	17.3	17.3	17.3
BELFAST INTER.	12.2	12.2	12.2	11.3	11.3	11.3
BIRMINGHAM	31.7	31.7	31.6	27.2	27.2	27.2
BOURNEMOUTH	19.0	19.0	19.0	15.9	15.9	15.9
BRISTOL	12.4	12.4	12.4	10.7	10.7	10.7
CARDIFF WALES	9.1	9.1	9.1	7.9	7.9	7.9
COVENTRY	26.1	26.1	26.1	21.6	21.6	21.6
EAST MIDLANDS	36.7	36.7	36.7	28.2	28.2	28.1
EDINBURGH	14.3	14.3	14.3	12.0	12.0	12.0
EXETER	8.7	8.7	8.7	7.3	7.3	7.3
GLASGOW	18.9	18.9	18.8	15.4	15.4	15.3
HUMBERSIDE	14.9	14.9	14.9	12.8	12.8	12.8
INVERNESS	2.1	2.1	2.1	1.8	1.8	1.8
LEEDS BRADFORD	21.0	21.0	21.0	18.2	18.2	18.1
LIVERPOOL	15.6	15.6	15.6	13.2	13.2	13.2
MANCHESTER	31.0	31.5	31.4	24.9	25.3	25.3
NEWCASTLE	8.4	8.4	8.4	7.2	7.2	7.2
NEWQUAY CORNWALL	6.2	6.2	6.2	5.4	5.4	5.4
PLYMOUTH	12.8	12.8	12.8	10.9	11.0	11.0
PRESTWICK	9.1	9.1	9.1	7.5	7.5	7.5
SHEFFIELD CITY	43.8	43.8	43.8	36.0	36.0	36.0
TEESSIDE	11.2	11.2	11.2	10.0	10.0	9.9

PM_{10}

Airport	Concentration (µg/m^3)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	12.6	12.6	12.6	11.7	11.7	11.7
BELFAST CITY	16.0	16.0	16.0	14.6	14.6	14.6
BELFAST INTER.	11.9	11.9	11.9	11.0	11.0	11.0
BIRMINGHAM	15.2	15.2	15.2	13.6	13.6	13.6
BOURNEMOUTH	13.8	13.8	13.8	12.4	12.4	12.4
BRISTOL	13.2	13.2	13.2	12.0	12.0	12.0
CARDIFF WALES	12.5	12.5	12.5	11.4	11.4	11.4
COVENTRY	14.6	14.6	14.6	13.0	13.0	13.0
EAST MIDLANDS	15.7	15.7	15.7	13.9	13.9	13.9
EDINBURGH	12.6	12.6	12.6	11.5	11.5	11.5
EXETER	12.5	12.5	12.5	11.3	11.3	11.3
GLASGOW	13.0	13.0	13.0	11.8	11.8	11.8
HUMBERSIDE	13.7	13.7	13.7	12.3	12.3	12.3
INVERNESS	10.4	10.4	10.4	9.7	9.7	9.7
LEEDS BRADFORD	13.8	13.8	13.8	12.5	12.5	12.5
LIVERPOOL	13.4	13.4	13.4	12.1	12.1	12.1
MANCHESTER	14.9	14.9	14.9	13.3	13.4	13.3
NEWCASTLE	14.8	14.9	14.9	13.3	13.4	13.4
NEWQUAY CORNWALL	11.9	11.9	11.9	10.9	10.9	10.9
PLYMOUTH	12.7	12.7	12.7	11.6	11.6	11.6
PRESTWICK	12.0	12.0	12.0	10.9	10.9	10.9
SHEFFIELD CITY	15.7	15.7	15.7	14.0	14.0	14.0
TEESSIDE	12.8	12.8	12.8	11.6	11.6	11.6

Table 3.2 Aircraft NO_x emissions (t/yr) for each year/scenario

Airport	Annual emissions (t/year)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	132.4	159.3	181.7	152.8	201.8	225.7
BELFAST CITY	90.9	68.8	58.6	127.6	121.9	55.9
BELFAST INT.	257.9	234.5	269.8	319.7	306.9	352.0
BIRMINGHAM	801.2	707.9	597.1	1275.5	1260.0	862.9
BOURNEMOUTH	40.4	43.2	37.8	90.0	104.7	78.6
BRISTOL	202.6	174.0	159.3	306.6	292.8	224.0
CARDIFF WALES	173.5	174.5	186.0	227.5	265.9	267.8
COVENTRY	13.5	8.7	8.7	22.0	19.6	19.6
EAST MIDLANDS	386.0	372.3	334.5	677.4	728.7	516.4
EDINBURGH	451.9	390.0	439.0	528.8	502.9	577.9
EXETER	28.7	23.4	39.4	45.4	33.4	60.1
GLASGOW	664.4	573.8	621.8	834.8	794.4	854.1
HUMBERSIDE	35.7	34.0	39.5	38.7	37.6	42.2
INVERNESS	20.6	17.0	19.1	24.2	22.7	22.3
LEEDS BRADFORD	163.4	149.9	104.4	204.5	193.1	115.2
LIVERPOOL	124.5	145.2	139.1	219.3	297.1	104.8
MANCHESTER	1898.4	1936.6	1842.2	2573.3	2687.0	2385.3
NEWCASTLE	310.0	278.1	298.7	422.0	417.1	415.5
NEWQUAY CORNWALL	7.9	36.9	25.7	9.0	34.1	35.3
PLYMOUTH	8.9	13.4	12.6	12.2	24.2	12.8
PRESTWICK	122.5	125.2	78.9	120.4	127.5	114.2
SHEFFIELD CITY	5.6	5.9	11.4	6.2	6.6	12.8
TEESSIDE	61.4	76.5	68.3	83.9	120.7	85.9

Table 3.3 NO_x emissions from airside support vehicles/plant

Airport	Annual emissions (t/year)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	23.0	26.3	26.5	16.8	21.5	22.0
BELFAST CITY	17.1	16.4	10.0	15.7	16.1	6.3
BELFAST INT.	33.5	33.2	35.0	29.4	29.3	31.6
BIRMINGHAM	88.7	89.8	77.3	83.2	85.6	64.2
BOURNEMOUTH	5.9	7.1	5.5	8.8	11.4	7.7
BRISTOL	24.3	24.5	21.1	25.9	26.6	19.9
CARDIFF WALES	19.2	20.9	20.9	16.8	19.9	19.6
COVENTRY	3.2	1.8	1.8	3.5	3.0	3.0
EAST MIDLANDS	46.8	47.7	44.6	55.9	59.4	46.8
EDINBURGH	65.3	66.0	65.2	58.1	59.4	57.5
EXETER	4.6	4.1	4.5	5.7	4.2	5.2
GLASGOW	73.0	73.4	68.9	64.9	65.5	58.0
HUMBERSIDE	5.0	5.2	4.6	4.9	5.2	4.1
INVERNESS	3.8	3.9	3.7	2.9	3.0	3.1
LEEDS BRADFORD	21.0	20.9	14.7	22.6	22.3	11.7
LIVERPOOL	20.5	21.8	17.7	26.4	30.6	9.6
MANCHESTER	176.5	181.1	172.4	165.5	173.3	156.5
NEWCASTLE	34.9	35.7	34.6	33.4	34.9	32.5
NEWQUAY CORNWALL	1.2	5.1	2.6	0.9	2.8	3.5
PLYMOUTH	2.0	2.6	2.0	1.7	3.0	1.5
PRESTWICK	10.1	10.5	9.0	9.8	10.8	9.5
SHEFFIELD CITY	1.2	1.2	1.7	1.2	1.3	2.6
TEESSIDE	9.7	11.5	8.6	9.4	13.4	7.4

Table 3.4 Aircraft PM_{10} emissions (t/yr) for each year/scenario

Airport	Annual emissions (t/year)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	4.5	5.0	5.1	4.7	5.7	5.6
BELFAST CITY	2.1	1.8	1.5	2.6	2.6	1.5
BELFAST INT.	4.0	3.6	3.6	4.6	4.3	4.3
BIRMINGHAM	10.4	10.3	8.8	13.1	13.7	10.2
BOURNEMOUTH	0.7	0.8	0.6	1.2	1.6	1.0
BRISTOL	2.8	2.9	2.7	3.6	3.8	3.1
CARDIFF WALES	2.2	2.4	2.3	2.4	2.8	2.6
COVENTRY	0.4	0.2	0.2	0.6	0.5	0.5
EAST MIDLANDS	6.6	6.7	5.3	9.0	9.5	7.4
EDINBURGH	8.9	9.1	7.9	10.4	10.6	9.1
EXETER	0.6	0.6	0.7	0.9	0.7	0.9
GLASGOW	9.2	9.5	8.8	10.3	10.5	9.7
HUMBERSIDE	1.0	1.0	0.8	1.0	1.1	0.8
INVERNESS	0.6	0.5	0.5	0.6	0.6	0.6
LEEDS BRADFORD	2.8	2.7	1.8	3.1	3.0	1.8
LIVERPOOL	2.4	2.6	2.3	3.9	4.6	1.9
MANCHESTER	21.2	21.9	19.9	24.0	25.2	21.8
NEWCASTLE	4.2	4.7	4.1	4.8	5.2	4.6
NEWQUAY CORNWALL	0.2	0.9	0.3	0.2	0.8	0.4
PLYMOUTH	0.3	0.4	0.3	0.3	0.6	0.3
PRESTWICK	1.5	1.6	1.1	1.8	1.9	1.5
SHEFFIELD CITY	0.2	0.2	0.3	0.2	0.2	0.3
TEESSIDE	1.4	1.6	1.1	1.6	2.1	1.3

Table 3.5 PM_{10} emissions from airside support vehicles/plant

Airport	Annual emissions (t/year)					
	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	2.0	2.3	2.4	1.3	1.7	1.8
BELFAST CITY	1.5	1.5	0.9	1.3	1.3	0.5
BELFAST INT.	3.0	3.0	3.1	2.4	2.3	2.5
BIRMINGHAM	7.9	8.0	6.9	6.7	6.8	5.1
BOURNEMOUTH	0.5	0.6	0.5	0.7	0.9	0.6
BRISTOL	2.2	2.2	1.9	2.1	2.1	1.6
CARDIFF WALES	1.7	1.9	1.9	1.3	1.6	1.6
COVENTRY	0.3	0.2	0.2	0.3	0.2	0.2
EAST MIDLANDS	4.2	4.2	4.0	4.5	4.7	3.7
EDINBURGH	5.8	5.9	5.8	4.6	4.7	4.6
EXETER	0.4	0.4	0.4	0.5	0.3	0.4
GLASGOW	6.5	6.5	6.1	5.2	5.2	4.6
HUMBERSIDE	0.4	0.5	0.4	0.4	0.4	0.3
INVERNESS	0.3	0.3	0.3	0.2	0.2	0.2
LEEDS BRADFORD	1.9	1.9	1.3	1.8	1.8	0.9
LIVERPOOL	1.8	1.9	1.6	2.1	2.4	0.8
MANCHESTER	15.7	16.1	15.3	13.2	13.9	12.5
NEWCASTLE	3.1	3.2	3.1	2.7	2.8	2.6
NEWQUAY CORNWALL	0.1	0.5	0.2	0.1	0.2	0.3
PLYMOUTH	0.2	0.2	0.2	0.1	0.2	0.1
PRESTWICK	0.9	0.9	0.8	0.8	0.9	0.8
SHEFFIELD CITY	0.1	0.1	0.1	0.1	0.1	0.2
TEESSIDE	0.9	1.0	0.8	0.8	1.1	0.6

Table 3.6 Results of applying the screening criterion based on the annual-mean NO_2 concentration at the representative off-airport location

Airport	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	✓	✓	✓	✓	✓	✓
BELFAST CITY	✓	✓	✓	✓	✓	✓
BELFAST INT.	✓	✓	✓	✓	✓	✓
BIRMINGHAM	✗	✗	✗	✗	✗	✗
BOURNEMOUTH	✓	✓	✓	✓	✓	✓
BRISTOL	✓	✓	✓	✓	✓	✓
CARDIFF WALES	✓	✓	✓	✓	✓	✓
COVENTRY	✓	✓	✓	✓	✓	✓
EAST MIDLANDS	✓	✓	✓	✗	✗	✗
EDINBURGH	✓	✓	✓	✓	✓	✓
EXETER	✓	✓	✓	✓	✓	✓
GLASGOW	✓	✓	✓	✓	✓	✓
HUMBERSIDE	✓	✓	✓	✓	✓	✓
INVERNESS	✓	✓	✓	✓	✓	✓
LEEDS BRADFORD	✓	✓	✓	✓	✓	✓
LIVERPOOL	✓	✓	✓	✓	✓	✓
MANCHESTER	✗	✗	✗	✗	✗	✗
NEWCASTLE	✓	✓	✓	✓	✓	✓
NEWQUAY CORNWALL	✓	✓	✓	✓	✓	✓
PLYMOUTH	✓	✓	✓	✓	✓	✓
PRESTWICK	✓	✓	✓	✓	✓	✓
SHEFFIELD CITY	✓	✓	✓	✓	✓	✓
TEESSIDE	✓	✓	✓	✓	✓	✓

✓ signifies that case met the screening criterion
✗ signifies that the case did not meet the screening criterion

Table 3.7 Results of applying the screening criterion based on the 99.8th percentile of 1-hour mean NO_2 concentrations at the representative terminal location

Airport	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	✓	✓	✓	✓	✓	✓
BELFAST CITY	✓	✓	✓	✓	✓	✓
BELFAST INT.	✓	✓	✓	✓	✓	✓
BIRMINGHAM	✓	✓	✓	✓	✓	✓
BOURNEMOUTH	✓	✓	✓	✓	✓	✓
BRISTOL	✓	✓	✓	✓	✓	✓
CARDIFF WALES	✓	✓	✓	✓	✓	✓
COVENTRY	✓	✓	✓	✓	✓	✓
EAST MIDLANDS	✓	✓	✓	✓	✓	✓
EDINBURGH	✓	✓	✓	✓	✓	✓
EXETER	✓	✓	✓	✓	✓	✓
GLASGOW	✓	✓	✓	✓	✓	✓
HUMBERSIDE	✓	✓	✓	✓	✓	✓
INVERNESS	✓	✓	✓	✓	✓	✓
LEEDS BRADFORD	✓	✓	✓	✓	✓	✓
LIVERPOOL	✓	✓	✓	✓	✓	✓
MANCHESTER	✗	✗	✗	✗	✗	✗
NEWCASTLE	✓	✓	✓	✓	✓	✓
NEWQUAY CORNWALL	✓	✓	✓	✓	✓	✓
PLYMOUTH	✓	✓	✓	✓	✓	✓
PRESTWICK	✓	✓	✓	✓	✓	✓
SHEFFIELD CITY	✓	✓	✓	✓	✓	✓
TEESSIDE	✓	✓	✓	✓	✓	✓

✓ signifies that case met the screening criterion

✗ signifies that the case did not meet the screening criterion

Table 3.8 Results of applying the screening criterion based on the 90th percentile of 24-hour mean PM_{10} concentrations

Airport	2005B	2005H	2005E	2010B	2010H	2010E
ABERDEEN	✓	✓	✓	✓	✓	✓
BELFAST CITY	✓	✓	✓	✓	✓	✓
BELFAST INT.	✓	✓	✓	✓	✓	✓
BIRMINGHAM	✓	✓	✓	✓	✓	✓
BOURNEMOUTH	✓	✓	✓	✓	✓	✓
BRISTOL	✓	✓	✓	✓	✓	✓
CARDIFF WALES	✓	✓	✓	✓	✓	✓
COVENTRY	✓	✓	✓	✓	✓	✓
EAST MIDLANDS	✓	✓	✓	✓	✓	✓
EDINBURGH	✓	✓	✓	✓	✓	✓
EXETER	✓	✓	✓	✓	✓	✓
GLASGOW	✓	✓	✓	✓	✓	✓
HUMBERSIDE	✓	✓	✓	✓	✓	✓
INVERNESS	✓	✓	✓	✓	✓	✓
LEEDS BRADFORD	✓	✓	✓	✓	✓	✓
LIVERPOOL	✓	✓	✓	✓	✓	✓
MANCHESTER	✗	✗	✗	✗	✗	✗
NEWCASTLE	✓	✓	✓	✓	✓	✓
NEWQUAY CORNWALL	✓	✓	✓	✓	✓	✓
PLYMOUTH	✓	✓	✓	✓	✓	✓
PRESTWICK	✓	✓	✓	✓	✓	✓
SHEFFIELD CITY	✓	✓	✓	✓	✓	✓
TEESSIDE	✓	✓	✓	✓	✓	✓

✓ signifies that case met the screening criterion

✗ signifies that the case did not meet the screening criterion

Table 3.9 Identification of links not meeting the NO_2 screening criterion based on the DMRB analysis

Link ID	Airport	Road	OS Co-ordinates of Nearest Receptor	Distance from centre of road (m)
1	Birmingham	A45	41492838	10
2	Birmingham	A45	41832830	10
3	Birmingham	A452	42062840	20
4	Birmingham	A45	42062831	20
5	Edinburgh	A902	31816737	10
6	Edinburgh	A8	31496725	10
7	Glasgow	M8	25156662	50
8	Leeds Bradford	A658	42154406	20
9	Liverpool	A561	34523836	20
10	Manchester	M56	38173876	50
11	Manchester	M56	38063855	40
12	Manchester	A538	37873862	10
13	Manchester	A538	38213829	10
14	Newcastle	A1	42355728	20

Table 3.10 Results of the NO_2 screening criterion based on the DMRB analysis

Link ID	Airport	2015R	2015H	2015E	2030R	2030H	2030E
1	Birmingham	✘	✘	✘	✘	✘	✘
2	Birmingham	✘	✘	✘	✘	✘	✘
3	Birmingham	✘	✘	✘	✘	✘	✘
4	Birmingham	✘	✘	✘	✘	✘	✓
5	Edinburgh	✘	✘	✘	✓	✓	✓
6	Edinburgh	✘	✘	✘	✘	✘	✘
7	Glasgow	✘	✘	✘	✘	✘	✓
8	Leeds Bradford	✘	✘	✓	✓	✓	✓
9	Liverpool	✘	✘	✓	✓	✓	✓
10	Manchester	✘	✘	✘	✘	✘	✘
11	Manchester	✘	✘	✘	✘	✘	✘
12	Manchester	✘	✘	✘	✓	✘	✓
13	Manchester	✘	✘	✘	✘	✘	✓
14	Newcastle	✘	✘	✘	✓	✓	✓

✓ signifies that case met the screening criterion

✘ signifies that the case did not meet the screening criterion

Table 3.11 Predicted 99.8th percentile of 1-hour mean NO$_2$ concentrations at representative (outdoor) terminal locations (AQS objective 200mg/m^3)

	Concentration (µg/m^3)					
	2015B	2015H	2015E	2030B	2030H	2030E
Manchester T1	154	159	149	154	159	149
Manchester T2	151	155	147	150	152	145

Table 3.12 Stage A annual-mean NO$_2$ concentrations at nearest receptor to key links

Link ID	Airport	2015R	2015H	2015E	2030R	2030H	2030E
1	Birmingham	67.0	67.4	66.9	57.7	59.8	52.4
2	Birmingham	52.1	52.8	49.3	64.6	69.9	42.7
3	Birmingham	57.3	57.6	56.4	52.5	55.0	43.8
4	Birmingham	41.3	41.6	40.5	41.7	44.1	33.1
5	Edinburgh	45.9	45.7	45.6	36.8	36.7	35.9
6	Edinburgh	65.2	65.0	65.1	52.5	52.5	51.0
7	Glasgow	54.7	54.9	55.1	40.7	41.1	39.7
8	Leeds Bradford	42.6	41.2	39.9	35.4	34.7	32.1
9	Liverpool	40.2	40.5	38.4	32.4	33.3	29.7
10	Manchester	79.0	79.0	77.8	66.3	71.8	61.7
11	Manchester	96.0	96.3	94.0	82.6	92.7	73.9
12	Manchester	44.0	44.2	43.3	39.8	43.4	36.6
13	Manchester	43.2	43.6	42.3	41.3	46.4	36.7
14	Newcastle	41.6	41.5	41.5	31.8	31.9	31.4

Fig 2.1 Diurnal profile of aircraft and road vehicle sources