Rushmoor Borough Council

Farnborough Airport

Odour Assessment

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Odour Assessment

August 2009

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It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party

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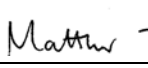
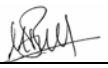
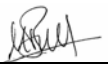
		Signature			
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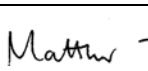
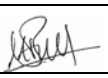
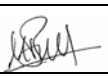
		Signature			
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Appendices

1 Introduction

Ove Arup and Partners Ltd (Arup) has been commissioned by Rushmoor Borough Council to undertake an odour assessment to determine the existing odour impacts associated with Farnborough Airport. The aim of the odour assessment was to monitor and report on the health effects of pollution from aviation movements at Farnborough Airport on local residents of the borough. In accordance with the Terms of Reference, the odour assessment had the following objectives:

1. In the context of current annual flight movements of up to 28,000, to determine the current:
    a. constituents of the fumes from the aircraft exhaust;
    b. likely health impacts on local residents around the airfield, particularly those in Pinehurst Cottages, Pinehurst Avenue, Farnborough; and
    c. extent that the odour, and any associated health effects, may spread to.
2. To consider these same impacts in the context of options for increased annual flight movements of: 35,000; 50,000 and 60,000+.

Following discussions with Rushmoor Borough Council it was agreed that the principal focus of the study related to aircraft waiting on the taxiway prior to take off, when engine exhausts are directed towards the nearby Pinehurst Cottages. However, complaints have also been recorded by Rushmoor Borough Council from residential properties at Kempton Court and by Hart District Council from residential properties in the Pondtail area of Fleet. The assessment has been extended to includes these receptors.

This Report includes:

- a discussion on the constituents of aircraft exhaust emissions based on a literature review;
- appropriate health and odour assessment criteria;
- a description of the assessment methodology;
- a review of odour complaint records;
- the results of field sampling for volatile organic compounds and odour;
- the results of modelling the dispersion of volatile organic compounds emitted from aircraft exhaust and the potential human health impact at identified receptors for the current and potential future scenarios;
- the results of modelling the dispersion of odours generated from aircraft exhaust and the potential nuisance impact at identified receptors for the current and potential future scenarios;
- opportunities for mitigation; and
- a summary and conclusions section.

Arup takes this opportunity to express its gratitude to TAG – the operators of Farnborough Airport – for its assistance in undertaking field sampling.

2 Literature Review – Aircraft Exhaust Emissions

A short review of the literature has been undertaken to determine the composition of exhaust emissions from aircraft that use Farnborough airport. The results are presented in this section and have been used as the basis for the assessment described in following sections.

2.1 Regulation of Aircraft Emissions

Aircraft are required to meet the engine certification standards adopted by the Council of the International Civil Aviation Organization (ICAO[1]). The ICAO is a UN Specialized Agency and is the global forum for civil aviation. Adopted engine certification standards are contained in the Convention on International Civil Aviation (Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions). These were originally designed to respond to concerns regarding air quality in the vicinity of airports and establish limits for emissions of nitrogen oxides, carbon monoxide, unburned hydrocarbons, for a reference landing and take-off (LTO) cycle below 915 metres of altitude. There are also provisions regarding smoke and vented fuel. In recent years, the emphasis of engine certification standards has shifted towards emissions at altitude and the global effects associated with greenhouse gases.

The ICAO Engine Exhaust Emissions Data Bank (Doc 9646), issued in 1995, contains a comprehensive database of aircraft jet engine emissions certification data. Subsequent updates of the data bank are available through the ICAO website.

2.2 Principal Constituents of Aircraft Emissions

The ICAO Airport Air Quality Guidance Manual[2] identifies primary pollutants for consideration within an aircraft /airport related emissions inventory as part of determining local air quality impacts:

- nitrogen oxides (NO_x) including nitrogen dioxide (NO_2) and nitrogen monoxide (NO);
- volatile organic compounds (VOCs) including non-methane hydrocarbons (NMHC);
- carbon monoxide (CO);
- particulate matter (fraction sizes $PM_{2.5}$ and PM_{10}); and
- sulphur oxides (SO_x).

The guidance manual suggests carbon dioxide (CO_2) could be included although this relates to a global rather than local impact.

2.3 VOC Constituents of Aircraft Emissions

The guidance manual identifies a number of hazardous air pollutants

- **1,3-butadiene (C_5H_6)** – a product of oil combustion, 1,3-butadiene is also a recognised genotoxic human carcinogen, as such, no absolutely safe level can be specified in ambient air. The health effect of most concern is the induction of cancer of the lymphoid system and blood–forming tissues, lymphoma and leukaemia;
- **acetaldehyde (CH_3CHO)** – a product of combustion (e.g. of oil or tobacco), acetaldehyde is toxic when applied externally for prolonged periods, an irritant, and a probable carcinogen;
- **acrolein (C_3H_4O)** – formed from the thermal decomposition of glycerol (contained within kerosene), acrolein is a severe pulmonary irritant and lachrymatory agent. Acrolein is

[1] www.icao.int/
[2] Airport Air Quality Guidance Manual – Preliminary Edition 2007, International Civil Aviation Organisation, available at www.icao.int

not a suspected human carcinogen but there is a proven link between acrolein in the smoke from tobacco cigarettes and the risk of lung cancer;

- **benzene (C_6H_6)** – a product of combustion, benzene is a recognised human carcinogen which attacks the genetic material and, as such, no absolutely safe level can be specified in ambient air. Studies in workers exposed to high levels have shown an excessive risk of leukaemia;
- **formaldehyde (CH_2O)** - an intermediate in the combustion of methane as well as other carbon compounds, formaldehyde can be toxic, allergenic, and carcinogenic. Formaldehyde can irritate the eyes and mucous membranes, cause headaches, a burning sensation in the throat, and difficulty in breathing, as well as triggering or aggravating asthma symptoms. Formaldehyde is a probable human carcinogen;
- **naphthalene ($C_{10}H_8$)** – a component of kerosene, exposure to large amounts of naphthalene may cause nausea, vomiting, diarrhoea, blood in the urine, and jaundice as well as damage or destroy red blood cells;
- **propionaldehyde (CH_3CH_2CHO)** - a component of kerosene;
- **toluene ($C_6H_5CH_3$)** - a component of kerosene, inhalation of toluene fumes can be intoxicating and in larger doses nausea-inducing; and
- **xylene ($C_6H_4C_2H_6$)** - a component of kerosene, exposure to xylene can cause headaches, lack of muscle coordination, dizziness and confusion. Short term exposure to high levels of xylene can cause irritation of the skin, eyes, nose, and throat, difficulty in breathing and other problems with the lungs, delayed reaction time, memory difficulties, stomach discomfort, and possibly adverse effects on the liver and kidneys.

In addition to the above, a few small aircraft use leaded fuel ('AvGas') with associated emissions of lead. None of the aircraft that form a part of the TAG operation runs on leaded fuel. Both jet and turbo prop aircraft run on JET A1 which is unleaded.

Measurements of emissions from in-use commercial, air freight and general aviation aircraft, including two executive jets, at Oakland International Airport[3] generated a uniform emissions profile of hydrocarbon emissions from a range of engine types for aircraft at near idle scaled to formaldehyde. The use of formaldehyde was based on its relative abundance in exhaust emissions rather than any other factor. The results of several studies were collated and compared to measurements at Oakland. The results are summarised in Table 1 overleaf.

Measurements at Oakland were used to determine the ratio between measured formaldehyde and total unburnt hydrocarbons (uHC) as estimated from the ICAO Emissions databank as being 0.35 – 0.5 when the aircraft is at idle (measured) and at 7% thrust (ICAO data). Further investigation of this data led to the conclusion that the estimate of uHC emissions derived from the ICAO Databank with the engine at 7% thrust may lead to an underestimation of emissions when the engine is idle by a factor of 1.5 – 2.2.

The data from Oakland is supported by measurements of hydrocarbons present in the exhaust of a commercial turbofan aircraft engine at idle undertaken at the North American Space Administration Dryden Flight Research Center in 2004[4]. These measurements generated emission indices (g per Kg of fuel burnt) for a range of hydrocarbons. Importantly, the conclusion was reached that hydrocarbon emission indices compared to the emission indices for formaldehyde were independent of power setting and fuel consumption.

[3] Herndon S *et al* (2009) *Aircraft Hydrocarbon Emissions at Oakland International Airport*, Environ. Sci. Technol. 2009, 43, 1730-1736
[4] Knighton W *et al* (2007) *Quantification of Aircraft Engine Hydrocarbon Emissions Using Proton Transfer Reaction Mass Spectrometry*, Journal of Propulsion and Power, Vol. 23, No. 5, September – October 2007, 949 - 957

Further analysis of this work[5] confirms that hydrocarbon emission indices are highest when the engine is at idle and decrease rapidly with increased thrust. Measurements at 1m, 10m and 30m downwind of the engine exhaust indicated no change in hydrocarbon emission indices within that range. Ambient temperature was shown to have a significant effect on hydrocarbon emissions, with emissions increasing with temperature.

Odour emissions from aircraft engines have been calculated at Copenhagen airport and used as input for dispersion modelling to determine the odour nuisance impact upon the surrounding area[6]. An odour emission factor of 57 ou/mg HC was experimentally derived which is in the range of 23 and 110 ou/mg HC from previous studies at other airports. The calculation principle assumes a linear relationship between odour units and hydrocarbon emissions. The odour emissions inventory compiled for Copenhagen was divided into aircraft operational phases with the majority (97%) associated with engines at idle. This work cites research from Frankfurt airport suggesting that the amount of unburnt fuel released from the main engines during the engine start phase is a significant source of odour, potentially representing 26% of the odour generated at Frankfurt.

Table 1: Aircraft Emission Indices for Hydrocarbons

Hydrocarbon	Index Ratio
Formaldehyde	1
Acetaldehyde	0.24 – 0.35
Ethene	0.76 – 1.26
Propene	0.31 – 0.45
Butenes + acrolein	0.25 – 0.45
Pentenes	0.11 – 0.31
Benzene	0.11 – 0.22
Toluene	0.05 – 0.09
1-ring aromatics	0.28 – 0.73
Styrene	0.03 – 0.04
Naphthalene	0.01 – 0.04
Note: Index ratio based on the results of eight reported studies.	

[5] Yelvington P E et al (2007) *Chemical Speciation of Hydrocarbon Emissions from a Commercial Aircraft Engine,* Journal of Propulsion and Power, Vol. 23, No. 5, September – October 2007, 912 - 918
[6] Winther M, Kousgaard U and Oxbøl A (2006) *Calculation of Odour Emissions from Aircraft Engines at Copenhagen Airport*, Science of the Total Environment 366 (2006) 218-232

3 Assessment Criteria

3.1 Volatile Organic Compounds

The Environment Agency has issued a series of Horizontal Guides covering all of the industrial (or agricultural) sectors that fall under Integrated Pollution Prevention and Control legislation. The first of these is on the assessment and appraisal of best available techniques[7]and includes environmental quality standards for air pollutants, based on European limit values, and environmental assessment levels (EALs) derived from occupational exposure limits, now replaced with workplace exposure limits in EH40/2005[8] assuming the workplace exposure limits are equivalent to the short term (rather than maximum) exposure limits. Although there are proposals to update the method for deriving EALs, the method described on H1 remains current. The relevant EALs for the hydrocarbons identified in Section 2 are included in Table 2. Note that this table has been extended to include relevant EALs for the hydrocarbons detected in the hydrocarbon survey detailed in section 4.2.1.

Table 2: Environmental Quality Standards and Assessment Levels for selected Aircraft Engine Exhaust and other Hydrocarbons

Hydrocarbon	Environmental Quality Standard/ Assessment Level ($\mu g/m^3$)	
	Annual mean	Hourly mean
Acetaldehyde	**370**	**9200**
Butenes + acrolein	**2.3**	**70**
Benzene	**16.25**	**208**
Ethylbenzene	4410	55200
Formaldehyde	**5**	**100**
Formamide	370	5600
Hexane	720	21600
Naphthalene	**530**	**8000**
Pentane	7160	89500
Styrene	**800**	**800**
Toluene	**1910**	**8000**
p-Xylene	4410	66200

Notes:

Hydrocarbons associated with aircraft exhausts are in bold. Other hydrocarbons are those detected in the hydrocarbon survey (see section 4.2.1).

Collated from IPPC H1[9]. Where environmental quality standards/assessment levels are not included in IPPC H1 they have been calculated from the workplace exposure limit in EH40/2005[8] using the methodology provided in IPPC H1.

[7] Environment Agency. Integrated Pollution Prevention and Control (IPPC). Horizontal Guidance H1 – Assessment and Appraisal of BAT. Version V July 2003

[8] EH40/2005 Workplace Exposure Limits, Health and Safety Executive 2005

3.2 Odour

Odour is a mix of volatile chemical compounds or a single compound that triggers a reaction in the olfactory organ, generally at very low concentrations. Appendix 1 of the Technical Guidance Note IPPC H4[9] provides four interlinked (sensory) characteristics that are used to describe an odorous emission:

- *Hedonic tone*: this is a judgement of the relative pleasantness or unpleasantness of an odour made by assessors in an odour panel;
- *Quality/Characteristics*: this is a qualitative attribute which is expressed in terms of "descriptors", e.g. "fruity", "almond", "fishy". This can be of use when establishing an odour source from complainants' descriptions;
- *Concentration*: the "amount" of odour present in a sample of air. It can be expressed in terms of parts per million, parts per billion or in mg/m^3 of air for a single odorous compound. More usually a mixture of compounds is present and the concentration of the mixture can be expressed in odour units per cubic metre (ou_E/m^3); and
- *Intensity*: is the magnitude (strength) of perception of an odour (from faint to strong). Intensity increases as concentration increases but the relationship is logarithmic. Increases or decreases in concentration of an odour do not always produce a corresponding proportional change in the odour strength as perceived by the human nose.

The most commonly used attribute is concentration. The odour concentration is measured in European odour units (ou_E/m^3). The odour concentration at the detection threshold[10] is defined to be 1 ou_E/m^3. If an odour sample has been diluted in an olfactometer[11] by a factor of 10,000 to reach the detection threshold, then the concentration of the original sample is 10,000 odour units

The IPPC H4 Technical Guidance notes that 5 ou_E/m^3 would be a 'faint' odour whilst 10 ou_E/m^3 would be considered a 'distinct' odour. Generally, an average person would be able to recognise the source of an odour at about 3 ou_E/m^3 although this can depend on the relative offensiveness of the odour.

There is no statutory limit in England and Wales for ambient odour concentration[12], whether set for individual chemical species or for mixtures. However, some guideline limits and custom-and-practice standards have been used in some circumstances. A summary is given below. Though these may be i

ndicative of a nuisance, they are not definitive.

The IPPC H4 Technical Guidance gives odour criteria that *'indicate the exposure that exposed people can tolerate without reasonable cause for annoyance'*. It also notes that the *'relationship between a percentile of hourly averages and the level of annoyance as indicated by surveys undertaken according to a defined methodology remain the best basis for determining odour exposure acceptability criteria'*.

The IPPC H4 Technical Guidance proposes a range of criteria based on the relative offensiveness of the odour. Thus the more unpleasant odours such as animal rendering a criterion of 1.5 ou_E/m^3 as a 98^{th} percentile is used, whilst more pleasant odours, for example from baking, have a less stringent standard of 6 ou_E/m^3 as a 98^{th} percentile of hourly means.

[9] Environment Agency. Integrated Pollution Prevention and Control (IPPC). Draft Horizontal Guidance for Odour Part1- regulation and Permitting. October 2002.

[10] The odour threshold is measured by presenting a sample of the gas at various dilutions to an odour panel. The threshold is found when 50% of that panel can detect the odour.

[11] Olfactometer: Apparatus in which a sample of odorous gas is diluted with neutral gas in a defined way and presented to an odour panel under reproducible conditions.

[12] Defra and Welsh Assembly Government. Code of Practice on Odour Nuisance from Sewage Treatment Works (2006)

More widely, a level of 5 ou_E/m^3 has often been applied particularly for waste water treatment works and intensive agriculture.

These criteria have been developed for sources that have constant odour emissions. The situation at Farnborough Airport is different as the sources of odour – essentially the engine emissions from aircraft on the apron, taxiing and waiting at the end of the taxiway to take off - are intermittent. No odour nuisance criteria are available for this type of situation, but it is useful to examine the Environment Agency H4 criteria further in order to understand the level of odour that is considered to give rise to a nuisance.

Breaching a typical odour criterion of 5 ou_E/m^3 as a 98^{th} percentile requires the hourly odour concentration to be above 5 ou_E/m^3 for at least 175 hours each year. This suggests a member of the public would detect a 'faint odour', which is detectable and identifiable, for periods of one hour for at least 175 hours in the year. However, the H4 guidance notes that within each hour, odour concentrations will fluctuate between zero and a level some 10 times above the hourly average over a period of a few minutes. Thus at a predicted level of 5 ou_E/m^3 as a 98^{th} percentile, the peak concentrations over a few minutes would be up to 50 ou_E/m^3. This implies that detectable and identifiable odour would be present for a few minutes even when the 98^{th} percentile concentrations were 0.5 ou_E/m^3. For the situation where the predicted 98^{th} percentile odour concentration was 5 ou_E/m^3, odour would be detectable and identifiable for much more than 175 hours in a year. In all likelihood, odour would be detectable several hundred times a year at a particular receptor even though the situation was fully compliant with the Environment Agency guidance. This is a reflection that, for an odour nuisance to occur, it is not sufficient to detect the odour occasionally, odour must be readily apparent on numerous occasions above a particular concentration to be considered a nuisance.

It should be noted that just before preparation of the final version of this report, the Environment Agency issued a new consultation version of the H4 document. This new consultation document retains the previous version's suggestions for levels at which odour might be unacceptable although much of the technical background information has been removed.

4 Assessment Methodology

4.1 Overview

The methodology adopted for this assessment reflects the scope of the commission, the resources available and the meteorological and airport operating conditions during the time required to complete the study. The methodology can be summarised as follows:

- a literature review to identify appropriate hydrocarbon species, odour emissions from aircraft and appropriate assessment criteria;
- hydrocarbon and odour survey of existing conditions;
- calculation of hydrocarbon and odour emissions from aircraft operations; and
- dispersion modelling of hydrocarbon and odour emissions to determine respective human health and odour nuisance impacts.

The first of these is included in Sections 2 and 3 of this report. Further details of the assessment methodology for the survey, calculation of emissions and dispersion modelling are presented below.

4.2 Survey of Existing Conditions

4.2.1 Hydrocarbon Sampling

Hydrocarbon sampling was carried out using Tenax absorption tubes supplied by Gradko International Limited. The tubes were located in duplicates at four locations (see Figure 1):

- on the airport close to the taxiway holding point A1 at the current location of a nitrogen dioxide diffusion tube;
- a further site in Pinehurst Avenue at the closest point to the airport;
- outside of the complainant's property in Pinehurst Avenue; and
- a background site south of the airport.

The tubes were installed on lampposts and other street furniture on 28 May 2009 and were retrieved on 11 June 2009 following a two week exposure period. This monitoring simply provides a "snapshot" of pollutant concentrations over a two week period but is useful to determine whether any increases in pollutants concentrations as a result of the airport operations can be detected during the monitoring period.

To meet the programme for the study, the tubes were ordered prior to undertaking the literature review. A standard absorbent was specified to ensure the widest range of hydrocarbon species could be detected. The analytical laboratory was asked to analyse the tubes for the top ten detectable hydrocarbons, focussing on those listed in Table 2 that are most associated with aircraft emissions. Sampling for formaldehyde requires using tubes with specific absorbent which is different to the one used.

4.2.2 Odour Sampling

Silsoe Odours Ltd was commissioned by Arup to undertake an odour survey at Farnborough Airport. The survey was conducted on 3 and 4 June 2009. Samples were taken:

- at points circa 45m and 100m downwind from aircraft waiting prior to using the runway for take off (F1 holding position);
- circa 35-45m behind aircraft waiting prior to using the runway for take off (F1 holding position);
- circa 35-45m behind aircraft on the parking apron during pre-flight testing; and
- at a background location within the airport.

The location of each odour sampling and measurement point is identified in Figure 1.

Air samples were analysed by dynamic olfactometry at the Silsoe laboratories to determine odour concentrations, expressed in European odour units per cubic metre (OU_E/m^3).

The full monitoring report prepared by Silsoe Odours Ltd is provided in Appendix A.

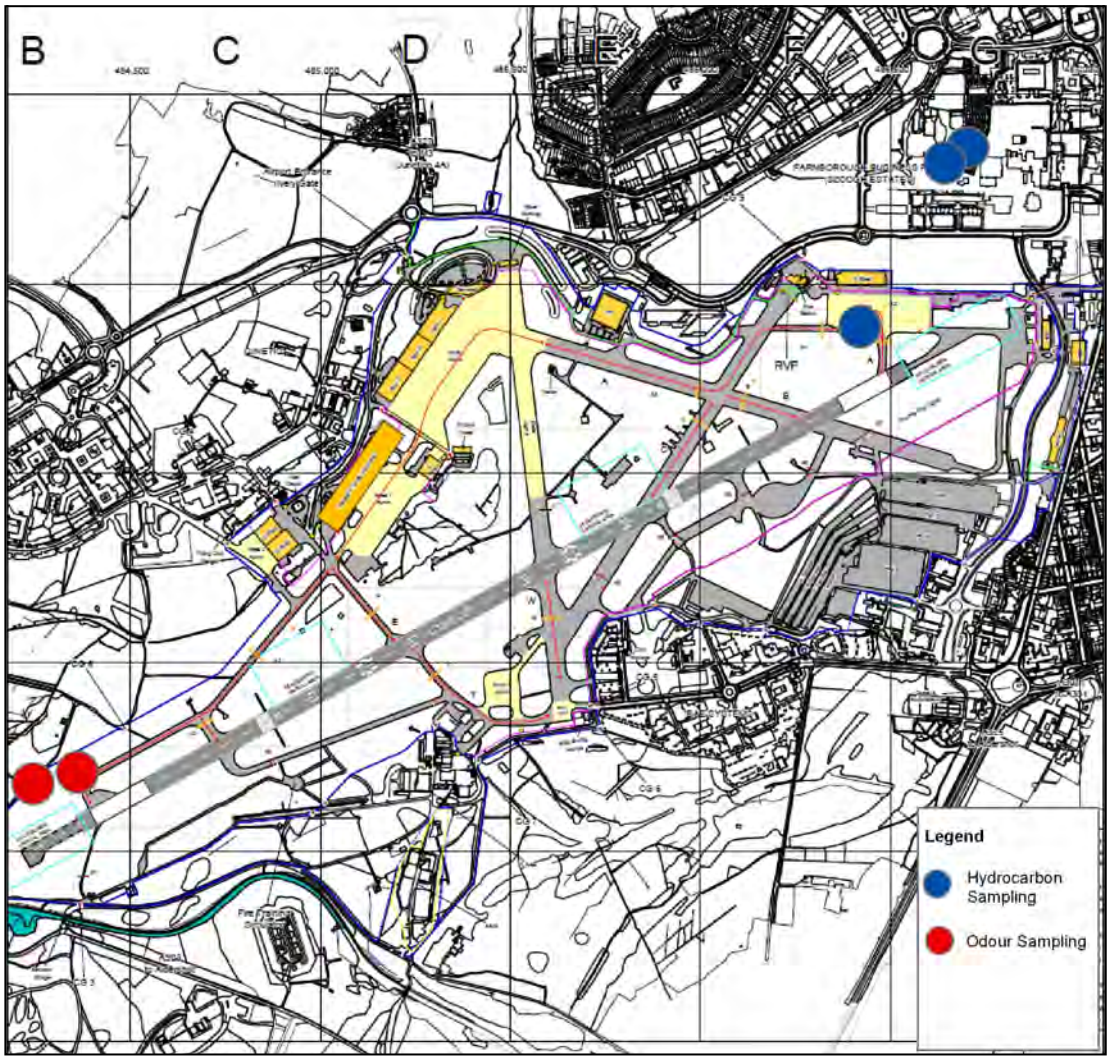

Figure 1 Location of Hydrocarbon and Odour Sampling Points

4.3 Calculation of Aircraft Emissions

Aircraft emissions vary at different stages of the operational flight cycle, which can be summarised as follows for Farnborough:

- Departure:
  - **Engine start** – the main engines are started immediately prior to taxi.
  - **Taxi to runway** – aircraft typically taxi out on all engines to the runway or holding area prior to entering the runway. Taxi-out is normally carried out at the idle/taxi power setting apart from brief bursts of power to overcome the initial inertia at the start of taxiing; or if necessary, to negotiate sharp turns.
  - **Holding on ground** – aircraft may be required to hold whilst awaiting clearance to enter the runway and taxi to the take-off position. Main engines are normally set to idle thrust with brief bursts of power to move into position.
  - **Take-off roll to lift-off** – The aircraft is accelerated along the runway to the end of the take-off, with the main engines set to take-off power. Operators rarely use full power for takeoff.
  - **Initial climb to power cutback** – After leaving the ground, the aircraft climbs at constant speed with the initial take-off power setting until the aircraft reaches the power cutback height (i.e. between 200 and 500 m above ground level) and the throttles are retarded.
  - **Acceleration, clean-up and en-route climb** – After the throttle cutback, the aircraft continues to climb at a thrust setting less than that used for take-off as the aircraft accelerates and reaches cruising altitude.
- Arrival:
  - **Final approach** – The stabilised final approach follows a relatively predictable glide slope at low engine thrusts. Thrust settings increase as flaps and the undercarriage are lowered, whilst speed decreases towards the flare.
  - **Flare, touchdown and landing roll** – Throttles are normally retarded to idle during the flare and landing roll. This is followed by application of wheel brakes and (where appropriate) reverse thrust to slow down the aircraft on the runway.
  - **Taxi from runway to parking stand** – Taxi-in from the runway is a similar process to taxi-out to the runway described above.
  - **Engine shutdown** – Remaining engines are shut down after the aircraft has stopped taxiing and power is available for onboard aircraft services.

For the purposes of determining engine exhaust emissions, the ICAO has derived a reference Emissions Certification Landing Take Off (LTO) Cycle – see Table 3 below.

Table 3: ICAO Reference Landing Take Off Cycle

Operating Phase	Time in Mode (minutes)	Thrust Setting (% of rated thrust)
Approach	4	30
Taxi and Ground Idle (in)	7	7
Taxi and Ground Idle (out)	19	7
Take-off	0.7	100
Climb	2.2	85

Note that the reference LTO cycle does not necessarily represent operating conditions at Farnborough airport but provides the basis for ICAO emission factors for different aircraft types. For the purposes of this assessment, an average Time in Mode of five minutes has been assumed for both Taxi and Ground Idle (in) and Taxi and Ground Idle (out).

The fuel used and the Emissions Index for different aircraft at the appropriate power (in this instance, 7% thrust) are available either from the ICAO databank or other sources such as the Swedish Defence Research Agency[13] or Switzerland's Federal Office of Civil Aviation[14]. Emissions indices are available for NO_x, CO and total hydrocarbons.

In this case, it is accepted that the odour problems arise from aircraft that are waiting at the end of the taxiway before being given permission to take off. The waiting period is variable depending on air traffic control. Wherever possible aircraft pass straight onto the runway without stopping and take off straightaway without a waiting period. There can , however, be a short waiting period of a few minutes before the aircraft receives permission to move onto the runway and take off. For the purposes of the dispersion modelling, only the waiting period has been assessed. Emissions from the other parts of the cycle are relatively short lived and are unlikely to be of the same magnitude.

[13] www.foi.se/FOI/templates/Page4618.aspx
[14] www.aviation.admin.ch/fachleute/lufttechnik/entwicklung/00653/00764/index.html?lang=en

5 Existing Conditions

5.1 Odour Complaints

Odour complaints are recorded by the Environmental Manager at Farnborough Airport, they records of complaints from 2007 were provided and the dates and location of the complaints are detailed in the table below. These have been matched with the wind speed and direction recorded at Heathrow at the same time – see Table 4 overleaf.

As can be noted from the location, the majority of complaints have been received at locations to the north of the airport close to the taxiway where vehicles wait before being released to take off. The wind direction recorded confirms that it is possible that the odour has come from the airport. It is interesting to note that odour has been detected at a range of wind speeds including relatively high speeds where enhanced dispersion would be expected.

Where a description has been provided by the complainant, this is frequently described as “fumes” or “aviation fuel”. In total 32 and 20 complaints were received in 2007 and 2008 respectively. Some complaints allege dumping of fuel but it is understood this does not take place at Farnborough as most of the aircraft using the airport are do not have the facility to dump fuel. In event, dumping of fuel in rare in the UK and normally happens in emergency situations over water.

Hart District Council also provided their records of odour complaints all of which were received from the Pondtail area to the west of the airport as follows:

Date	Approximate address
06.10.08	Farnham Road
29.05.08	Williams Way
18.02.08	Frensham Avenue
18.02.08	Wood Lane
15.02.08	Guildford Road
15.02.08	Kenwith Avenue
31.10.03	Kenwith Close
22.01.97	Fuglemere Road
23.09.94	Cedar Drive

Unfortunately the time of the complaints are not recorded and hence they cannot be correlated with the recorded wind speed and direction at the time of the complaint.

Table 4: Odour Complaints

Date	Time	Location	Wind Speed (m/s)	Wind Direction (deg. from north)
26/01/2007	17:15:00	Sandy Lane	3.1	290
28/03/2007	10:10:00	Kempton Court	1.0	280
22/04/2007	14:50:00	Kempton Court	6.2	220
18/05/2007	12:23:00	Kempton Court	7.2	210
14/06/2007	15:23:00	Kempton Court	5.7	210
15/06/2007	09:30:00	Kempton Court	4.6	210
28/06/2007	16:37:00	Kempton Court	8.2	220
28/06/2007	21:14:00	Kempton Court	6.2	210
08/07/2007	17:54:00	Kempton Court	6.7	230
12/07/2007	19:05:00	Kempton Court	7.2	240
17/07/2007	11:56:00	Kempton Court	8.2	200
17/07/2007	18:30:00	Kempton Court	9.3	210
27/07/2007	13:13:00	Pinehurst Cottages	7.2	230
31/07/2007	12:40:00	Kempton Court	3.1	190
31/07/2007	12:40:00	Kempton Court	3.1	190
12/09/2007	17:20:00	Sandy Lane	2.1	20
11/10/2007	20:30:00	Farnborough College of Technology	2.1	280
12/11/2007	18:44:00	Pinehurst Avenue	1.5	310
12/11/2007	19:25:00	Kempton Court	1.5	290
28/11/2007	10:40:00	Kempton Court	5.7	210
30/11/2007	13:56:00	Kempton Court	7.2	220
04/12/2007	18:55:00	Kempton Court	7.7	220
04/12/2007	21:27:00	Kempton Court	7.2	210
04/12/2007	22:15:00	Kempton Court	8.7	210
06/12/2007	07:05:00	Kempton Court	6.7	200
11/12/2007	16:22:00	Kempton Court	2.6	270
27/12/2007	10:45:00	Kempton Court	7.7	210
31/12/2007	06:00:00	Guildford Road West	0.5	110
29/01/2008	15:30:00	Kempton Court	5.1	230
27/02/2008	16:50:00	Coleford Brodge Road	3.1	270
03/03/2008	15:09:00	Kempton Court	9.8	250
06/03/2008	09:39:00	Kempton Court	4.1	240
04/04/2008	14:00:00	Ively Road	4.6	260
12/04/2008	11:42:00	Albert Road	9.3	240
30/05/2008	12:58:00	Firtree Way	2.6	300
22/06/2008	09:18:00	Kempton Court	9.3	220
02/09/2008	17:11:00	Kempton Court	8.7	220
03/09/2008	19:11:00	Kempton Court	8.7	220
12/10/2008	17:50:00	Coleford Bridge Road	3.6	180
17/10/2008	18:00:00	Wilton Court	2.6	230
29/10/2008	18:00:00	Southern Way	2.1	180
03/12/2008	18:30:00	Kempton Court	2.6	290
19/12/2008	10:26:00	Albert Road	4.6	250
20/12/2008	10:20:00	Albert Road	7.7	260

Note:
A small number of complaints excluded if wind speed and direction could not be matched.

5.2 Hydrocarbon Survey

The results of sampling hydrocarbons over the period 28 May to 11 June 2009 are presented in Table 5. With only a very limited sampling period, no firm conclusions can be drawn from these results although the following observations can be made:

- For all hydrocarbons detected, the concentrations were well within, typically within one and three orders of magnitude, applicable EALs;
- Three hydrocarbons associated with aircraft engine emissions (benzene, naphthalene and toluene) were detected although they would be expected to be present in an urban environment with road traffic emissions;
- Concentrations of benzene at Stand A1 appear to be elevated compared to observed concentrations at other locations; and
- Concentrations of hydrocarbons in general appeared to be higher at Blandford House.

Winds were generally from the east during the sampling period, resulting in aircraft emissions being blown away from sampling sites at Stand A1, Pinehurst Avenue and Pinehurst Cottages but towards Blandford House. During the sampling period, aircraft were taxiing to the southwest end of the runway, i.e. away from the sample sites.

Further sampling is required to substantiate these observations.

Table 5: Hydrocarbon Survey Results

Hydrocarbon	Mean Concentration (28 May – 11 June 2009) (µg/m^3)			
	Stand A1	Pinehurst Avenue (closest point to the airport)	Pinehurst Cottages (complainant's property)	Blandford House (background site)
Benzene	**1.04 -**	**0.42 – 0.43**	**0.44 – 0.47**	**0.43 – 0.71**
Decane	-	-	0.45 -	-
Dodecane	-	-	-	0.98 -
Ethylbenzene	-	0.25 – 0.26	0.28 – 0.33	0.41 -
Formamide	0.17 -	-	-	0.39 -
Hexane	-	0.31 -	-	0.49 -
Naphthalene	**0.54 – 0.55**	**<LOD – 0.62**	**0.23 – 0.72**	**4.53 – 4.54**
Octane	0.42 -	-	-	-
Pentane	0.17 – 0.17	0.24 – 0.36	0.28 -	0.24 -
Tetradecane	-	-	3.61 -	1.31 – 13.51
Toluene	**-**	**1.14 – 1.28**	**1.25 – 1.46**	**0.80 – 1.41**
Undecane	-	-	-	0.59 -
p-Xylene	0.33 – 0.35	0.75 – 0.79	0.68 – 0.85	0.67 – 1.27

Note:

Duplicate sampling was undertaken at each site. Results are presented based on an analysis to determine the ten hydrocarbons with the highest concentrations.

Bold indicates hydrocarbons associated with aircraft emissions.

5.3 Odour Survey

Silsoe Odours Ltd was commissioned by Arup to undertake an odour survey at Farnborough Airport. The survey was conducted on 3 and 4 June 2009. The location of sampling and measurement points are identified in Figure 1. The results are summarised in Table 7, Table 6 and Table 8.

The six samples taken 45m behind aircraft indicate odour concentrations are 480 ou_E/m^3 although this excludes one outlier with a measured odour concentration of 5524 ou_E/m^3. This outlier may have been observed when the main engines were being started rather than being at idle. However, this is an indication that some types of aircraft operation can give rise to higher levels of odour emissions than normal although there is evidence from elsewhere that odour samples taken directly behind engine exhausts may be confounded by high NO_2 concentrations[6].

The eight samples taken downwind of aircraft waiting at the end of the taxiway prior to entering the runway indicate odour concentrations are 134 ou_E/m^3 50m downwind reducing to 90 ou_E/m^3 150m downwind. These samples were generally taken perpendicular to the direction of engine exhaust.

The two background samples indicate odour concentrations in the airport are 89-123 ou_E/m^3. It can be difficult to interpret the background results, the odour sampling can only assess the odour and not the actual aircraft components of that odour. Therefore, it is not strictly applicable to directly subtract the background values from the measured odour concentration near to aircraft. If is considered, however, that the measured odour concentrations near to the aircraft will contain an element of “background” odour and hence the odour actually arising from the aircraft will not be the total value measured.

Note that all these samples were taken over a short period and cannot be extrapolated to determine odour concentrations over a year, for example. The results do, however, provide reference concentrations for evaluation of dispersion modelling.

As can be seen from the results, elevated odour concentrations are found directly behind the aircraft of nearly 500 ou_E/m^3. However, these elevated values are only found if sampling is undertaken directly downwind of the jet exhaust. When sampling is carried out at a similar distance downwind of aircraft but where the engines are not orientated towards the sampling point, concentrations are considerably lower and only marginally above the measured background concentrations. This indicates the importance of the direction of the engines when waiting at the taxiway.

Odour complaints tend to arise when there is a rapid change in the odour environment. People tend to tolerate constant levels of relatively unobjectionable odours. However, given the results of the odour sampling it is apparent that there will be brief but large increases in odour concentrations on occasions. This situation is very likely to give rise to complaint if it happens sufficiently frequently.

Table 6: Odour Sampling Results – Locations Behind Aircraft Exhaust

Time/date of sample	Sample Ref	Aircraft type and sampling position	Odour concentration (OU_E/m^3)	Distance behind aircraft (m)	Wind speed (m/s)
11:53 3 June 09	20090604 F6	Exhaust of Citation 500 on apron	5524	35	3.1-4.1
08:56 4 June 09	20090605 F1	Exhaust of HS146 at F1	394	45	2.1-3.1
12:50 4 June 09	20090605 F3	Exhaust of Global Express at F1	470	45	< 2.1
12:52 4 June 09	20090605 F5	Exhaust of Global Express at F1*	1017	45	< 2.1
14:30 4 June 09	20090605 F6	Exhaust of Global Express at F1*	389	45	< 2.1
14:40 4 June 09	20090605 F7	Exhaust of N475M at F1	128	45	< 2.1
Notes: Average odour concentration **45m behind aircraft = 480 ou_E/m^3** (128 – 1017ou_E/m^3) excludes outlier. * sampled by opening the bag rather than by pumping.					

Table 7: Odour Sampling Results – Locations Downwind of Aircraft

Time/date of sample	Sample Ref	Aircraft type and sampling position	Odour concentration (OU_E/m^3)	Distance downwind of aircraft (m)	Wind speed (m/s)
09:12 3 June 09	20090604 F1	MWMWM at F1	102	50	3.6-4.1
09:12 3 June 09	20090604 100-1	MWMWM at F1	65	150	3.6-4.1
10:13 3 June 09	20090604 F2	Twin turbo at F1	119	50	3.6
10:20 3 June 09	20090604 F3	Lear 60 at F1	188	50	3.6
10:20 3 June 09	20090604 100-2	Lear 60 at F1	115	150	3.1-4.1
10:25 3 June 09	20090604 F4	Lear 60 at F1	188	50	3.1-4.1
10:44 3 June 09	20090604 F5	Cherokee at F1	77	50	3.1-4.1
08:57 4 June 09	20090605 F2	HS146 at F1	127	50	< 2.1
Average odour concentration **50m downwind = 134 ou_E/m^3** (77 – 188 ou_E/m^3)					
Average odour concentration **150m downwind = 90 ou_E/m^3** (65 – 115 ou_E/m^3)					

Table 8: Odour Sampling Results – Background Location in Airport

Time/date of sample	Sample Ref	Aircraft type and sampling position	Odour concentration (OU_E/m^3)	Distance downwind of aircraft (m)	Wind speed (m/s)
12:20 4 June 09	20090605 BLANK 1	Not applicable	89	Not applicable	< 2.1
12:25 4 June 09	20090605 BLANK 2	Not applicable	123	Not applicable	< 2.1
Average odour concentration **background = 106 ou_E/m^3** (89 – 123 ou_E/m^3)					

6 Dispersion Modelling

6.1 Introduction

Computer dispersion modelling was used to estimate the impact of the emissions from the aircraft operating at Farnborough Airport. Dispersion modelling allows comparison with numerical standards previously described in this report.

The dispersion model ADMS4 was used for this assessment. It is a new generation dispersion model and has all the required features for this study. This type of model is required to be used by the Environment Agency and hence ADMS4 has been widely applied for this type of study in the UK.

This model has one feature that is useful for assessment of aircraft emissions which is the ability to define a jet source. This allows direct modelling of a source where the emissions are directed horizontally rather vertically as in standard emission models. However, the jet source feature has one limitation in that it assumes that the horizontal direction of the source is within ±20° of the wind direction. Therefore it can only be used to examine the situation where the receptors are downwind of the jet source.

To make a more general assessment of conditions over the year, the emissions from the aircraft could be modelled as a volume source, as this would represent the initial dispersion of the exhaust gases as they exit the aircraft. As part of this assessment aircraft emissions were initially modelled using both types of sources (i.e. jet source and volume source) to determine which source type would be appropriate for this model. The results of this preliminary study showed that the differences between modelled concentrations using jet sources and modelled concentrations using volume sources were negligible. As a result, it was considered appropriate to use jet sources for the assessment of aircraft emissions.

Modelling has been carried out to examine odour and hydrocarbon impacts. In both cases, the model has been used to examine short term peak concentrations (using both the jet and area source features) and the annual average or 98th percentile concentrations over the year.

6.2 Model Inputs and Assumptions

6.2.1 Meteorological Data

The sequential meteorological data for 2008 have been obtained in ADMS format from Atmospheric Dispersion Modelling Ltd. from the Heathrow Airport Meteorological Station. The wind rose for derived from this data is presented in Figure 3 showing the very large proportion of south westerly winds in the area. 2008 data was used as aircraft data were supplied for the same year.

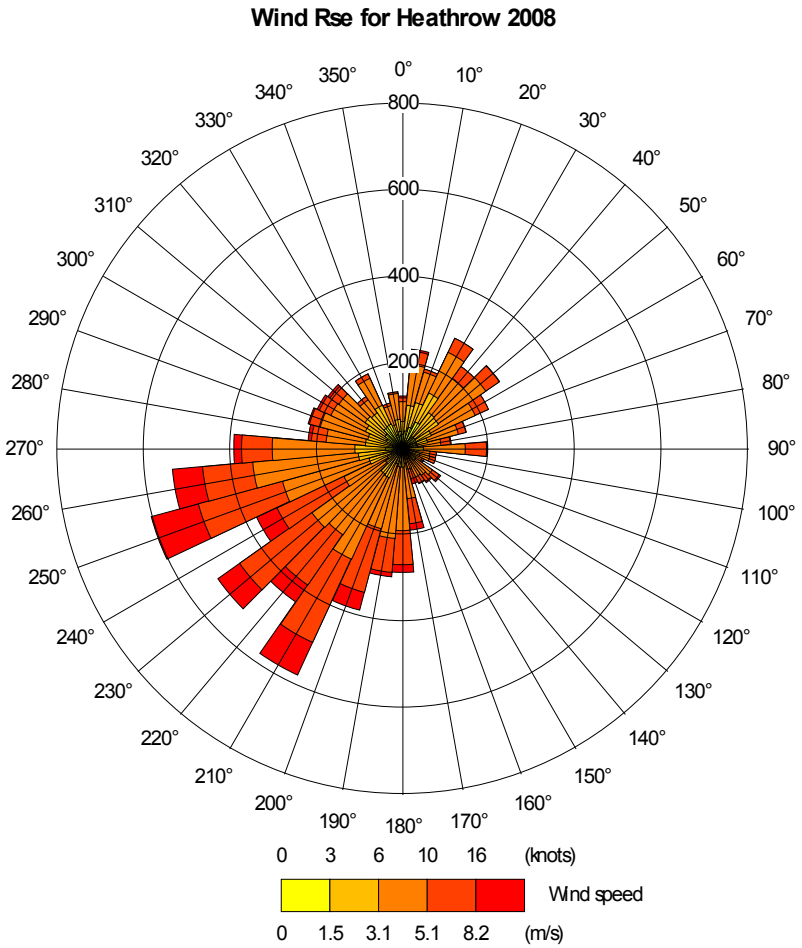

Figure 2: Wind Rose from Heathrow Airport Meteorological Station for 2008

6.2.2 Aircraft Exhaust Emissions

As described in Section 2 emissions resulting from air traffic are generated by a fleet of different aircraft types with varying characteristics operating in different modes.

Emissions from aircraft engines for a particular mode of operation can be calculated using the following formula:

$E_{ATM,m,p} = 0.5 \Sigma M_j N_{(j)} C_{m,l(j)} t_{mN(j} e_{S(m),l(j),p}$

Where:

$E_{ATM,m,p}$ = the annual emission of pollutant p from air traffic movements exhaust emissions, from a particular mode m.

M_j = the annual number of air traffic movements (which is the sum of arrivals and departures) of aircraft type j from/to the airport.

$N_{(j)}$ = the number of engines of aircraft of category j

$C_{m,l(j)}$ = the fuel consumption in the mode of operation m for engines of type l (determined by the aircraft type j).

$t_{m,N(j)}$ = the time spent in mode m by aircraft with N engines

$e_{S(m),l(j),p}$ = the emission factor for pollutant p for engines of type l in mode M

Information on the number of ATMs and aircraft type operating at Farnborough airport for the year 2008 were provided by TAG.

In order to calculate emissions from aircraft operation it is essential to identify the specific engine types and numbers fitted to the different aircraft that make up the annual total

movements. Due to the fact there is a very large number of different aircraft operating at Farnborough, the data provided were interrogated and a list of the top ten most frequently operating aircraft established (see Table 9). The top ten aircraft account for approximately 50% of all aircraft and helicopter movements. Specific engine types were then identified for these ten aircraft types.

Table 9: Top Ten Aircraft and Associated Engine Type

Aircraft name	Engine
Bombardier Challenger 600	CF34-3B
Cessna 560XL	JT15D-5C
Hawker Siddeley HS125	PW306A
Beech 200 Super King Air	PT6A-42
Learjet 45	TFE731-2-2B
Dassault Falcon 900	PW306A
Dassault Falcon 2000	PW306A
Raytheon Premier 1	JT15D-4 series
Gulfstream V	BR700-710A1-10
Gulfstream IV	TAY Mk611-8

Emission rates were calculated for the aircraft listed in Table 9. As mentioned in Section 2, for the purpose of this assessment only emissions occurring during idling/taxiing have been taken into account.

Emission rates were calculated for HC and CO_2 (as C). In order to calculate CO_2 emissions, a carbon content of aviation fuel of 859g/kg was assumed (taken from NAEI).

The average emission rate was calculated from the ten available emission rates of HC and CO_2 and used to calculate annual emission rates emitted at the airport.

6.2.3 Spatial Representation of aircraft exhaust emissions during idling

Emissions from aircraft moving to the point of take-off and from the point of landing respectively have been modelled as line sources along the airport taxiways. In order to take account of aircraft waiting prior to taking-off, a jet source has been included in the model at the end of each taxiway. In addition, it has been assumed that the aircraft spend approximately five minutes at the stand area.

There are two runways at Farnborough airport, namely runway 24 and runway 06. Both runways use the same stretch of 'road' but are directional opposites. Runway model splits were provided by TAG. In 2008, 78% of aircraft movements took place on runway 24. The resulting utilisation of runway 06 accounted to 22%.

6.2.4 Model validation and verification

ADMS4 is recognised by the Department of Environment, Food and Rural Affairs as a validated model for air quality modelling studies in the UK. The inclusion of a jet source is consistent with the ADMS Airport model developed for the Project for the Sustainable Development of Heathrow which was subject to independent peer review. The model has been set up and used in a manner consistent with modelling studies of airports elsewhere.

Model verification involves comparing model results with monitoring results and, if no agreement between the results is observed, a further process of checking and refining of model inputs. Adjustment of model results may be undertaken following this checking and refining process. With limited monitoring data available at this time no model verification has been undertaken.

6.3 Dispersion Modelling Results

6.3.1 Hydrocarbons

The results of modelling hydrocarbon emissions at the specified receptors are presented in Table 10 below for formaldehyde and for all hydrocarbons in Appendix B. Results for formaldehyde are presented as this hydrocarbon appears to be a marker species for aircraft emissions as well as having the most stringent EAL (see Table 2). A contour plot of maximum modelled 1-hour mean concentrations of formaldehyde is presented in Figure 3. Figure 4 shows the modelled annual mean concentration of formaldehyde.

Maximum modelled 1-hour concentrations of formaldehyde were all within the Environmental Assessment Level of 100 µg/m^3 at discrete receptors outside the airport. The highest modelled concentration at a discrete receptor point outside the airport was 92µg/m^3 at Kempton Court. However, Figure 3 shows that there are residential properties at the western edge of Kempton Court that fall within the 100 – 150µg/m^3 concentration band. Interrogating the contour plot data at the receptor closest to the emission source shows that formaldehyde concentrations of up to 115µg/m^3 were calculated. With prevailing winds from the southwest, these receptors are located downwind of the main apron area where aircraft start main engines (see Figure 3). The apron area has been modelled as a single area source covering the concrete area in front of the hangar building. Given the elevated modelled concentrations at sensitive receptors, further modelling of the area in more detail may be useful, for example adding several smaller area sources at locations where aircraft start. However, detailed discussions with the airport operator would be required in order to fully understand aircraft movements within this area enhanced by further sampling.

In addition, it should be noted that the calculation of formaldehyde is based on a worst case assumption, i.e. the highest factor (0.5) out of the presented range (0.35 – 0.5) was used to convert concentrations of modelled hydrocarbons into formaldehyde concentrations. When using a factor of 0.35, formaldehyde concentrations at Kempton Court would be within the Environmental Assessment Level. In addition, the proportion of formaldehyde in the engine exhausts decreases as the engine thrust increases and the actual concentrations are likely to be lower than those modelled.

Modelled annual mean concentrations of formaldehyde are all well below the Environmental Assessment Level at receptors outside the airport (see Figure 4).

Table 10: Results of Modelling Formaldehyde

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	92	1.0
Maitland Road	27	0.4
Ively Road	86	0.5
Pinehurst Avenue	31	0.4
Pinehurst Cottages	30	0.3
Albert Road	26	0.3
Guildford Rd West	28	0.3
College of Technolog	26	0.4
F1	31	0.6
100m from F1	30	0.4
Tenax Tube 001	108	4.3
Environmental Assessment Level	**100**	**5**

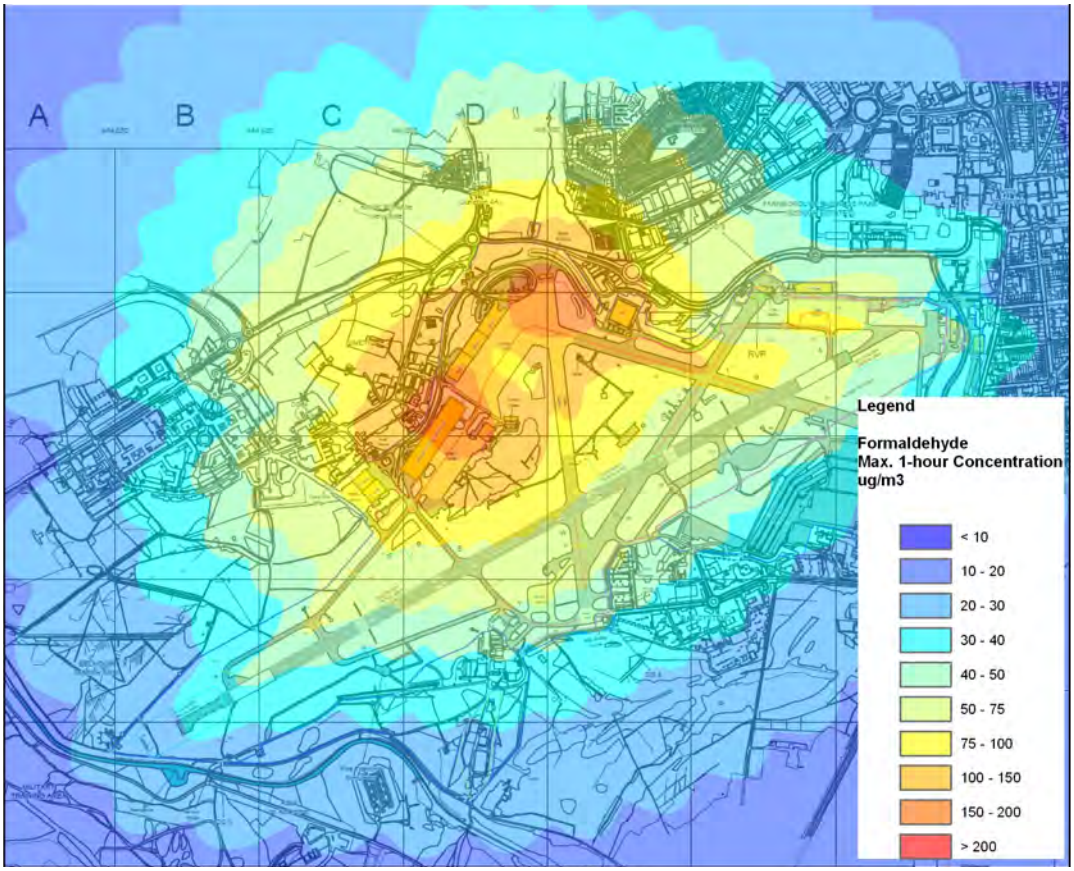

Figure 3: Maximum Modelled 1-hour Concentrations of Formaldehyde (µg/m^3)

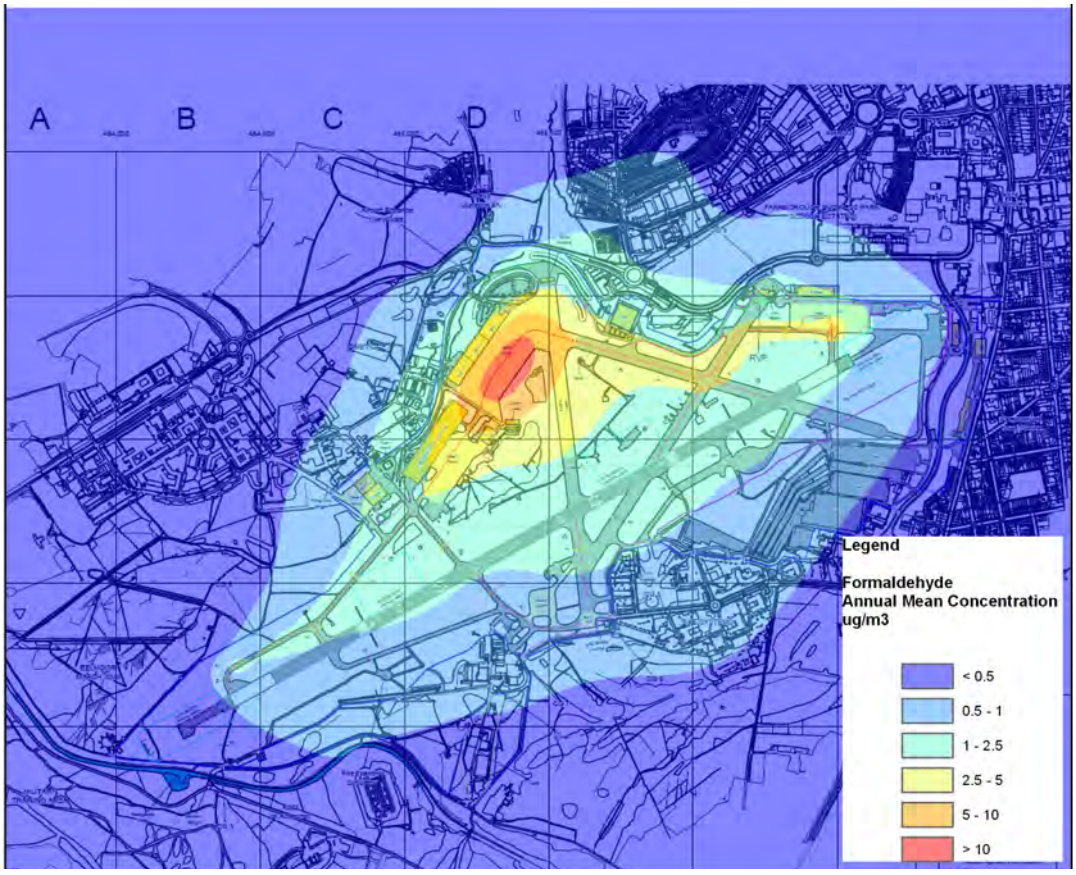

Figure 4: Modelled Annual Mean Concentration of Formaldehyde (µg/m^3)

6.3.2 Odour

The results of modelling aircraft odour emissions at the specified receptors are presented in Table 11 for the 98th percentile of hourly means, the maximum 1 hour mean and the peak value. A contour plot of the 98th percentile of hourly mean odour concentrations is provided in Figure 3.

As can be seen in Table 11, the predicted 98th percentile of hourly means are all 1.0U_E/m^3 or less suggesting odour emissions are within the acceptable levels detailed in the Environment Agency H4 guidance. However, maximum 1 hour odour concentrations are up to 10.0U_E/m^3 suggesting a 'faint odour' will be detectable and identifiable at Kemton Court and Ively Road. Peak values within each hourly period would be up to 10 times higher, suggesting 'distinct odours' would be experienced at receptors around the airport on occasions.

The model results clearly demonstrate that the operation of the aircraft will result in odour being detected at residential properties on occasion rather than on a regular basis. The nature of such short term odour peaks is the type of situation where odour complaints may be more likely.

Increases in aircraft movements at the airport will give rise to a proportional increase in the number of occasions where the aircraft operations and orientation is such that odour could be detected at residential properties. As a result, it can be expected that the level of complaint would increase, although this may not be in direct proportion to the increase in number of aircraft movements as people may become more accustomed to aircraft smells in the area.

Table 11: Results of Modelling Odour

Receptor	Odour Concentration (OU_E/m^3)		
	Peak value	Maximum 1-hour	98th percentile
Kempton Court	100	10	1.0
Maitland Road	30	3	0.7
Ively Road	100	10	0.4
Pinehurst Avenue	40	4	0.3
Pinehurst Cottages	30	3	0.2
Albert Road	30	3	0.3
Guildford Rd West	30	3	0.3
College of Technology	30	3	0.6
F1	40	4	0.8
100m from F1	30	3	0.4

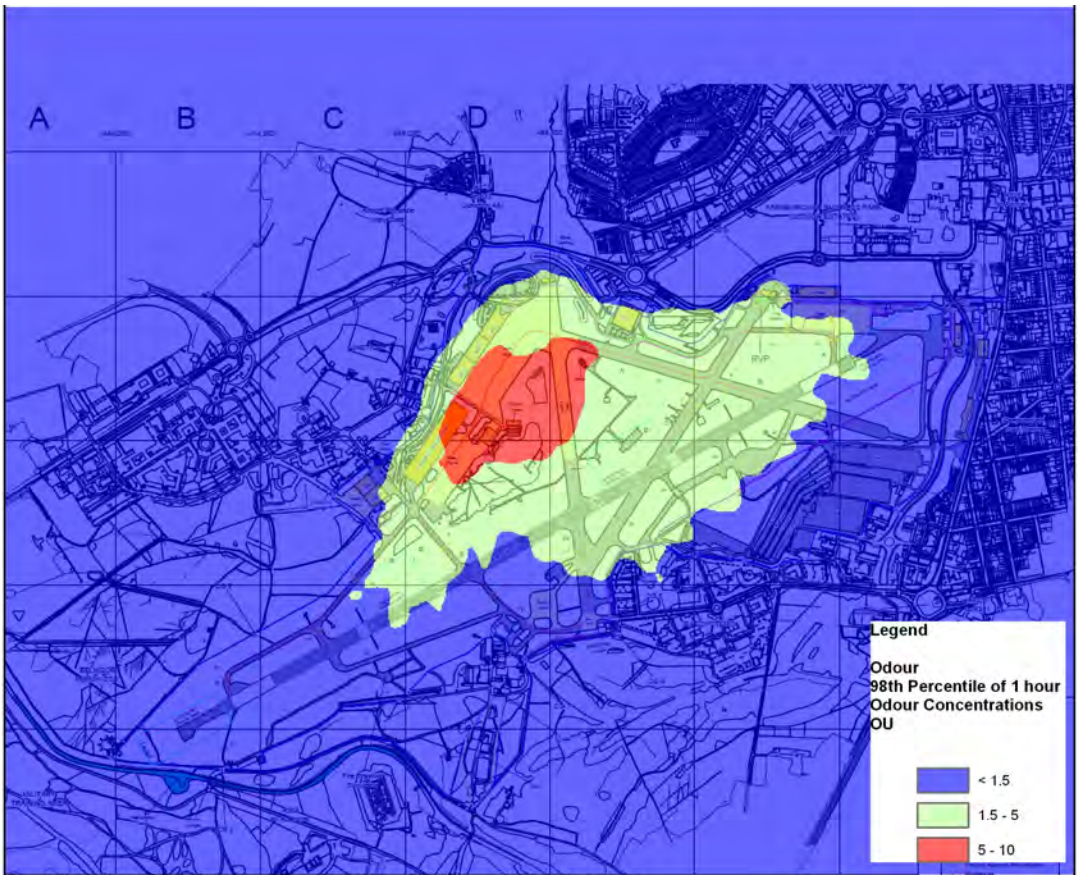

Figure 5: Modelled 98th Percentile of 1-hour Odour Concentrations

6.3.3 Assessment of Possible Future Year Scenarios

In order assess the potential effects an increase in annual flight movements operating at Farnborough airport might have, emissions of hydrocarbons were calculated for 35,000 movements, 50,000 movements and 60,000 movements.

Tables 12, 13, 14 and 15 show the results of the dispersion model at discrete receptor locations for the different flight movements for Formaldehyde (Tables 12 and 13) and Odour (Tables 14 and 15).

The results indicate there is potential for formaldehyde to breach the short term (1 hour) EALs Kempton Court and Ively Road and hence, further investigation is warranted. The model results indicate the long term (annual mean) EAL for formaldehyde would not be breached.

The results of modelling odour emissions confirm the findings in section 6.3.2 that an increase in odour complaint would be expected with increase aircraft movements. Notably, the number of receptors experiencing a maximum 1 hour odour concentration of 5 ou_E/m^3 or more would rise from two currently to all receptors modelled with 50,000 aircraft movements or more.

Table 12: Results of Modelling Formaldehyde (Maximum Modelled 1-hour Concentrations) for Increased Aircraft Movement Projections

Receptor	Maximum Modelled 1-hour Concentration ($\mu g/m^3$)			
	28,000	35,000	50,000	60,000
Kempton Court	92	121	173	208
Maitland Road	27	35	50	60
Ively Road	86	113	161	193
Pinehurst Avenue	31	41	59	70
Pinehurst Cottages	30	39	56	67
Albert Road	26	35	50	60
Guildford Rd West	28	37	52	63
College of Technology	26	34	48	58
F1	31	41	58	70
100m from F1	30	39	55	66
Tenax Tube 001	108	143	204	245
Environmental Assessment Level	**100**			

Table 13: Results of Modelling Formaldehyde (Annual Mean Concentrations) for Increased Aircraft Movement Projections

Receptor	Annual Mean Concentration ($\mu g/m^3$)			
	28,000	35,000	50,000	60,000
Kempton Court	1.0	1.3	1.8	2.2
Maitland Road	0.4	0.5	0.7	0.8
Ively Road	0.5	0.6	0.9	1.1
Pinehurst Avenue	0.4	0.5	0.7	0.8
Pinehurst Cottages	0.3	0.4	0.6	0.7
Albert Road	0.3	0.4	0.6	0.7
Guildford Rd West	0.3	0.4	0.6	0.7
College of Technology	0.4	0.5	0.7	0.8
F1	0.6	0.8	1.1	1.3
100m from F1	0.4	0.5	0.7	0.8
Tenax Tube 001	4.3	5.6	8.0	9.6
Environmental Assessment Level	**5**			

Table 14: Results of modelling Odour (Maximum Modelled 1-hour Concentrations) for Increased Aircraft Movement Projections

Receptor	Maximum Modelled 1-hour Concentration (OU_E/m^3)			
	28,000	35,000	50,000	60,000
Kempton Court	10	14	20	24
Maitland Road	3	4	6	7
Ively Road	10	13	18	22
Pinehurst Avenue	4	5	7	8
Pinehurst Cottages	3	4	6	8
Albert Road	3	4	6	7
Guildford Rd West	3	4	6	7
College of Technology	3	4	5	7
F1	4	5	7	8
100m from F1	3	4	6	8

Table 15: Results of modelling Odour (98th Percentile of Annual Mean Concentrations) for Increased Aircraft Movement Projections

Receptor	Modelled 98th Percentile (OU_E/m^3)			
	28,000	35,000	50,000	60,000
Kempton Court	1.0	1.3	1.8	2.1
Maitland Road	0.7	0.9	1.3	1.5
Ively Road	0.4	0.6	0.8	1.0
Pinehurst Avenue	0.3	0.4	0.6	0.7
Pinehurst Cottages	0.2	0.3	0.5	0.5
Albert Road	0.3	0.4	0.6	0.7
Guildford Rd West	0.3	0.4	0.6	0.8
College of Technology	0.6	0.8	1.2	1.4
F1	0.8	1.1	1.6	1.9
100m from F1	0.4	0.6	0.8	0.9

7 Mitigation

The assessment demonstrates that the levels of most hydrocarbons around the airport are not likely to be of concern and hence no mitigation would be required even if the activity at the airport increases. Initial modelling of formaldehyde suggests that further assessment is required to determine the situation for this pollutant.

An increase in the number of aircraft movements is likely to increase the number of occasions where odour will be detected at nearby properties. Given that the odour is likely to be detected on occasions where the aircraft engines are directed towards the properties then it could be expected that the number of occasions where odour could be detected will increase in proportion to the number of aircraft movements. To reduce the incidence of odour detection (and hence possibly complaint) either the location of the source needs to be moved, the orientation of the engines needs to be changed, the operating time of aircraft on the ground needs to be reduced or an obstruction needs to be placed between the source and the sensitive receptors to change the direction of the jet exhaust.

The location of the taxiway is fixed, although it would be possible to undertake works that would introduce minor changes to the taxiway layout such that waiting aircraft are less likely to direct their exhausts towards nearby housing. It is considered that it would be may difficult to design a suitable obstruction that would redirect the exhaust flow effectively, such a structure would have to be substantial to be effective and the actual mitigation may not be substantial and would need careful examination with CFD modelling.

The most suitable mitigation would be to introduce operational procedures to ensure that aircraft were not waiting with engines running in the apron area or on the taxiway waiting for take off with their engines directed towards the housing. This does appear to be a relatively simple operational measure that should be effective in reducing odour levels at residential areas.

Appendix A

Silsoe Odour Report

COMMERCIAL - IN CONFIDENCE

SILSOE ODOURS Ltd
Building 42 Wrest Park, Silsoe
Bedfordshire, MK45 HP

UKAS TESTING
0609

REPORT
To
ARUP

Odour Emissions from Aircraft at Farnborough Airport June 2009

Date of report June 2009

Robert Sneath, CEnv, MIAgrE
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Bedfordshire, MK45 HP.
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Contents

Odour Emissions from Aircraft at Farnborough Airport June 2009

1. Introduction

Farnborough Airport is the subject of odour complaints, so in order to quantify the emissions from the site and to help decide on design criteria for abatement of the odours an odour sampling survey of jet engine exhaust was proposed.

Silsoe Odours Ltd visited Farnborough Airport June 2009 to collect samples from the down wind of aircraft at the holding stand and from the engine exhaust.

Only odour concentration measurements are covered by our UKAS accreditation (Testing Laboratory No. 0609).

2. Sampling for concentration measurements

We sampled at the following places:

2.1. To assess the concentration downwind of aircraft at the F1 holding position

We collected samples from a sampling point about 45 m down wind of the F1 line near the F1 sign on both days and 100m further downwind on the first day. The sample was collected during the time aircraft stood under orders from Air Traffic Control.

2.2. To assess the odour concentration of the exhaust from aircraft on the parking apron during pre-flight testing

We collected a sample from a sampling point about 35 m behind the aircraft, in the jet stream, that was carrying out pre-flight checks on the apron. Only one sample was collected using this method because there was rarely sufficient time to position the sampling equipment before the area behind the plane became to dangerous to work.

2.3. To assess the odour concentration of the exhaust from aircraft at the F1 holding position

We collected samples from a sampling point about 45 m behind the F1 holding line in the jet stream from the engine. The sample was collected during the time aircraft stood under orders from Air Traffic Control.

3. Analysis methods

3.1. Odour concentration

Odour concentrations were measured according to EN13725 standard for olfactometry.

Air samples were analysed by dynamic olfactometry at the Silsoe Odours Ltd laboratory in Bedfordshire, a UKAS accredited laboratory using the procedures set out in the Silsoe Odours Ltd Odour Lab Procedure OL1 which incorporates BSEN13725:2003 “Air quality – Determination of odour concentration measurement by dynamic olfactometry”.

Fig 1 Silsoe Odours Ltd's UKAS accredited odour laboratory

The olfactometry measurement quantifies the concentration of odour in air samples by diluting the air sample under test with known ratios of odour-free air. The diluted samples are presented to a panel of six people to determine the odour threshold value. The threshold value is the odour concentration just perceived by 50% of the panel via statistical analysis of dilution test results. Odour concentration results are expressed in European odour units per cubic metre ($ou_E\ m^{-3}$), which equates to the number of dilutions to the detection threshold. The odour concentration of an undiluted sample which is at threshold level is 1 $ou_E\ m^{-3}$.

Air samples were collected through FEP sampling tubes with stainless steel fittings and collected in Nalophan-NA sample bags. The sample bags were fitted in "barrels" which were partially evacuated to provide the motive force (vacuum) to draw air from the ducts being sampled into the bags.

4. Results

4.1. The Odour concentration downwind of aircraft at the F1 holding position

Odour samples were collected from downwind of the holding position F1 of the emission from 5 planes. Concentrations ranged between 77 and 188 $ou_E m^{-3}$. These low concentrations should be compared with the background sample results in sect 4.4.

4.2. To assess the odour concentration of the exhaust from aircraft on the parking apron during pre-flight testing

A sample of exhaust from one Citation 500 plane on the apron was collected from about 35m behind the engines. The odour concentration of this sample was 5524 $ou_E m^{-3}$.

4.3. To assess the odour concentration of the exhaust from aircraft at the F1 holding position

As an alternative to working on the apron sampling equipment was set up at a position that was usually in the jet-stream of planes holding at F1. about 45 m from the line. Three samples were collected here. The odour concentration of the exhaust from an HS146 was 394$ou_E m^{-3}$ and the

sample collected simultaneously downwind of the aircraft was 127 $ou_E m^{-3}$ (compare with background sample sect 4.4)

The second sample, from in the jet-stream of a Global Express, collected from using the pump sampler had a concentration of 470 $ou_E m^{-3}$ and a sample from the same aircraft collected by opening the sample bag within the jet-stream had a concentration of 1,017$ou_E m^{-3}$. The jet-stream of a second Global Express was sampled by opening the sample bag within the jet-stream had a concentration of 389 $ou_E m^{-3}$.
A sample from the smaller jet Reg. N475M had a concentration of 128 $ou_E m^{-3}$.

4.4. Background odour samples

Two samples were collected on 5 June when the wind was from the north, the wind fetch included an area of airport grass, rough grazing and woodland. Odour concentrations measured were 89 $ou_E m^{-3}$ and 123 $ou_E m^{-3}$.

4.5. Hydrogen Sulphide measurements

We made measurements of the odour samples with a Hydrogen Sulphide analyser not for the concentration of H_2S but because the instrument has some cross sensitivity for hydrocarbons. Thus it can be seen that the raised H_2S concentrations of the samples from the Exhaust of Citation 500 on Apron, the Exhaust of HS146 at F1, the Exhaust of Global Express at F1, and the Exhaust of Global Express at F1 sampled by opening the bag contrast with the H_2S concentrations of the other samples collected down wind of the aircraft and the background samples.

5. Conclusions

Some useful guidance on the odour emission from jet aircraft has been gathered. However the methods of collection were very dependant on the wind direction and speed. A more robust method would be to collect directly from the engine exhaust in a test area at the engine loadings experienced during holding, taxiing and takeoff then to extrapolate, using dispersion modelling, the concentration at odour receptors.

Table 1 Results of odour sampling and other sampling data sampling

Sampling Time	Sample No.	Plane type or I/D and sampling position	Comments on sampling	Wind speed, knots	Odour concentration of the sample $ou_E\ m^{-3}$ (including pre-dilution)	H_2S ppm
Wednesday 3 June 2009						
09:12	20090604 F1	MWMWM at F1	50 metres downwind	7-8	102	0.006
09:12	20090604 100-1	100 metres from F1	150 metres from plane	5	65	0.002
10:13	20090604 F2	Twin turbo at F1	50 metres downwind	7	119	0.002
10:20	20090604 F3	Lear 60 at F1	50 metres downwind	7	188	0.003
10:20	20090604 100-2	100 metres from F1	150 metres from plane	6-8	115	0.003
10:25	20090604 F4	Lear 60 at F1	50 metres downwind	6-8	188	0.002
10:44	20090604 F5	Cherokee at F1	Piston engine, 50 metres downwind	6-8	77	0.003
11:53	20090604 F6	Exhaust of Citation 500 on Apron	35metres behind aircraft	6-8	5,524	0.013
Thursday 4 June 2009						
8:56	20090605 F1	Exhaust of HS146 at F1	45m behind plane	4-6	394	0.009
8:57	20090605 F2	Downwind of HS146 at F1	At F1 sign	light	127	0.002
12:50	20090605 F3	Exhaust of Global Express at F1	Pumped sample	light	470	0.013
12:52	20090605 F5	Exhaust of Global Express at F1	Sampled by opening the bag	light	1,017	0.026
12:20	20090605 Blank1	Back ground	Wind from North	light	89	
12:25	20090605 Blank2	Back ground	Wind from North	light	123	
14:30	20090605 F6	Exhaust of Global Express at F1	Sampled by opening the bag	light	389	0.001
14:40	20090605 F7	Exhaust of N475M at F1	Pumped sample	light	128	0.001

Olfactometric measurements for: ARUP; Farnborough on 04, 05 June 2009

UKAS TESTING 0609

6. Appendix 1 Olfactometric measurements

Contract Report Number:	CR/SO410/09/ARUP001
Customer Reference:	
Measurements carried out by:	L. McCartney, G. Liddle
1. Contact:	M. Ireland ARUP, 13 Fitzroy Street, London, W12 4BQ Tel: 020 7755 2782 Fax: 020 7755 2451
2. Odour source:	Airport
3. Sampler: *	R.W. Sneath
4. Sampling date: *	03, 04 June 2009
5. Laboratory Temperature and CO_2	23.3^{o}C, 616 ppm
6. Measurement date:	04, 05 June 2009
7. Presentation mode:	Forced choice
8. Olfactometer:	Project Research n6. Serial number OLF-N6-J-A
9. Pre-Dilution Gas Meter:	Kimmon Model SK25 Ser No 0003171
10. Reference odorant/accepted reference value	n-butanol. 60 ppm/ 40ppb
11. Calibration Status of Laboratory	Accuracy, A_{od} 0.308
12. Method:	Following Odour Lab Procedure OL1 which incorporates BSEN13725 "Air quality – Determination of odour concentration measurement by dynamic olfactometry".
13. Special remarks:	None
14. Approved by	Compiled by

R W Sneath

R.W. Sneath

Head of Laboratory.

L. McCartney

Manager of Laboratory

"This laboratory is accredited in accordance with the recognised International Standard ISO/IEC 17025:2005. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer joint ISO-ILAC-IAF communiqué dated 18 June 2005)"

Results:

Table 1: Results of odour measurements on 4 and 5 June 2009

Analysis Time	Sample No.	Sample Source and Position	Odour Panel Threshold $ou_E\ m^{-3}$	Pre-dilution	Odour concentration of the sample $ou_E\ m^{-3}$ (including pre-dilution)	H_2S
09:12	20090604 100-1	100 metres from F1	65	none	65	0.002
09:30	20090604 100-2	100 metres from F1	115	none	115	0.003
09:41	20090604 F1	MWMWM at F1	102	none	102	0.006
09:56	20090604 F2	Twin turbo at F1	119	none	119	0.002
10:13	20090604 F3	Lear 60 at F1	188	none	188	0.003
10:26	20090604 F4	Lear 60 at F1	188	none	188	0.002
10:33	20090604 F5	Cherokee at F1	77	none	77	0.003
10:50	20090604 F6	Exhaust of Citation 500 on Apron	5,524	none	5,524	0.013
09:02	20090605 Blank1		89	none	89	
09:16	20090605 Blank2		123	none	123	
10:32	20090605 F1	Exhaust of HS146 at F1	394	none	394	0.009
10:22	20090605 F2	Downwind of HS146 at F1	127	none	127	0.002
10:07	20090605 F3	Exhaust of Global Express at F1	470	none	470	0.013
10:44	20090605 F5	Exhaust of Global Express at F1	1,017	none	1,017	0.026
09:51	20090605 F6	Exhaust of Global Express at F1	389	none	389	0.001
09:35	20090605 F7	Exhaust of N475M at F1	128	none	128	0.001

Deviation from the standard

None.

<u>The following data is not covered by our UKAS Accreditation</u>

Appendix B

Hydrocarbon Model Results

B1 Hydrocarbon Model Results

Appendix B1 provides further information on the results of the hydrocarbon modelling. Figure B1.1 and Figure B1.2 show contour plots for total hydrocarbon annual mean concentrations and total hydrocarbon maximum modelled 1 hour concentrations.

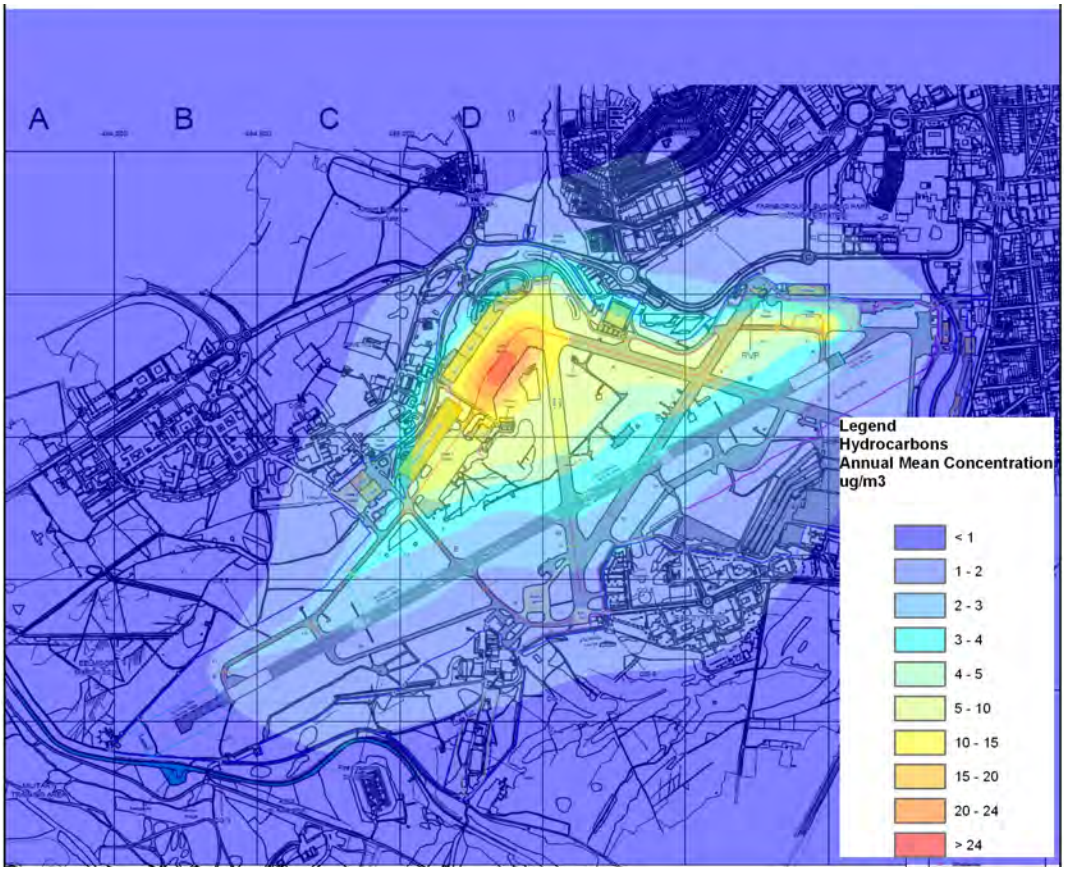

Figure B1.1: Modelled Annual Mean Concentration of Hydrocarbons (µg/m^3)

Figures B1.1 shows that elevated annual mean concentrations of hydrocarbons are restricted to areas within the airport, predominantly around the aircraft stand area, taxiways and take-off waiting area for runway 24.

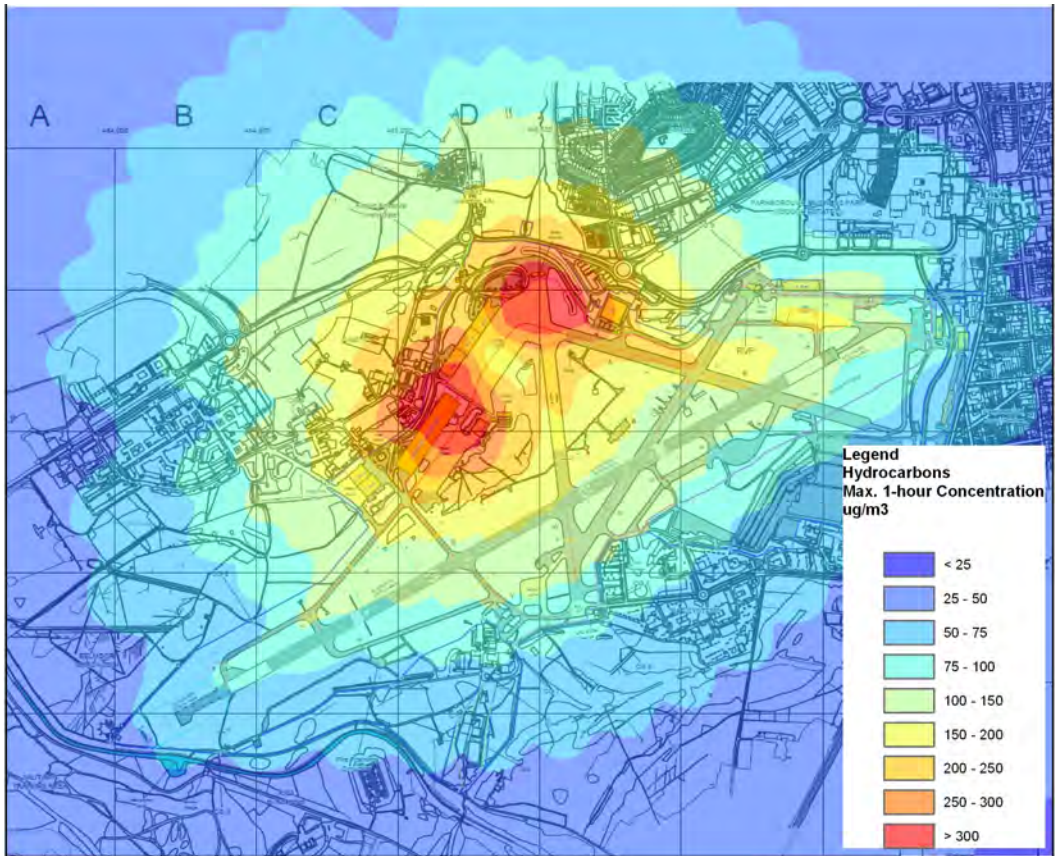

Figure B1.2: Maximum Modelled 1-hour Concentrations of Hydrocarbons (µg/m^3)

Figure B1.2 shows the extent of maximum modelled 1-hour concentrations. As for annual mean concentrations, highest hydrocarbon concentrations are restricted to an area within the airport boundary. However, there are locations outside the airport (Kempton Court) that appear to experience elevated levels of hydrocarbons.

Tables B1.1 to B1.5 show calculated concentrations of specific hydrocarbons and their Environmental Assessment Level (EAL) where available.

Table B1.1: Results of Modelling Acetaldehyde

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	32	0.3
Maitland Road	9	0.1
Ively Road	30	0.2
Pinehurst Avenue	11	0.1
Pinehurst Cottages	10	0.1
Albert Road	9	0.1
Guildford Rd West	10	0.1
College of Technolog	9	0.1
F1	11	0.2
100m from F1	10	0.1
Tenax Tube 001	38	1.5
Environmental Assessment Level	**9200**	**370**

Table B1.2: Results of Modelling Benzene

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	20	0.2
Maitland Road	6	0.1
Ively Road	19	0.1
Pinehurst Avenue	7	0.1
Pinehurst Cottages	7	0.1
Albert Road	6	0.1
Guildford Rd West	6	0.1
College of Technolog	6	0.1
F1	7	0.1
100m from F1	6	0.1
Tenax Tube 001	24	0.9
Environmental Assessment Level	**208**	**16.25**

Table B1.3: Results of Modelling Ethene

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	116	1.2
Maitland Road	34	0.4
Ively Road	108	0.6
Pinehurst Avenue	39	0.5
Pinehurst Cottages	37	0.4
Albert Road	33	0.4
Guildford Rd West	35	0.4
College of Technolog	32	0.5
F1	39	0.7
100m from F1	37	0.4
Tenax Tube 001	136	5.4
Environmental Assessment Level	**n/a**	**n/a**

Table B1.4: Results of Modelling Styrene

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	0.4	0.04
Maitland Road	0.2	0.01
Ively Road	0.2	0.02
Pinehurst Avenue	0.2	0.01
Pinehurst Cottages	0.1	0.01
Albert Road	0.1	0.01
Guildford Rd West	0.1	0.01
College of Technolog	0.2	0.02
F1	0.3	0.02
100m from F1	0.2	0.01
Tenax Tube 001	1.9	0.17
Environmental Assessment Level	**800**	**800**

Table B1.5: Results of Modelling Naphtalene

Receptor	Concentration (µg/m^3)	
	1-hour	Annual mean
Kempton Court	0.4	0.04
Maitland Road	0.2	0.01
Ively Road	0.2	0.02
Pinehurst Avenue	0.2	0.01
Pinehurst Cottages	0.1	0.01
Albert Road	0.1	0.01
Guildford Rd West	0.1	0.01
College of Technolog	0.2	0.02
F1	0.3	0.02
100m from F1	0.2	0.01
Tenax Tube 001	1.9	0.17
Environmental Assessment Level	**8000**	**530**

The results presented in Tables B1.1 to B1.5 show that the EAL values are met at all assessed receptor locations.