Heathrow Airport 2016 Emission Inventory

Report for Heathrow Airport Limited

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Glossary

APU	Auxiliary Power Unit
CAEP	Committee on Aviation Environmental Protection
EFPS	Electronic Flight Processing Strips
ICAO	International Civil Aviation Organisation
LTO	Landing and Take-Off
mppa	million passengers per annum
NATS	National Air Traffic Services
NTK	Noise and Track-Keeping
nvPM	non-volatile particulate matter
OPR	Overall Pressure Ratio
OSI	Operational Safety Instruction

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1 Introduction

This report presents the results of an air quality emission study of Heathrow Airport for the year 2016, concentrating on aircraft related emissions. It is the latest in a series of annual updates, which are based on the methodology for a study of the 12-month period April 2008 to March 2009. The 2008/9 study included an emission inventory[i], a dispersion modelling study[ii] and a model evaluation study[iii], which compared model results with measured concentrations. For 2013 there was a thorough update of the inventory and dispersion modelling[iv] and a new model evaluation study[v]. Subsequent annual updates for the calendar years 2014[vi] AND 2015[vii] have included specific components of the HAL 2013 emission inventory.

1.1 Aircraft and APU emissions

The motivation for the updates is that total aircraft emissions from the airport will change from one twelve-month period to another. There are a variety of reasons for this, and it is useful to identify two components to the overall change:

a) The change in the number of movements of aircraft of various types
b) The change in the operational parameters (times-in-mode, thrust settings etc.) applicable to aircraft of a given type

Changes to times-in-mode might arise, for example, as a result of infrastructure changes on the airport affecting taxiing routes. Changes in thrust might arise, for example, as a result of a systematic change in load factors or in the distribution of destinations served by a given aircraft type.

It is judged that variations of type "b" above will be modest on the timescale of a few years unless the airport undergoes a major reorganisation, although average parameters may drift slowly over a period of several years. Thus, two timescales can be considered in the process of annual updating of the aircraft emission inventory: aircraft movement and fleet mix data are updated on an annual basis to refer to the actual set of flights that used the airport in the relevant year, whereas operational parameters (e.g. taxiing time by aircraft type) are updated on a longer timescale. This concept is applied here to generate the 2016 calendar year aircraft emissions inventory by retaining operational parameters derived from data for 2013 but updating the aircraft movement and fleet mix data.

However, for this update, data on taxi and hold times, derived from the electronic flight processing strips (EFPS) used by controllers, were available for 2016. These data have been analysed and the effects on the calculated emissions determined. Results using previous (2013), suitably averaged, taxi and hold times are presented as an alternative estimate to the main results.

For APUs, new observations of running times were made during 2016; the new APU data have been analysed and the effects on the calculated emissions determined. Results using previous (2013) APU data are presented as an alternative estimate to the main results.

The main results constitute an enhanced annual update and the alternative estimates a more basic update. A full update would include the following:

- Updated times-in-mode for take-off roll, initial climb, climb-out, approach and landing roll
- Updated thrust settings for take-off roll, initial climb and climb-out
- Updated reverse thrust settings for landing roll
- Updated climb and approach profiles
- Inclusion of reduced-engine taxiing in the modelling
- Updated source data for other airport sources:
    - Ground Support Equipment
    - Heating Plant
    - Car Parks
- Updated source data for off airport sources:
    - Landside Roads

Such a comprehensive update to the modelling would require updated data on the elements such as times-in-mode, use of reduced-engine taxiing, etc., potentially from surveys. The updated climb and approach profiles would be derived from records of radar-based track data (i.e. from the noise and track-keeping (NTK) data).

The details of the methodology for quantifying aircraft emissions have been given in the report quoted earlier[i], and are not discussed further in this report.

1.2 Reduced-engine taxi

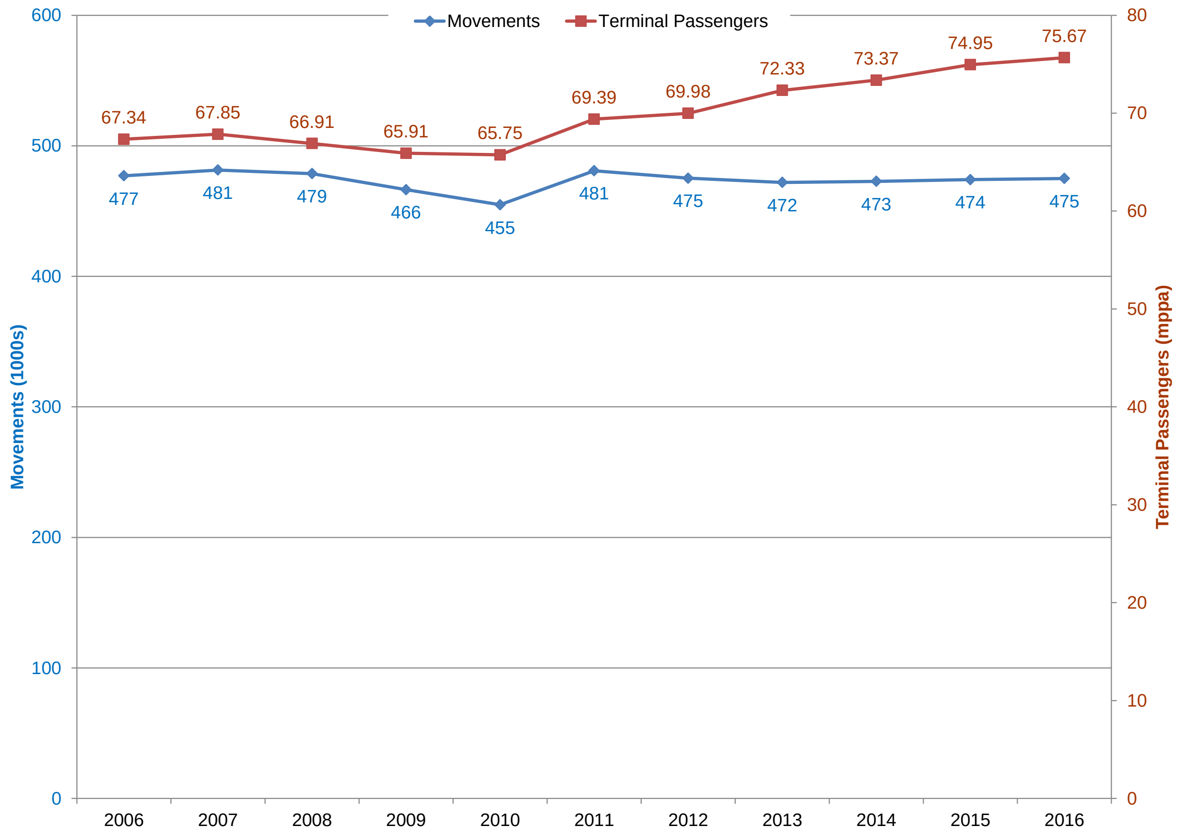
Heathrow have started to record the use of reduced-engine taxiing. However, they do not record the duration of its use nor the associated APU use off-stand. Although not included in the main inventory, alternative results are presented that take account of reduced-engine taxiing, albeit making assumptions regarding the duration of its use and the associated APU use off-stand.

2 Input data

2.1 Movements and passenger numbers

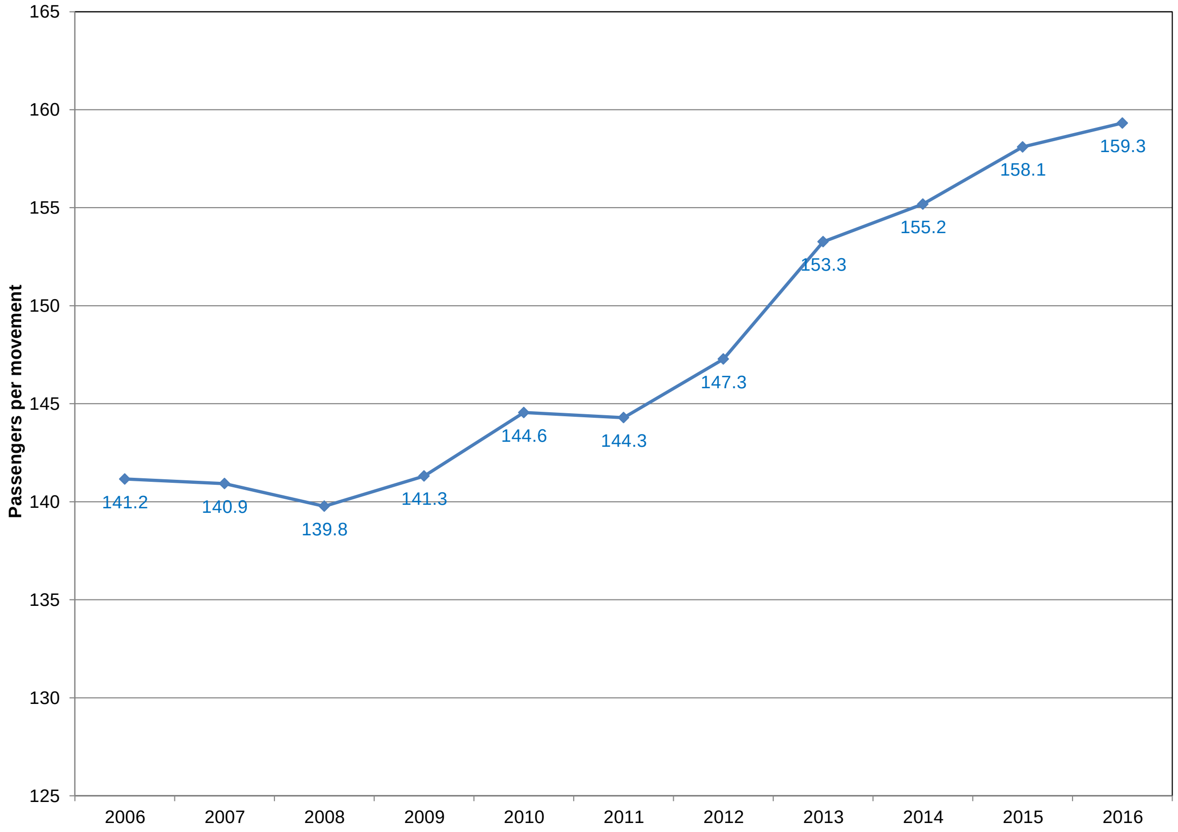
Figure 1 shows the trend in the number of aircraft movements and passengers over the last ten years. The number of aircraft movements has remained broadly constant, reflecting the fact that the airport is operating close to maximum capacity. However, the number of passengers has risen steadily over the period, accommodated by a larger number of passengers per movement on average (Figure 2).

Figure 1 Aircraft movement[1] and passenger numbers[2]



[1] ATMs and non-ATMs
[2] Terminal passengers

Figure 2 Average number of passengers[1] per movement[2]



[1] Terminal passengers
[2] ATMs and non-ATMs

2.2 Aircraft data

Aircraft movement data for the calendar year 2016 were provided by Heathrow Airport as an extract from their BOSS (Business Objective Search System) database. For each aircraft movement in the 2016 period, the following data fields are used in the emissions inventory:

- aircraft registration number (which allows an engine type to be assigned to the movement)
- flight date and time (which allows effects of meteorological parameters on emissions to be calculated)
- runway identifier and whether arrival and departure
- stand number (with the last two items used to determine taxiing and other times-in-mode)

The inventory includes emissions from non-ATMs (non-Air Transport Movements) – for example, positioning movements and private flights. The original 2008/9 study did not include non-ATMs, but the 2009 annual update report[viii] includes 2008/9 emissions recalculated to include non-ATMs, so that the results can be compared on a like-for-like basis.

Table 1 gives a breakdown of the movements by aircraft type alongside the equivalent breakdown for 2013, 2014 and 2015. The annual increase in movements seen in 2016 was 884. This represents a growth of 0.2% (from 474,094 in 2015 to 474,978 in 2016), which is less than half the growth seen in both 2014 and 2015, reflecting the fact that the airport in nearing its agreed capacity in terms of annual movements. The annual growth in passenger seen in 2016 was 1.0% (from 74.95 mppa in 2015 to 75.67 mppa in 2016).

Figure 3 shows the trend in the number of aircraft movements broken down by aircraft type.

There have been some significant changes in the fleet mix from 2015 to 2016. The B787 increased its share from 3.3% of the movements (15,601) in 2015 to 5.8% of the movements (27,591) in 2016. This seems to have been partially at the expense of the B747, whose share has reduced from 5.4%

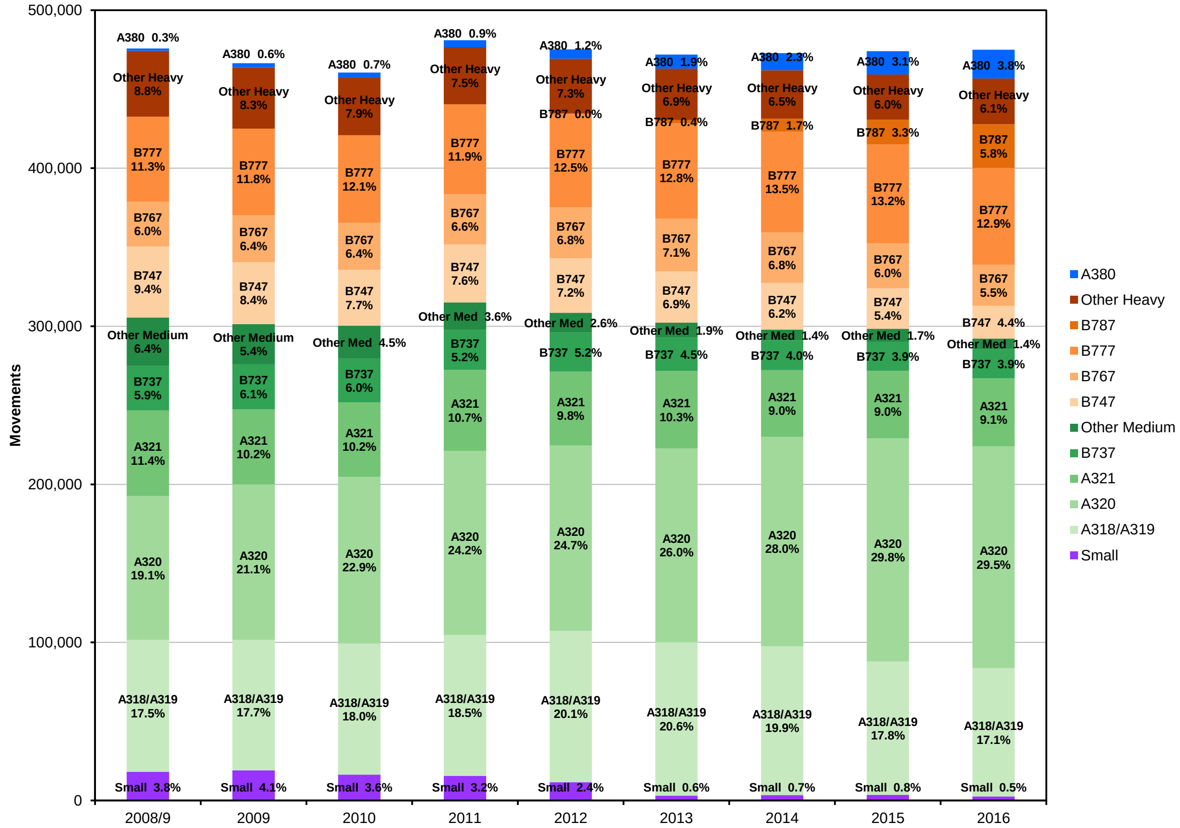
(25,662 movements) in 2015 to 4.4% (20,668 movements) in 2016. The A380 has also seen a significant increase in its share from 3.1% (14,826 movements) in 2015 to 3.8% (18,265 movements) in 2016. Conversely, the A318/A319 group and the B767 have seen significant decreases in their shares from 17.8% (84,352 movements) and 6.0% (28,342 movements) in 2015, respectively, to 17.1% (81,196 movements) and 5.5% (25,949 movements) in 2016, respectively.

Table 1 Aircraft movements[1] by aircraft type: comparison of 2016 with 2013, 2014 and 2015

Aircraft Type	2013	2014	2015	2016	Change (%)		
					2013[a]	2014[b]	2015[c]
Small	3,050	3,415	3,562	2,510	−17.7	−26.5	−29.5
Medium	299,207	294,428	294,837	289,768	−3.2	−1.6	−1.7
A318/A319	97,108	94,057	84,352	81,196	−16.4	−13.7	−3.7
A320	122,638	132,490	141,169	140,303	14.4	5.9	−0.6
A321	48,837	42,324	42,765	43,040	−11.9	1.7	0.6
B737	21,459	18,898	18,376	18,712	−12.8	−1.0	1.8
Others	9,165	6,659	8,175	6,517	−28.9	−2.1	−20.3
Heavy	160,750	164,161	160,869	164,435	2.3	0.2	2.2
B747	32,378	29,510	25,662	20,668	−36.2	−30.0	−19.5
B767	33,322	31,990	28,342	25,949	−22.1	−18.9	−8.4
B777	60,542	63,774	62,611	61,241	1.2	−4.0	−2.2
B787	2,012	8,134	15,601	27,591	1271.3	239.2	76.9
Other	32,496	30,753	28,653	28,986	−10.8	−5.7	1.2
A380	8,931	10,813	14,826	18,265	104.5	68.9	23.2
Total	471,938	472,817	474,094	474,978	0.6	0.5	0.2

[1] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Figure 3 Number of movements[1] by aircraft type: 2008/9 to 2016



[1] ATMs and non-ATMs

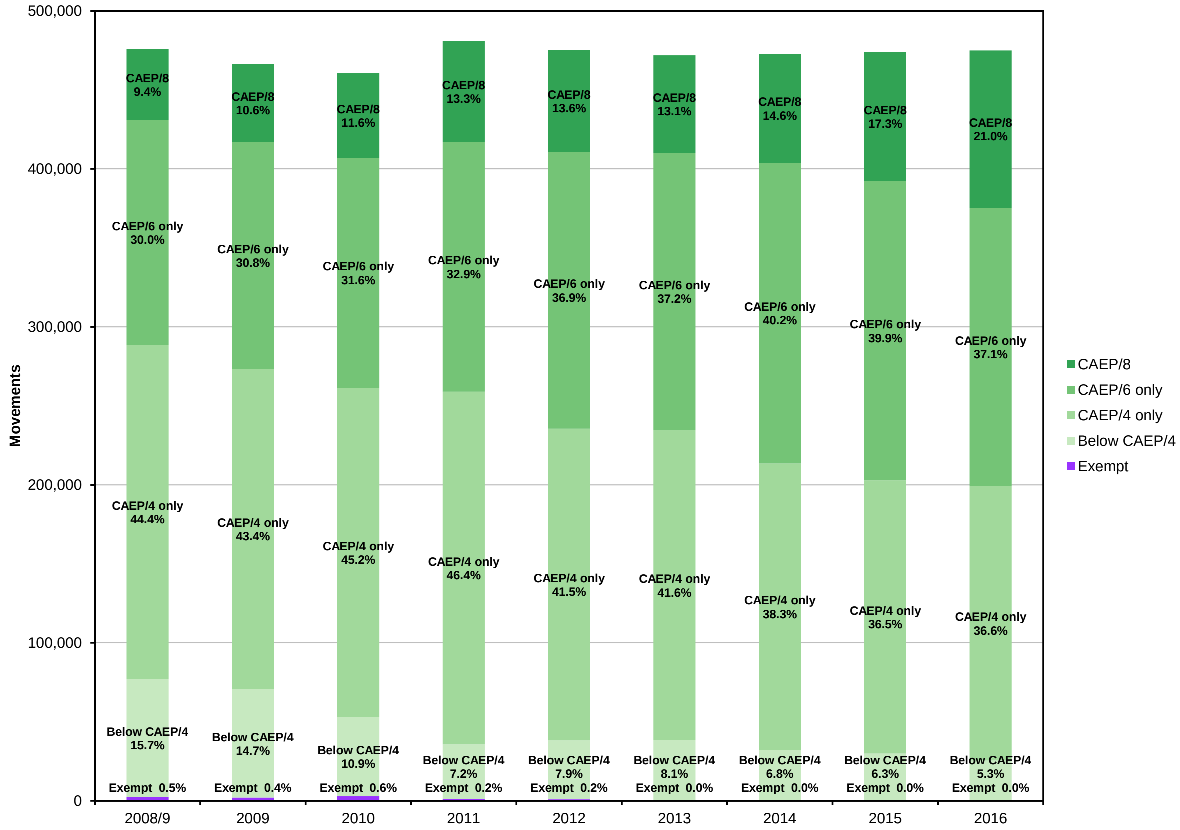
2.3 Engine assignment

Aircraft engine assignments have been taken directly from the airlines via Heathrow's AWUR database.

Prior to 2014 the inventories took aircraft engine assignments from JP Airline Fleets. However, for 2012 and 2013 this introduced a problem with certain engines (CFM56-5B1 to CFM56-5B9, GEnx-1B64 and GEnx-1B70) as their precise combustor variants were no longer reported. This led to the fraction of engines meeting the CAEP/8 emission standard being overestimated.

Figure 4 shows the trend in the number of movements by aircraft meeting the various CAEP emission standards. The values for 2012 and 2013 have been revised, in line with Heathrow's AWUR database, from those reported in the 2013 study[iv].

Figure 4 Total movements[1] by CAEP standard[2]



[1] ATMs and non-ATMs
[2] "CAEP/4 only" means engines that meet the CAEP/4 standard but **not** the CAEP/6 standard. Similarly, "CAEP/6 only" means engines that meet the CAEP/6 standard but **not** the CAEP/8 standard.

These results show a continuing trend of an increasing number of aircraft that meet the most recent CAEP NO_x standards (CAEP/6 and CAEP/8) and a reducing number of aircraft that fail to meet the older standard (CAEP/4). This is the natural result of normal fleet replacement as more modern aircraft are more likely to meet the latest standards. (All newly manufactured engines since 01 January 2013 must comply with the CAEP/6 standard, while all new engines types since 01 January 2014 must comply with the CAEP/8 standard.)

2.4 APU running times

The APU running times for this 2016 emission inventory update are derived from new observations of running times made during 2016. The new APU data were supplied by Heathrow Airport in the same form as that provided for previous inventories since 2013. These data have been analysed using the same methodology as used in the previous work to extract average running times on arrival and on departure, for narrow and wide-bodied aircraft types. The Airbus A380 was analysed separately from other wide-bodied aircraft as its APU is generally run for longer and the number of APU running times recorded were significant enough to warrant separate analysis. (Heathrow's Operational Safety Instruction "OSI/21/11" allows for longer running times for the A380 compared with other wide-bodied aircraft.)

The 2013 inventory only considered APU use on-stand. However, if aircraft operate using reduced-engine taxi, they usually keep their APUs running during taxiing. At the time of the 2013 inventory no data were available regarding the deployment of reduced-engine taxi at Heathrow, so it was not considered in the inventory. However, anecdotal information now indicates that single- (or reduced-) engine taxiing is widely used during taxi-in after landing and is beginning to be used more widely during taxi-out for take-off. The inclusion of reduced-engine taxiing in the modelling, based on information on its frequency of use from surveys of airlines, would be a useful enhancement to the analysis.

To remain consistent with previous annual updates (where only aircraft movement data were updated), APU running times taken from the 2013 assessment have been used to generate 'alternative' inventories.

The results presented make comparisons with the emissions calculated using the 'alternative' APU running times, allowing the effect on emissions of updating the times to be quantified.

Table 2 shows the APU running times derived from data for the year 2013 to 2016.

The 2016 data suggest that total running times for narrow-bodied aircraft are about 42% higher than for the previous year and that total running times for wide-bodied aircraft, excluding the A380, are about 41% higher than for the previous year. Conversely, the 2016 data suggest that total running times for the A380 are about 26% lower than for the previous year. The increase in APU running time seen for narrow-bodied and wide-bodied aircraft (excluding the A380) is likely to relate to issues with PCA use in 2016. Whereas the reduced running times for the A380 are more likely to be an artefact of the small sample size.

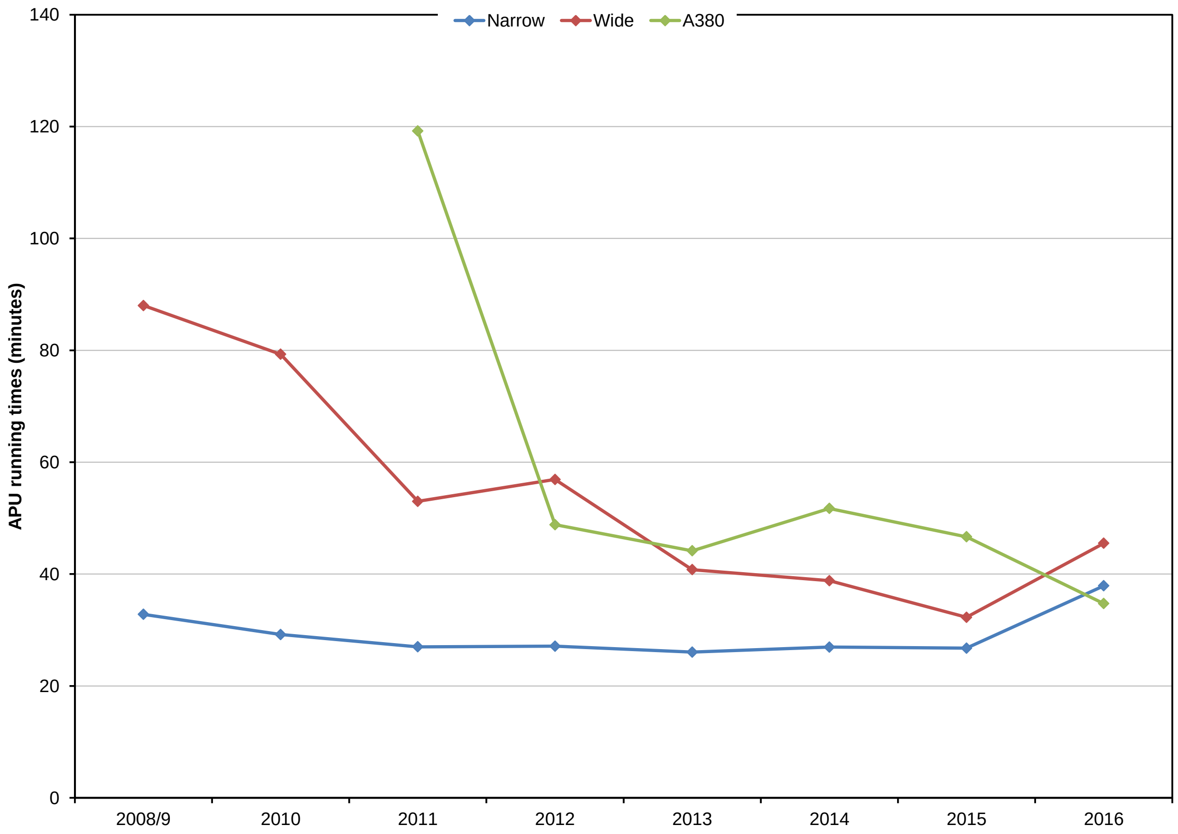
Figure 5 shows the trend in the APU running times since 2008/9. There is clearly a downward trend for wide-bodied aircraft. However APU running times for narrow-bodied aircraft have remained more or less constant over the last five years. For narrow-bodied aircraft, 2016 stands clearly above the long-term trend, which had been relatively constant. Prior to 2016, times for wide-bodied aircraft had been on a downward trend, but for 2016, now show a significant increase.

Table 2 APU running times: comparison of 2016 with 2013, 2014 and 2015

		APU running time (minutes)				Change from (%)		
		2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Narrow-bodied	Arrival	6.7	6.8	6.9	11.1	65.6	62.4	61.3
	Departure	19.4	20.1	19.9	26.8	38.5	33.2	34.8
	Total	26.1	26.9	26.8	37.9	45.5	40.6	41.6
Wide-bodied	Arrival	12.0	8.9	8.2	15.4	28.1	71.8	86.8
	Departure	28.8	29.9	24.0	30.1	4.7	0.9	25.4
	Total	40.8	38.8	32.3	45.5	11.5	17.2	41.0
A380	Arrival	18.2	11.9	11.2	16.1	−11.6	35.5	43.8
	Departure	26.0	39.9	35.5	18.7	−28.2	−53.2	−47.4
	Total	44.2	51.7	46.7	34.7	−21.4	−32.9	−25.6

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Figure 5 APU running times



2.5 Taxi and hold times

The taxi and hold times for this 2016 emission inventory update are taken from data, for 2016, extracted from a NATS database that is populated using electronic flight processing strips (EFPS).

For departures, the EFPS database records time of pushback, time at hold, and actual time of departure, to 1 second precision[1]. It therefore includes times for hold, line-up and pilot reaction as well as taxi-out, and these have also been incorporated. For arrivals, it records actual time of arrival and time on-stand, again to 1 second precision; taxi-in times were obtained by subtracting landing roll times.

It was possible to match 99% of departures with an EFPS record so that they had individual taxi-out and hold times, and similarly for 99% of arrivals. For the other movements which could not be matched, times were taken from tables of times by runway/apron combination derived by averaging the EFPS data.

To remain consistent with previous annual updates (where only aircraft movement data were updated), average taxi and hold times taken from the 2013 assessment have been used to generate 'alternative' inventories.

The results presented make comparisons with the emissions calculated using the 'alternative' taxi and hold times, allowing the effect on emissions of updating the times to be quantified.

Table 3 show taxi-in times derived from data for the years 2013 to 2016, by runway and terminal. Table 4 and Table 5 show similar data for taxi-out and hold respectively. Table 6 shows that overall, the 2016 taxi and hold times are very similar to the 2013, 2014 and 2015 times. However, there is considerable variation in the differences between runway and terminal pairings.

[1] The EFPS system records the time when controllers react to an observation or perform an action, so times are not necessarily *accurate* to 1 second.

Table 3 Aircraft taxi-in times: comparison of 2016 with 2013, 2014 and 2015

Runway	Terminal	Taxi-in (s)				Change from (%)		
		2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
09L	T1	256	253	246	289	12.9	14.3	17.4
09L	T2	327	406	435	407	24.4	0.1	−6.4
09L	T3	389	399	407	419	7.8	5.1	3.1
09L	T4	732	722	718	694	−5.1	−3.8	−3.3
09L	T5	493	493	478	456	−7.5	−7.6	−4.5
09L	Cargo	669	667	687	670	0.2	0.4	−2.4
09R	T1	517	397	431	460	−11.0	15.9	6.8
09R	T2	471	315	306	308	−34.7	−2.3	0.6
09R	T3	383	395	409	417	8.9	5.6	1.9
09R	T4	291	289	268	262	−9.9	−9.2	−2.0
09R	T5	639	586	582	578	−9.6	−1.4	−0.7
09R	Cargo	307	306	318	260	−15.3	−15.1	−18.1
27L	T1	484	486	499	563	16.2	15.8	12.8
27L	T2	576	411	367	339	−41.1	−17.6	−7.5
27L	T3	328	329	323	350	6.7	6.4	8.4
27L	T4	398	398	359	345	−13.2	−13.3	−3.8
27L	T5	423	430	424	447	5.7	3.9	5.4
27L	Cargo	223	221	200	185	−17.1	−16.5	−7.7
27R	T1	272	273	285	355	30.4	29.9	24.5
27R	T2	402	494	521	498	23.9	0.9	−4.4
27R	T3	329	339	369	389	18.3	14.7	5.6
27R	T4	719	728	734	764	6.2	5.0	4.0
27R	T5	428	423	403	424	−0.9	0.4	5.2
27R	Cargo	667	654	667	640	−4.1	−2.2	−4.1

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 4 Aircraft taxi-out times: comparison of 2016 with 2013, 2014 and 2015

Runway	Terminal	Taxi-out (s)				Change from (%)		
		2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
09L	T1	734	681	518	N/A[1]	N/A[1]	N/A[1]	N/A[1]
09L	T2	907	848	845	734	−19.1	−13.4	−13.1
09L	T3	840	714	712	747	−11.0	4.6	5.0
09L	T4	874	871	935	723	−17.2	−17.0	−22.7
09L	T5	628	558	637	607	−3.3	8.7	−4.7
09L	Cargo	854	681	763	606	−29.0	−11.0	−20.6
09R	T1	717	719	803	913	27.4	27.1	13.7
09R	T2	853	658	604	638	−25.2	−3.0	5.7
09R	T3	608	592	609	642	5.6	8.5	5.5
09R	T4	619	604	596	614	−0.8	1.7	3.0
09R	T5	508	503	530	527	3.7	4.6	−0.6
09R	Cargo	572	562	541	536	−6.3	−4.7	−0.9
27L	T1	544	541	577	629	15.7	16.3	9.0
27L	T2	573	485	463	458	−20.1	−5.7	−1.1
27L	T3	634	622	661	676	6.6	8.7	2.2
27L	T4	519	531	544	556	7.0	4.7	2.1
27L	T5	751	765	815	832	10.8	8.9	2.1
27L	Cargo	743	719	656	703	−5.3	−2.1	7.2
27R	T1	455	460	519	554	21.7	20.4	6.7
27R	T2	526	565	568	563	7.1	−0.3	−0.8
27R	T3	702	713	747	726	3.5	1.9	−2.8
27R	T4	512	516	513	504	−1.6	−2.4	−1.7
27R	T5	786	826	852	779	−0.9	−5.7	−8.6
27R	Cargo	785	718	678	644	−18.0	−10.3	−5.1

[1] There were no departures from T1 using 09L in 2016
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 5 Aircraft hold times: comparison of 2016 with 2013, 2014 and 2015

Runway	Terminal	Hold[1] (s)				Change from (%)		
		2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
09L	T1	722	480	113	N/A	N/A	N/A	N/A
09L	T2	819	458	589	421	−48.6	−8.2	−28.6
09L	T3	817	655	546	350	−57.1	−46.5	−35.8
09L	T4	1109	638	806	753	−32.1	18.0	−6.6
09L	T5	765	559	670	419	−45.2	−25.1	−37.4
09L	Cargo	830	473	674	1015	22.3	114.7	50.7
09R	T1	605	628	631	666	10.2	6.1	5.6
09R	T2	642	646	642	665	3.6	2.9	3.5
09R	T3	668	687	697	713	6.8	3.9	2.4
09R	T4	666	660	676	704	5.7	6.6	4.0
09R	T5	689	695	690	713	3.5	2.6	3.5
09R	Cargo	531	577	517	500	−5.8	−13.4	−3.3
27L	T1	569	589	595	654	15.0	11.1	9.9
27L	T2	593	578	554	593	0.1	2.7	7.1
27L	T3	609	627	621	653	7.2	4.0	5.0
27L	T4	558	554	553	577	3.3	4.1	4.3
27L	T5	584	604	591	618	5.9	2.4	4.6
27L	Cargo	484	559	551	505	4.3	−9.7	−8.4
27R	T1	532	541	539	587	10.4	8.5	9.0
27R	T2	555	527	537	589	6.1	11.7	9.5
27R	T3	587	575	579	631	7.4	9.7	8.9
27R	T4	801	802	828	881	10.0	9.9	6.3
27R	T5	560	561	560	620	10.8	10.7	10.8
27R	Cargo	807	746	748	758	−6.1	1.5	1.3

[1] Includes time for line-up and pilot reaction
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 6 Weighted average[1] taxi and hold times

Mode	2013	2014	2015	2016	Change from (%)		
					2013[a]	2014[b]	2015[c]
Taxi-In	443	447	438	439	−1.0	−1.9	0.2
Taxi-Out	649	640	661	655	0.9	2.4	−0.9
Hold[2]	603	615	614	650	7.8	5.7	5.9

[1] Derived from movements in 2016
[2] Includes time for line-up and pilot reaction
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

3 Taxiing emissions

3.1 Conventional taxiing

Taxiing is assigned a thrust setting of 7% in the standard ICAO LTO cycle. There has been evidence available for some years (e.g. the Loughborough study at Gatwick[ix]) that actual taxiing thrust settings are on average less than this. However, it was unclear how emission indices would behave at lower thrust settings. For the products of incomplete combustion, such as CO and HC, the emission indices (g pollutant per kg fuel burned) are likely to be higher for lower thrust settings, with the reverse likely to be true for NO_x; the position for Smoke Number and PM_{10} emission indices is unclear.

For taxi-out and for taxi-in on all engines, the PSDH recommended that idle thrust settings lower than 7% should be taken into account. FDR data compiled for the PSDH indicate that in most cases the ground-idle thrust setting used during most of taxiing and hold is around 5% except for aircraft fitted with Rolls Royce engines, for which 3% thrust is nearer the mark. Clearly, there will be brief periods of higher thrust (perhaps 10% to 15%) to get the aircraft rolling or to negotiate sharp turns, but superimposed on much longer periods at the ground idle setting, so the average thrust level will be significantly below 7%.

It is easier to estimate the impact of these lower thrust settings on fuel flow than on emission indices. Considering the available data as a whole, the PSDH recommended that fuel flow rates for engine types other than Rolls Royce be set 15% - 20% lower than the ICAO 7% value and for Rolls Royce engines be set 30% - 35% lower than the ICAO 7% value, and these recommendations were implemented for Heathrow by using the mid-point of the ranges, i.e. 17.5% and 32.5% respectively, with the values applied to all periods of taxiing and hold. The PSDH further recommended that the NO_x and PM_{10} emission indices at the lower fuel flow rate be held the same as the value at 7% thrust. As noted earlier, this is likely to yield a somewhat conservative estimate (i.e. overestimate) of taxiing NO_x emissions; current information[x], albeit more uncertain, suggests that this assumption is also likely to be conservative for PM_{10}. These recommendations have been applied to LHR inventories since 2008/9.

3.2 Reduced-engine taxi

Reduced-engine taxiing is the practice of shutting down an engine during taxi operations, which helps reduce fuel use, emissions, and noise. In theory, reductions of 20% to 40% of the ground level fuel burn and CO_2, and 10% to 30% of ground level NO_x emissions, may be realised dependant on aircraft type and operator technique[2].

The estimation of taxiing emissions is made potentially more complex by the practice of reduced-engine taxiing. At the time of the PSDH there were no robust statistical data on the practice at Heathrow, although the PSDH expert panel report estimated it was used for around 25% or less of arrivals. Reduced-engine taxiing for departures was not common practice at the time. In light of this, the PSDH report made no specific recommendation for taking account of reduced-engine taxiing on NO_x and PM emissions.

Since the publication of the PSDH report the practice of reduced-engine taxiing has become more widespread, due in part to the achieved fuel savings. Since the summer of 2014, Heathrow have recorded the use of reduced-engine taxiing for departures. During 2016 about 18% of departures used reduced-engine taxiing. The use of reduced-engine taxiing on arrival is expected to be more common than on departures. However, systems to record its use on arrival are not yet available at Heathrow or any other major airport, generally. Currently, Heathrow only record if reduced-engine taxiing is used on departure. They do not record the duration of its use or the associated APU use off-stand.

3.2.1 Taxi-out

In the assessment of reduced-engine taxiing we have assumed that aircraft using reduced-engine taxiing will operate on all engines for the final 2 to 3 minutes of taxi-out; this is to allow for the engines to fully warm-up prior to take-off. During reduced-engine taxiing we have assigned the standard ICAO thrust setting of 7%. We have also assumed that airlines will operate their APUs whilst taxiing using reduced engines. It is likely that the APU would be needed to provide on-board power to the aircraft and to start the remaining engine(s).

3.2.2 Taxi-in

Although reduced-engine taxiing was not recorded for arrivals, anecdotal evidence suggests its use on arrival is much more common than for departures. We have therefore extended the methodology to cover the arrivals corresponding to the reduce engine departures of the turnarounds (~18% of arrivals). We have conservatively assumed that aircraft using reduced-engine taxiing will operate on all engines for the first 2 to 3 minutes of taxi-in; this is to allow for engine cool-down and runway clearance. Anecdotal evidence suggests that pilots shut down one or more engines prior to 2 minutes after touch-down.

[2] http://www.sustainableaviation.co.uk/wp-content/uploads/2015/09/Departures-Code-of-Practice-June-2012.pdf

3.2.3 100% reduced engine taxi

We have included an additional sensitivity test, which assumes that reduced engine taxiing is used for all movements. This test is designed to estimate the potential reductions that are achievable from more widespread use of reduced engine taxiing.

4 Results

4.1 NO_x

Table 7 shows aircraft emissions broken down by mode (i.e. phase of the LTO cycle), using the same categories as in the 2008/9 inventory report and the subsequent annual updates. The 2016 values have been compared with equivalent reported values for 2013, 2014 and 2015. The calculated total aircraft NO_x emissions (up to 1000 m altitude) for 2016 are 2.0% higher than the equivalent value for 2015, for a 1.0% increase in the number of passengers.

All of this increase could be explained by the changes in times-in-mode (¾ of which is due to changes in APU running times and ¼ is due to changes in taxi and hold times). However, a further increase, of approximately 1 ½ percentage points, due principally to aircraft fleet changes is almost entirely offset by a similar sized reduction due to meteorological effects. 2016 had higher average humidity (which inhibits NO_x production) than 2015.

Table 7 Breakdown of aircraft NO_x emissions by mode: comparison of 2016 with 2013, 2014 and 2015

Mode	Annual NO_x emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Ground-level							
Landing roll	41.04	43.91	44.42	45.71	11.4	4.1	2.9
Taxi-in	153.51	163.60	163.51	162.24	5.7	−0.8	−0.8
Taxi-out	237.53	251.18	259.11	252.36	6.2	0.5	−2.6
Hold	225.63	235.80	234.50	246.16	9.1	4.4	5.0
Take-off roll	681.80	741.75	726.78	729.50	7.0	−1.7	0.4
APU	182.05	185.24	190.02	255.45	40.3	37.9	34.4
Engine testing[1]	2.80	2.80	2.80	2.80	0.0	0.0	0.0
Total ground-level	**1524.36**	**1624.28**	**1621.14**	**1694.21**	**11.1**	**4.3**	**4.5**
Elevated							
Approach	594.64	628.51	623.51	616.99	3.8	−1.8	−1.0
Initial climb	773.17	838.77	825.12	830.53	7.4	−1.0	0.7
Climb out	1393.60	1452.24	1427.51	1445.07	3.7	−0.5	1.2
Total elevated	**2761.41**	**2919.52**	**2876.14**	**2892.59**	**4.8**	**−0.9**	**0.6**
Total	**4285.76**	**4543.80**	**4497.28**	**4586.80**	**7.0**	**0.9**	**2.0**

[1] Engine testing emissions were not recalculated for 2016. However, they represent a small fraction of the total.
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 8 shows the values of annual aircraft LTO NO_x emissions normalised by the number of passengers and movements. The NO_x per passenger for 2016 is 1.0% higher than for 2015 and the NO_x per movement is 1.8% higher.

Table 8 LTO NO_x emissions per passenger and per movement: comparison of 2016 with 2013, 2014 and 2015

	2013	2014	2015	2016	Change from (%)		
					2013[a]	2014[b]	2015[c]
LTO NO_x (tonnes per year)	4285.76	4543.80	4497.28	4586.80	7.0	0.9	2.0
Passengers[1] (mppa)	72.33	73.37	74.95	75.67	4.6	3.1	1.0
LTO NO_x (g per passenger[1])	59.25	61.93	60.00	60.61	2.3	−2.1	1.0
Movements[2] (1000s)	471.94	472.80	474.09	474.96	0.6	0.5	0.2
LTO NO_x (kg per movement[2])	9.08	9.61	9.49	9.66	6.3	0.5	1.8

[1] Excludes transit passengers
[2] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

From a local air quality perspective, emissions from aircraft on the ground have a greater impact than elevated emissions. The calculated value of ground-level aircraft NO_x emissions (including APU emissions and engine testing emissions) for 2016 is 4.5% higher than the equivalent value for 2015, for a 0.2% increase in the total number of movements (1.0% increase in total number of passengers). Compared with 2015, the fractional range for the individual ground-level modes (excluding engine testing) shown in Table 7 vary from −2.6% (for Taxi out) to +34.4% (for APU). The variability reflects the changes in times-in-mode, particularly the increases in APU running times. Changes in the fleet will also affect the individual modes differently, as the emission rates vary with thrust settings.

Table 9 gives a breakdown of ground-level aircraft NO_x emissions (omitting APUs and engine testing) by aircraft type, comparing the distribution in 2016 with the equivalent distribution in 2015. As expected from the movement breakdowns in Table 1 the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction of the emissions in both years (24.5% in 2016 and 25.0% in 2015). However, the larger aircraft types, B747, B777 and A380, together contribute approximately half of the emissions in each period (50.7% in 2016 and 52.3% in 2015), despite accounting for less than a quarter of the total movements.

Table 9 also gives ground-level emissions per movement (excluding APU and engine testing emissions) for each aircraft type, comparing values for 2016 with those for 2015. There is variability in emissions from year-to-year, due to the changeable effects of ambient meteorological conditions. For a given aircraft type, the emissions per movement are also affected by changes to the distribution of sub-aircraft types and/or engine models, which have different emission characteristics. The table shows that the values of ground-level emissions per movement for the large aircraft types (B747 and B777) are around a factor of five higher than the average for A318/A319/A320/A321 or B737 aircraft. Of course, the larger types carry more passengers than the A320/B737 families, but only around twice as many passengers, so the NO_x per passenger ratio is roughly double that of the A320/B737 families. The reasons for this are well understood and result from two main causes:

- The larger aircraft types tend to be operated on long-haul rather than short-haul flights, so fuel comprises a much greater proportion of the aircraft take-off mass, requiring significantly higher take-off thrust (per passenger).
- Engine manufacturers have previously concentrated their efforts on fuel efficiency on larger engines (as fitted to these larger aircraft types) as, globally, they consume more fuel than the smaller types. A key technology for increasing fuel efficiency is the use of higher overall pressure ratios (OPR) and the CAEP standards allow engines with higher OPRs to emit more NO_x than those with lower OPRs (after normalising by the engine rated thrust).

Table 9 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type

Aircraft Type	2015			2016		
	NO_x (t/year)	%	NO_x (kg/mvt)	NO_x (t/year)	%	NO_x (kg/mvt)
Small	2.26	0.2	0.64	1.53	0.1	0.61
Medium	390.37	27.3	1.32	380.71	26.5	1.31
A318/A319	101.59	7.1	1.20	99.88	7.0	1.23
A320	181.23	12.7	1.28	176.98	12.3	1.26
A321	74.76	5.2	1.75	74.51	5.2	1.73
B737	20.51	1.4	1.12	19.96	1.4	1.07
Others	12.29	0.9	1.50	9.38	0.7	1.44
Heavy	892.11	62.5	5.55	878.66	61.2	5.34
B747	193.64	13.6	7.55	156.61	10.9	7.58
B767	88.07	6.2	3.11	76.94	5.4	2.96
B777	409.96	28.7	6.55	397.07	27.7	6.48
B787	56.76	4.0	3.64	109.96	7.7	3.99
Other	143.69	10.1	5.01	138.08	9.6	4.76
A380	143.57	10.1	9.68	175.07	12.2	9.58
Total	1428.32	100.0	3.01	1435.97	100.0	3.02

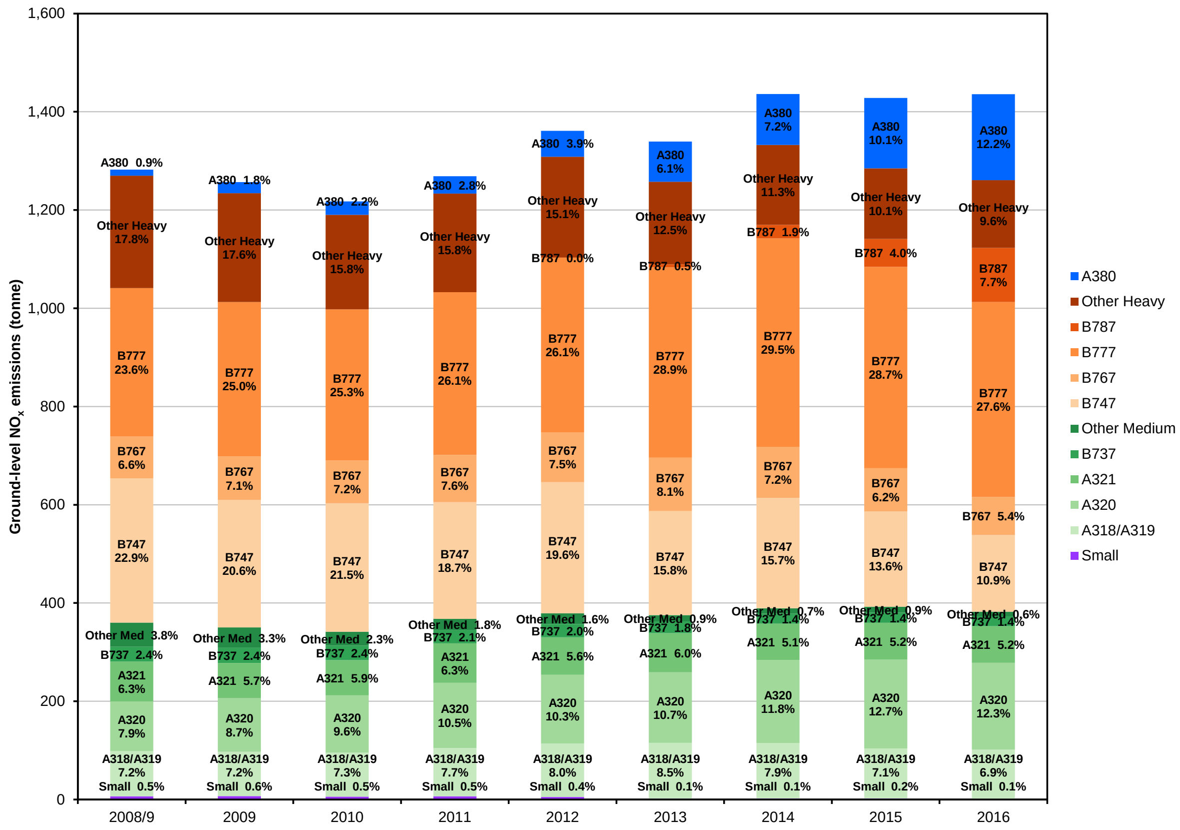
[1] Ground-level emissions from main engines only (omitting APU and engine testing)

Overall, the fleet-averaged value of ground-level aircraft NO_x emissions per movement, excluding APUs and engine testing, has risen by 0.3% between the 2015 inventory and the 2016 inventory, from 3.01 kg per movement in 2015 to 3.02 kg per movement in 2016.

Including APUs and engine testing, the increase from the 2015 inventory is 4.3%, from 3.42 kg per movement in 2015 to 3.57 kg per movement in 2016.

Figure 6 shows the trend in ground-level aircraft NO_x emissions broken down by aircraft type since 2008/9.

Figure 6 Breakdown of ground-level aircraft NO_x emissions[1] by aircraft type: 2008/9 to 2016



[1] Ground-level emissions from main engines only (omitting APU and engine testing)

4.1.1 Alternative operating times

Table 10 presents NO_x emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 operating times (APU running, taxi and hold), comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 operating times, so the differences between the analyses are restricted to the numbers of movements, the frequency of use of terminals and runways and the fleet mix). This table is the 'alternative' equivalent of Table 7. Table 10 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) were 0.4% higher in 2016 than in 2015 and ground-level aircraft emissions were 0.1% higher than in 2015.

For comparison using the specific year times, the whole LTO cycle emissions were 2.0% higher in 2016 than in 2015 and ground-level aircraft emissions were 4.5% higher than in 2015.

Table 10 Aircraft NO_x emissions using 'alternative' operating times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 operating times)

Mode	Annual NO_x emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	153.51	159.61	161.92	159.29	3.8	−0.2	−1.6
Taxi-out	237.53	242.53	244.33	240.96	1.4	−0.6	−1.4
Hold	225.63	225.52	229.41	222.90	−1.2	−1.2	−2.8
APU	182.05	187.00	211.63	221.43	21.6	18.4	4.6
Ground-level	1524.36	1603.12	1621.29	1622.59	6.4	1.2	0.1
Total aircraft LTO	4285.76	4522.64	4497.43	4515.18	5.4	−0.2	0.4

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 11 compares the two methodologies, showing emissions calculated for the 2016 aircraft movements using the 'alternative' 2013 operating times (refer to Table 10) and using the 2014, 2015 and 2016 operating times (refer to Table 7).

Table 11 Aircraft NO_x emissions – 2016: comparison of emissions calculated using 2016 operating times with those calculated using 2013, 2014 and 2015 operating times

Mode	2016 NO_x emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	159.29	161.07	157.50	162.24	1.9	0.7	3.0
Taxi-out	240.96	240.67	248.50	252.36	4.7	4.9	1.6
Hold	222.90	228.08	227.97	246.16	10.4	7.9	8.0
APU	221.43	225.96	199.78	255.45	15.4	13.1	27.9
Ground-level	1622.59	1633.79	1611.77	1694.21	4.4	3.7	5.1
Total aircraft LTO	4515.18	4526.38	4504.36	4586.80	1.6	1.3	1.8

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Results for the 'alternative' 2013 APU running and taxi and hold times are presented individually in the appendix.

4.1.2 Reduced-engine taxi

Table 12 presents NO_x emissions taking account of reduced-engine taxi. It compares emissions that account for reduced-engine taxi on both departure and arrival and emissions that account for reduced-engine taxi-out only with emissions calculated assuming conventional taxi.

Table 12 Breakdown of aircraft NO_x emissions by mode – 2016: comparison of reduced-engine taxi with conventional taxi

Mode	Annual NO_x emissions (tonnes)				Change (%)		
	Conventional	RET-o[1]	RET[2]	100%[3]	RET-o[4]	RET[5]	100%[6]
Taxi-in	162.24	162.24	157.74	124.36	0.0	−2.8	−23.4
Taxi-out	252.36	243.33	243.32	184.15	−3.6	−3.6	−27.0
APU	255.45	262.18	265.53	348.02	2.6	3.9	36.2
Ground-level	1694.21	1691.92	1690.76	1680.70	−0.1	−0.2	−0.8
Total aircraft LTO	4586.80	4584.51	4583.35	4573.29	−0.1	−0.1	−0.3

[1] Reduced-engine taxi-out only
[2] Reduced-engine taxi-in and taxi-out
[3] Reduced-engine taxi applied to all movements
[4] Change % = 100 * (RET-o value − Conventional value) / (Conventional value)
[5] Change % = 100 * (RET value − Conventional value) / (Conventional value)
[6] Change % = 100 * (100% value − Conventional value) / (Conventional value)

4.2 PM_{10} and $PM_{2.5}$

Table 13 shows aircraft PM_{10} emissions broken down by mode (phase of the LTO cycle), using the same categories as in the 2008/9 inventory report and the subsequent annual updates. Table 14 shows the equivalent comparison for $PM_{2.5}$. The 2016 values have been compared with equivalent values for from the 2013, 2014 and 2015 inventories. The calculated total aircraft PM_{10} ($PM_{2.5}$) emissions (up to 1000 m) for 2016 are 3.6% (3.9%) higher than the equivalent value for 2015, for a 0.2% increase in the number of movements.

It should be noted that for aircraft exhaust emissions all the mass has been assumed to be associated with particles less than 2.5 µm in diameter (as it is widely understood that all particulate matter emitted by aircraft engines is smaller than this size), so PM_{10} and $PM_{2.5}$ exhaust emissions are the same. However, not all of the particulate matter generated by brake and tyre wear is associated with particles of less than 2.5 µm in diameter (see Reference i for details).

Table 13 Breakdown of aircraft PM_{10} emissions by mode: comparison of 2016 with 2013, 2014 and 2015

Mode	Annual PM_{10} emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Ground-level							
Landing roll	0.55	0.53	0.53	0.54	−1.1	3.0	2.1
Taxi-in	3.18	3.12	3.16	3.17	−0.5	1.4	0.4
Taxi-out	4.90	4.75	4.93	4.87	−0.6	2.5	−1.3
Hold	4.62	4.47	4.46	4.75	2.8	6.2	6.5
Take-off roll	3.34	3.07	2.99	2.99	−10.3	−2.7	−0.1
Brake wear	9.25	9.45	9.58	9.74	5.3	3.0	1.7
Tyre wear	6.10	6.27	6.38	6.51	6.8	3.9	2.1
APU	3.52	3.47	3.15	4.33	23.0	24.8	37.4
Engine testing[1]	0.06	0.06	0.06	0.06	0.0	0.0	0.0
Total ground-level	**35.51**	**35.19**	**35.24**	**36.96**	**4.1**	**5.0**	**4.9**
Elevated							
Approach	5.69	5.50	5.50	5.50	−3.4	0.0	0.0
Initial climb	3.27	3.01	2.95	2.95	−9.5	−1.7	0.1
Climb out	6.50	5.99	5.86	5.92	−8.9	−1.1	1.1
Total elevated	**15.46**	**14.50**	**14.32**	**14.38**	**−7.0**	**−0.8**	**0.4**
Total	**50.97**	**49.69**	**49.56**	**51.34**	**0.7**	**3.3**	**3.6**

[1] Engine testing emissions were not recalculated for 2016. However, they represent a small fraction of the total.
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 14 Breakdown of aircraft $PM_{2.5}$ emissions by mode: comparison of 2016 with 2013, 2014 and 2015

Mode	Annual $PM_{2.5}$ emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Ground-level							
Landing roll	0.55	0.53	0.53	0.54	−1.1	3.0	2.1
Taxi-in	3.18	3.12	3.16	3.17	−0.5	1.4	0.4
Taxi-out	4.90	4.75	4.93	4.87	−0.6	2.5	−1.3
Hold	4.62	4.47	4.46	4.75	2.8	6.2	6.5
Take-off roll	3.34	3.07	2.99	2.99	−10.3	−2.7	−0.1
Brake wear	3.68	3.76	3.81	3.88	5.3	3.0	1.7
Tyre wear	4.27	4.39	4.47	4.56	6.8	3.9	2.1
APU	3.52	3.47	3.15	4.33	23.0	24.8	37.4
Engine testing[1]	0.06	0.06	0.06	0.06	0.0	0.0	0.0
Total ground-level	**28.11**	**27.62**	**27.56**	**29.14**	**3.7**	**5.5**	**5.7**
Elevated							
Approach	5.69	5.50	5.50	5.50	−3.4	0.0	0.0
Initial climb	3.27	3.01	2.95	2.95	−9.5	−1.7	0.1
Climb out	6.50	5.99	5.86	5.92	−8.9	−1.1	1.1
Total elevated	**15.46**	**14.50**	**14.32**	**14.38**	**−7.0**	**−0.8**	**0.4**
Total	**43.57**	**42.12**	**41.88**	**43.52**	**−0.1**	**3.3**	**3.9**

[1] Engine testing emissions were not recalculated for 2016. However, they represent a small fraction of the total.
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 15 shows the values of annual aircraft LTO PM_{10} and $PM_{2.5}$ emissions normalised by the number of passengers and movements. The PM_{10} per passenger is 2.6% higher than in 2015 and the

PM_{10} per movement is 3.4% higher than in 2015. The $PM_{2.5}$ per passenger is 2.9% higher than in 2015 and the $PM_{2.5}$ per movement is 3.7% higher than in 2015.

Table 15 LTO PM emissions per passenger and per movement: comparison of 2016 with 2013, 2014 and 2015

	2013	2014	2015	2016	Change from (%)		
					2013[a]	2014[b]	2015[c]
LTO PM_{10} (tonnes per year)	50.97	49.69	49.56	51.34	0.7	3.3	3.6
LTO $PM_{2.5}$ (tonnes per year)	43.57	42.12	41.88	43.52	−0.1	3.3	3.9
Passengers[1] (mppa)	72.33	73.37	74.95	75.67	4.6	3.1	1.0
LTO PM_{10} (g per passenger[1])	0.70	0.68	0.66	0.68	−3.7	0.2	2.6
LTO $PM_{2.5}$ (g per passenger[1])	0.60	0.57	0.56	0.58	−4.5	0.2	2.9
Movements[2] (1000s)	471.94	472.80	474.09	474.96	0.6	0.5	0.2
LTO PM_{10} (kg per movement[2])	0.11	0.11	0.10	0.11	0.1	2.8	3.4
LTO $PM_{2.5}$ (kg per movement[2])	0.09	0.09	0.09	0.09	−0.8	2.9	3.7

[1] Excludes transit passengers
[2] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

From a local air quality perspective, emissions from aircraft on the ground have a greater impact than elevated emissions. The calculated value of ground-level aircraft PM_{10} emissions (including brake and tyre wear, APU and engine testing emissions) for 2016 is 4.9% (5.7% for $PM_{2.5}$) higher than the equivalent value for 2015, for a 0.2% increase in the total number of movements.

For APUs, PM emissions were 37.4% higher than in 2015, reflecting the increases in APU running times.

For the main engine exhaust emissions, the difference from 2015 ranges from −1.3% (Taxi-out) to +6.5% (Hold). PM exhaust emission factors are derived from Smoke Numbers given in the ICAO emissions databank. The maximum Smoke Number of an engine is subject to CAEP regulatory control although, unlike the situation for NO_x, the standard has not become more stringent over time. Modern jet engines usually have Smoke Numbers well below the CAEP limit, so there is no regulatory pressure for continuous improvement. As a result, there can be large non-systematic variations (albeit below the limit) from engine to engine, so the variation in total airport PM emissions over time is sensitive to the specific engines fitted to the principal aircraft types in the fleet.

It is known that the International Civil Aviation Organisation (ICAO) Committee on Aviation Environmental Protection (CAEP) is currently working to develop a new standard for non-volatile particulate matter (nvPM) emissions from aircraft engines, with agreement expected in 2019. This will bring the regulatory approach more in line with that of NO_x and may result in more regulatory pressure on PM emissions, either immediately or over time as more stringent subsequent standards are brought in. It will also lead to new data for nvPM mass emissions from engines (and particle numbers) becoming available and will result in new approaches for calculating PM emissions for airport inventories (replacing the current, smoke number-based, approaches).

For PM, non-exhaust emissions (aircraft brake and tyre wear) are a significant contributor to the ground-level aircraft emissions, together accounting for 44.0% of the ground-level PM_{10} emissions in 2016 (28.9% for $PM_{2.5}$). The increase in this combined contribution from 2015 to 2016 is 1.8% for PM_{10} and 1.9% for $PM_{2.5}$.

Table 16 gives a breakdown of ground-level aircraft exhaust PM emissions (omitting brake and tyre wear, APUs and engine testing) by aircraft type, comparing the distribution in 2016 with the equivalent distribution in 2015. As expected from the movement breakdowns in Table 1, the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction of the emissions in both years (45.3% in 2016 and 45.3% in 2015). The larger aircraft types, B747, B777 and A380, together contribute over third of the emissions in each year (35.5% in 2016 and 36.6% in 2015), despite accounting for less than a quarter of the total movements.

Table 16 also gives ground-level emissions per movement (excluding APU, engine testing and brake and tyre wear emissions) for each aircraft type, comparing values for 2016 with those for 2015. As explained in the NO_x discussion, this value may change over time even for a given aircraft type as a result of changes in sub-series and/or engine models in the fleet. Typically, the values for the larger aircraft types (B747, B777 and A380) are around a factor of 2 to 3 times higher than for the single-aisle jets.

Table 16 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type

Aircraft Type	2015			2016		
	PM (t/year)	%	PM (g/mvt)	PM (t/year)	%	PM (g/mvt)
Small	0.08	0.5	21.9	0.06	0.4	22.8
Medium	7.71	48.0	26.2	7.78	47.7	26.9
A318/A319	2.43	15.1	28.9	2.51	15.4	30.9
A320	3.59	22.3	25.4	3.56	21.8	25.4
A321	1.27	7.9	29.6	1.32	8.1	30.6
B737	0.29	1.8	15.7	0.29	1.8	15.4
Others	0.13	0.8	16.3	0.10	0.6	16.0
Heavy	7.28	45.3	45.3	7.21	44.2	43.8
B747	1.90	11.8	74.0	1.58	9.7	76.2
B767	0.99	6.1	34.8	0.94	5.8	36.3
B777	2.98	18.5	47.6	2.95	18.1	48.2
B787	0.32	2.0	20.7	0.58	3.6	21.1
Other	1.10	6.8	38.4	1.16	7.1	40.0
A380	1.00	6.2	67.7	1.27	7.8	69.6
Total	16.08	100.0	33.9	16.32	100.0	34.4

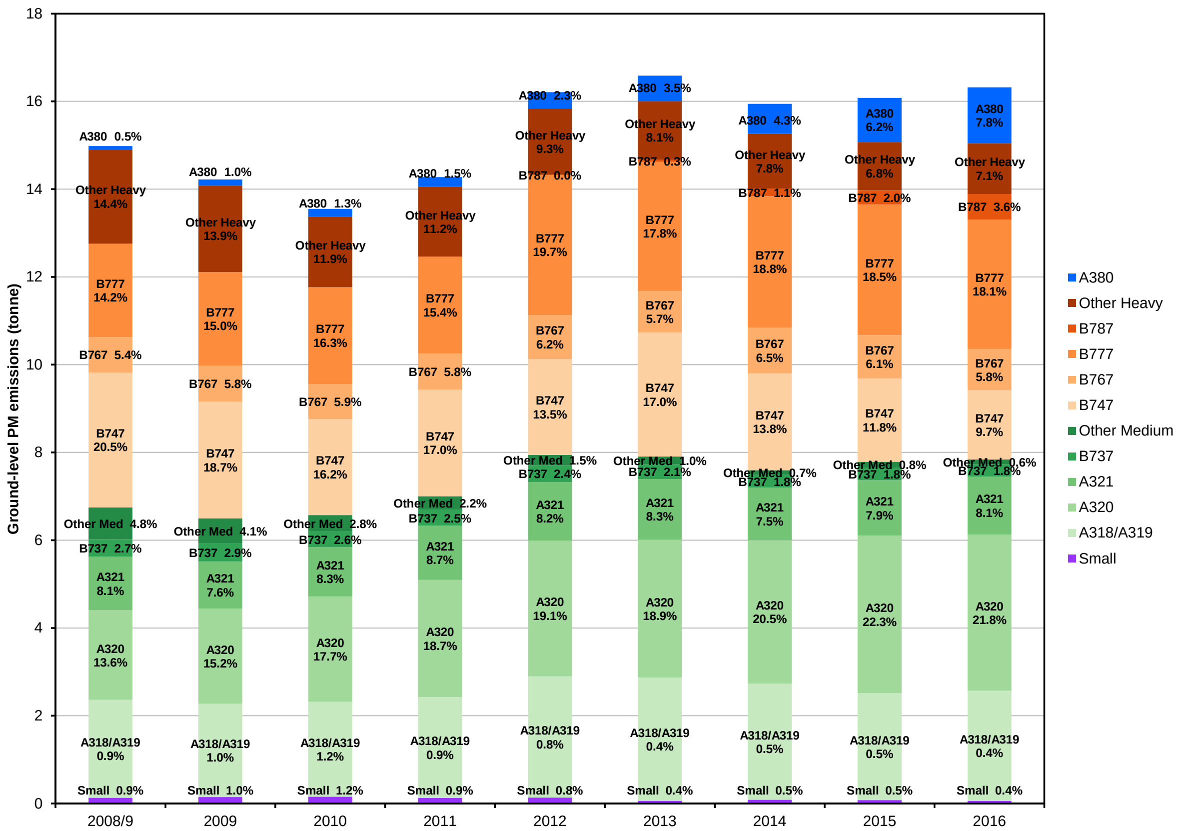
[1] For exhaust emissions, PM_{10} and $PM_{2.5}$ have been taken to be the same.
[2] Ground-level emissions from main engines only (omitting APU, engine testing, brake wear and tyre wear)

Overall, the fleet-averaged value of ground-level aircraft PM emissions per movement, excluding APUs, engine testing, brake wear and tyre wear, has risen by 1.3% between the 2015 inventory and the 2016 inventory, from 33.9 grams per movement in 2015 to 34.4 grams per movement in 2016.

Including APUs, engine testing, brake wear and tyre wear, the increase in ground-level aircraft PM_{10} emissions per movement from the 2015 inventory is 4.7% (5.5% for $PM_{2.5}$), from 74.3 grams of PM_{10} (58.1 grams of $PM_{2.5}$) per movement in 2015 to 77.8 grams of PM_{10} (61.4 grams of $PM_{2.5}$) per movement in 2016.

Figure 7 shows the trend in ground-level aircraft PM emissions broken down by aircraft type since 2008/9.

Figure 7 Breakdown of ground-level aircraft PM[1] emissions[2] by aircraft type: 2008/9 to 2016



[1] For exhaust emissions, PM_{10} and $PM_{2.5}$ have been taken to be the same.
[2] Ground-level emissions from main engines only (omitting APU, engine testing, brake wear and tyre wear)

4.2.1 Alternative operating times

Table 17 and Table 18 present PM_{10} and $PM_{2.5}$ emissions, respectively, for the 2016 aircraft movements calculated using the 'alternative' 2013 operating times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 operating times). These tables are the 'alternative' equivalents of Table 13 and Table 14. Table 17 and Table 18 show that calculated aircraft emissions of PM_{10} ($PM_{2.5}$) for the whole LTO cycle were 0.5% (0.3%) higher in 2016 than in 2015 and ground-level aircraft emissions were 0.5% (0.2%) higher than in 2015.

For comparison using the specific year times, the whole LTO cycle emissions were 3.6% (3.9%) higher in 2016 than in 2015 and ground-level aircraft emissions were 4.9% (5.7%) higher than in 2015.

Table 17 Aircraft PM_{10} emissions using 'alternative' operating times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 operating times)

Mode	Annual PM_{10} emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	3.18	3.10	3.17	3.16	−0.9	1.8	−0.6
Taxi-out	4.90	4.64	4.71	4.70	−4.1	1.3	−0.3
Hold	4.62	4.32	4.42	4.35	−6.0	0.7	−1.7
APU	3.52	3.49	3.47	3.46	−1.6	−0.7	−0.3
Ground-level	35.51	34.92	35.32	35.51	0.0	1.7	0.5
Total aircraft LTO	50.97	49.42	49.64	49.88	−2.1	0.9	0.5

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 18 Aircraft $PM_{2.5}$ emissions using 'alternative' operating times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 operating times)

Mode	Annual $PM_{2.5}$ emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	3.18	3.10	3.17	3.16	−0.9	1.8	−0.6
Taxi-out	4.90	4.64	4.71	4.70	−4.1	1.3	−0.3
Hold	4.62	4.32	4.42	4.35	−6.0	0.7	−1.7
APU	3.52	3.49	3.47	3.46	−1.6	−0.7	−0.3
Ground-level	28.11	27.35	27.64	27.69	−1.5	1.2	0.2
Total aircraft LTO	43.57	41.84	41.95	42.07	−3.4	0.5	0.3

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 19 and Table 20 compare the two methodologies, showing emissions calculated for 2016 using the 'alternative' 2013 operating times (refer to Table 17 and Table 18) and using the 2014, 2015 and 2016 operating times (refer to Table 13 and Table 14).

Table 19 Aircraft PM_{10} emissions – 2016: comparison of emissions calculated using 2016 operating times with those calculated using 2013, 2014 and 2015 operating times

Mode	2016 PM_{10} emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	3.16	3.19	3.12	3.17	0.4	−0.6	1.4
Taxi-out	4.70	4.68	4.85	4.87	3.6	3.9	0.4
Hold	4.35	4.45	4.45	4.75	9.3	6.7	6.9
APU	3.46	3.46	3.14	4.33	25.0	25.1	37.7
Ground-level	35.51	35.63	35.40	36.96	4.1	3.7	4.4
Total aircraft LTO	49.88	50.01	49.78	51.34	2.9	2.7	3.1

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Table 20 Aircraft $PM_{2.5}$ emissions – 2016: comparison of emissions calculated using 2016 operating times with those calculated using 2013, 2014 and 2015 operating times

Mode	2016 $PM_{2.5}$ emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	3.16	3.19	3.12	3.17	0.4	−0.6	1.4
Taxi-out	4.70	4.68	4.85	4.87	3.6	3.9	0.4
Hold	4.35	4.45	4.45	4.75	9.3	6.7	6.9
APU	3.46	3.46	3.14	4.33	25.0	25.1	37.7
Ground-level	27.69	27.81	27.59	29.14	5.2	4.8	5.6
Total aircraft LTO	42.07	42.19	41.97	43.52	3.5	3.1	3.7

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

4.2.2 Reduced-engine taxi

Table 21 and Table 22 present PM_{10} and $PM_{2.5}$ emissions, respectively, taking account of reduced-engine taxi. They compare emissions that account for reduced-engine taxi on both departure and arrival and emissions that account for reduced-engine taxi-out only with emissions calculated assuming conventional taxi.

Table 21 Breakdown of aircraft PM_{10} emissions by mode - 2016: comparison of reduced-engine taxi with conventional taxi

Mode	Annual PM_{10} emissions (tonnes)				Change (%)		
	Conventional	RET-o[1]	RET[2]	100% RET[3]	RET-o[4]	RET[5]	100% RET[6]
Taxi-in	3.17	3.17	3.04	2.40	0.0	−4.2	−24.3
Taxi-out	4.87	4.60	4.60	3.49	−5.4	−5.4	−28.3
APU	4.33	4.48	4.55	5.75	3.4	5.1	32.8
Ground-level	36.96	36.84	36.78	36.23	−0.3	−0.5	−2.0
Total aircraft LTO	51.34	51.22	51.16	50.61	−0.2	−0.3	−1.4

[1] Reduced-engine taxi-out only
[2] Reduced-engine taxi-in and taxi-out
[3] Reduced-engine taxi applied to all movements
[4] Change % = 100 * (RET-o value − Conventional value) / (Conventional value)
[5] Change % = 100 * (RET value − Conventional value) / (Conventional value)
[6] Change % = 100 * (100% value − Conventional value) / (Conventional value)

Table 22 Breakdown of aircraft $PM_{2.5}$ emissions by mode - 2016: comparison of reduced-engine taxi with conventional taxi

Mode	Annual $PM_{2.5}$ emissions (tonnes)				Change (%)		
	Conventional	RET-o[1]	RET[2]	100% RET[3]	RET-o[4]	RET[5]	100% RET[6]
Taxi-in	3.17	3.17	3.04	2.40	0.0	−4.2	−24.3
Taxi-out	4.87	4.60	4.60	3.49	−5.4	−5.4	−28.3
APU	4.33	4.48	4.55	5.75	3.4	5.1	32.8
Ground-level	29.14	29.02	28.97	28.42	−0.4	−0.6	−2.5
Total aircraft LTO	43.52	43.40	43.34	42.79	−0.3	−0.4	−1.7

[1] Reduced-engine taxi-out only
[2] Reduced-engine taxi-in and taxi-out
[3] Reduced-engine taxi applied to all movements
[4] Change % = 100 * (RET-o value − Conventional value) / (Conventional value)
[5] Change % = 100 * (RET value − Conventional value) / (Conventional value)
[6] Change % = 100 * (100% value − Conventional value) / (Conventional value)

4.3 CO_2

In contrast to NO_x and PM, the emissions index (quantity of emission per kg of fuel burnt) for CO_2 is not a function of the engine type, but is a constant[3] (3.15 kg/kg). Therefore, the CO_2 emissions are calculated simply by multiplying the calculated fuel burn by that emissions index. Table 23 shows aircraft emissions of CO_2 broken down by mode (i.e. phase of the LTO cycle), using the same categories as in the 2008/9 inventory report and the subsequent annual updates. The 2016 values have been compared with equivalent values for 2013, 2014 and 2015. The calculated total aircraft CO_2 emission (up to 1000m) for 2016 is 3.4% higher than the equivalent value for the 2015, for a 1.0% increase in the number of passengers.

APU emissions were 31.5% higher than in 2015, reflecting the increases in APU running times.

[3] Strictly, the emissions index for CO2 is a function of the chemistry of the fuel; it is slightly different for other fuels such as gasoline or diesel.

Table 23 Breakdown of aircraft CO_2 emissions by mode: comparison of 2016 with 2013, 2014 and 2015

Mode	Annual CO_2 emissions (kilotonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Ground-level							
Landing roll	19.77	20.07	20.25	20.78	5.1	3.6	2.6
Taxi-in	105.45	108.87	109.48	110.26	4.6	1.3	0.7
Taxi-out	161.15	165.34	171.25	169.39	5.1	2.5	−1.1
Hold	152.63	154.55	154.46	164.99	8.1	6.8	6.8
Take-off roll	92.26	92.09	91.89	92.43	0.2	0.4	0.6
APU	63.98	64.41	64.14	84.36	31.8	31.0	31.5
Engine testing[1]	1.21	1.21	1.21	1.21	0.0	0.0	0.0
Total ground-level	**596.46**	**606.53**	**612.69**	**643.42**	**7.9**	**6.1**	**5.0**
Elevated							
Approach	184.96	184.59	184.47	185.19	0.1	0.3	0.4
Initial climb	89.27	88.63	88.72	89.35	0.1	0.8	0.7
Climb out	177.13	174.27	174.13	177.84	0.4	2.0	2.1
Total elevated	**451.36**	**447.49**	**447.32**	**452.38**	**0.2**	**1.1**	**1.1**
Total	**1047.82**	**1054.02**	**1060.01**	**1095.80**	**4.6**	**4.0**	**3.4**

[1] Engine testing emissions were not recalculated for 2016. However, they represent a small fraction of the total.
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 24 shows the values of annual aircraft LTO CO_2 emissions normalised by the number of passengers and movements. The CO_2 per passenger has risen by 2.4% since 2015 and the CO_2 per movement is 3.2% higher than in 2015.

Table 24 LTO CO_2 emissions per passenger and per movement: comparison of 2016 with 2013, 2014 and 2015

	2013	2014	2015	2016	Change from (%)		
					2013[a]	2014[b]	2015[c]
LTO CO_2 (kilotonnes per year)	1047.82	1054.02	1060.01	1095.80	4.6	4.0	3.4
Passengers[1] (mppa)	72.33	73.37	74.95	75.67	4.6	3.1	1.0
LTO CO_2 (kg per passenger[1])	14.49	14.37	14.14	14.48	0.0	0.8	2.4
Movements[2] (1000s)	471.94	472.80	474.09	474.96	0.6	0.5	0.2
LTO CO_2 (tonnes per movement[2])	2.22	2.23	2.24	2.31	3.9	3.5	3.2

[1] Excludes transit passengers
[2] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 25 gives a breakdown of LTO aircraft CO_2 emissions (omitting APUs and engine testing) by aircraft type, comparing the distribution in 2016 with the equivalent distributions in 2015. As expected from the movement breakdowns in Table 1, the A320 aircraft family (A318/A319, A320 and A321) account for a significant fraction of the emissions in both years (30.7% in 2016 and 31.2% in 2015). However, the larger aircraft types, B747, B777 and A380, together contribute almost half of the emissions in each period (44.5% in 2016 and 45.7% in 2015), despite accounting for less than a quarter of the total movements.

Table 25 also gives LTO emissions per movement (excluding APU and engine testing emissions) for each aircraft type. Emissions of CO_2 have global impacts on climate change, rather than the more local effects of pollutants such as NO_x and PM. Therefore, the values are presented for the complete movement (up to 1,000 m altitude) rather than just the ground-level emissions as presented for the other pollutants. The table shows that the values of LTO emissions per movement for the large aircraft types (B747 and B777) are around a factor of four higher than the average for A318/A319/320/321 or B737 aircraft. Of course, the large types carry more passengers than the A320/B737 families, but only around twice as many passengers, so the CO_2 /passenger ratio is roughly double that of the A320/B737 families.

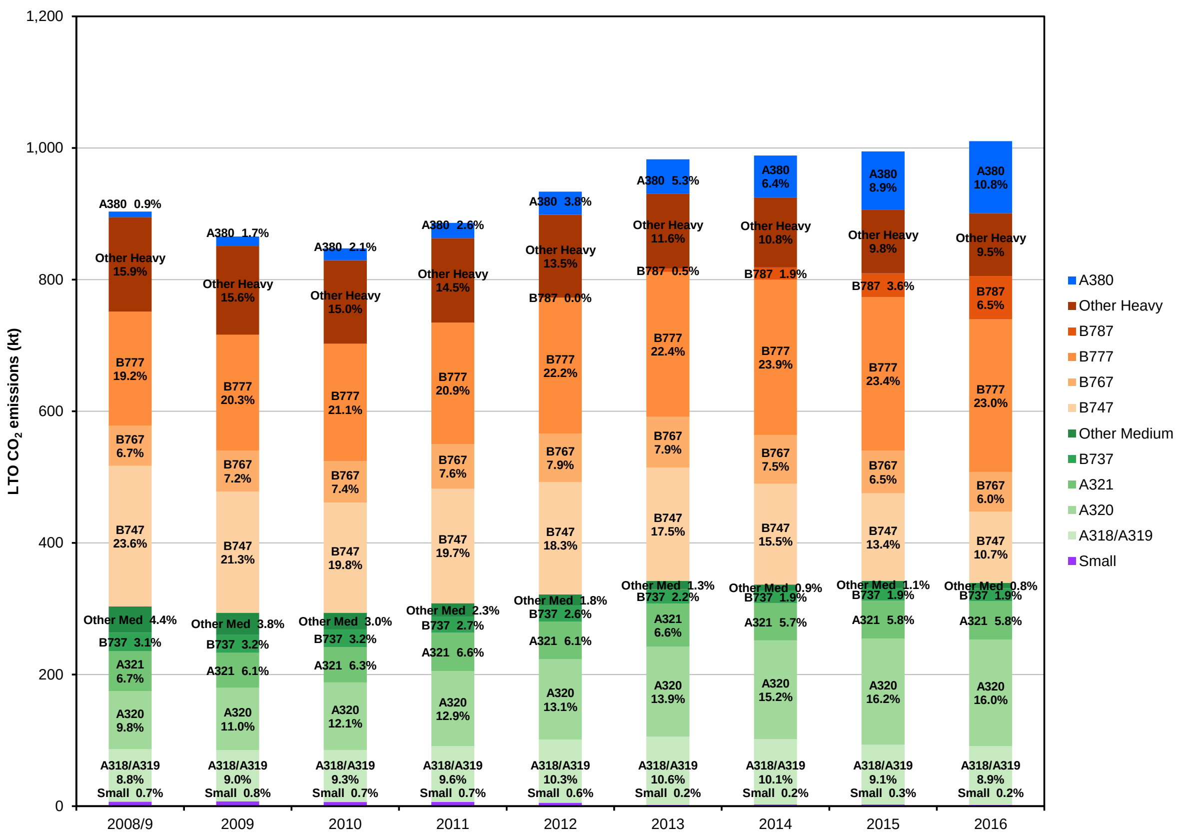
Table 25 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type

Aircraft Type	2015			2016		
	CO_2 (kt/year)	%	CO_2 (t/mvt)	CO_2 (kt/year)	%	CO_2 (t/mvt)
Small	2.52	0.3	0.71	1.78	0.2	0.71
Medium	339.56	34.1	1.15	337.34	33.4	1.16
A318/A319	90.69	9.1	1.08	89.72	8.9	1.10
A320	161.29	16.2	1.14	161.42	16.0	1.15
A321	57.88	5.8	1.35	58.72	5.8	1.36
B737	19.15	1.9	1.04	19.15	1.9	1.02
Others	10.53	1.1	1.29	8.33	0.8	1.28
Heavy	564.36	56.7	3.51	561.89	55.6	3.42
B747	133.14	13.4	5.19	108.26	10.7	5.24
B767	65.08	6.5	2.30	60.26	6.0	2.32
B777	233.05	23.4	3.72	231.96	23.0	3.79
B787	36.10	3.6	2.31	65.87	6.5	2.39
Other	97.00	9.8	3.39	95.54	9.5	3.30
A380	88.22	8.9	5.95	109.22	10.8	5.98
Total	994.66	100.0	2.10	1010.23	100.0	2.13

[1] LTO emissions from main engines only (omitting APU and engine testing).

Figure 8 shows the trend in LTO aircraft CO_2 emissions broken down by aircraft type since 2008/9.

Figure 8 Breakdown of LTO aircraft CO_2 emissions[1] by aircraft type: 2008/9 to 2016



[1] LTO emissions from main engines only (omitting APU and engine testing).

4.3.1 Alternative operating times

Table 26 presents CO_2 emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 operating times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 operating times). This table is the 'alternative' equivalent of Table 23. Table 26 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) in 2016 were 0.6% higher than in 2015 and ground-level aircraft emissions were 0.1% higher than in 2015.

For comparison using the specific year times, the whole LTO cycle emissions were 3.4% higher in 2016 than in 2015 and ground-level aircraft emissions were 5.0% higher than in 2015.

Table 26 Aircraft CO_2 emissions using 'alternative' operating times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 operating times)

Mode	Annual CO_2 emissions (kilotonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	105.45	106.43	108.79	108.64	3.0	2.1	−0.1
Taxi-out	161.15	159.90	162.20	162.27	0.7	1.5	0.0
Hold	152.63	148.67	152.28	150.27	−1.5	1.1	−1.3
APU	63.98	65.20	71.44	73.29	14.5	12.4	2.6
Ground-level	596.46	593.55	608.07	608.90	2.1	2.6	0.1
Total aircraft LTO	1047.82	1041.05	1055.38	1061.27	1.3	1.9	0.6

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 27 compares the two methodologies, showing emissions calculated for 2016 using the 'alternative' 2013 operating times (refer to Table 26) and using the 2014, 2015 and 2016 operating times (refer to Table 23).

Table 27 Aircraft CO_2 emissions – 2016: comparison of emissions calculated using 2016 operating times with those calculated using 2013, 2014 and 2015 operating times

Mode	2016 CO_2 emissions (kilotonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	108.64	109.82	107.43	110.26	1.5	0.4	2.6
Taxi-out	162.27	161.83	167.03	169.39	4.4	4.7	1.4
Hold	150.27	153.71	153.63	164.99	9.8	7.3	7.4
APU	73.29	74.24	66.15	84.36	15.1	13.6	27.5
Ground-level	608.90	614.02	608.66	643.42	5.7	4.8	5.7
Total aircraft LTO	1061.27	1066.40	1061.04	1095.80	3.3	2.8	3.3

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

4.3.2 Reduced-engine taxi

Table 28 presents CO_2 emissions taking account of reduced-engine taxi. It compares emissions that account for reduced-engine taxi on both departure and arrival and emissions that account for reduced-engine taxi-out only with emissions calculated assuming conventional taxi.

Table 28 Breakdown of aircraft CO_2 emissions by mode - 2016: comparison of reduced-engine taxi with conventional taxi

Mode	Annual CO_2 emissions (kilotonnes)				Change (%)		
	Conventional	RET-o[1]	RET[2]	100% RET[3]	RET-o[4]	RET[5]	100% RET[6]
Taxi-in	110.26	110.26	107.22	84.49	0.0	−2.8	−23.4
Taxi-out	169.39	163.28	163.28	123.55	−3.6	−3.6	−27.1
APU	84.36	86.36	87.35	112.87	2.4	3.5	33.8

Ground-level	643.42	639.31	637.26	600.32	−0.6	−1.0	−6.7
Total aircraft LTO	1095.80	1091.68	1089.64	1052.69	−0.4	−0.6	−3.9

[1] Reduced-engine taxi-out only
[2] Reduced-engine taxi-in and taxi-out
[3] Reduced-engine taxi applied to all movements
[4] Change % = 100 * (RET-o value − Conventional value) / (Conventional value)
[5] Change % = 100 * (RET value − Conventional value) / (Conventional value)
[6] Change % = 100 * (100% value − Conventional value) / (Conventional value)

5 Summary and conclusions

The total annual emissions of NO_x, PM_{10}, $PM_{2.5}$ and CO_2 from aircraft movements at Heathrow have been calculated for the 2016 calendar year, based on detailed flight records held by Heathrow Airport. This updates the aircraft component of the published 2013, 2014 and 2015 Heathrow Airport emissions inventories. With the exception of APU running times and taxi and hold times, the update makes the assumption that the set of aircraft operational parameters (such as the time that aircraft spend in various operational phases of the LTO cycle) derived for the 2008/9 and 2013 inventories were also applicable in 2016.

Table 29 shows some summary information about total emissions from the LTO (including APUs, engine testing and brake and tyre wear), while Table 30 presents the same information for ground-level emissions only. Figure 9 to Figure 12 show some trends over the years from 2008/9 to 2016. Note that in these graphs, the vertical scales are chosen to exaggerate the trends, which are typically of the order of one percent per year.

The number of movements in 2016 was 0.2% higher than in 2015, whereas the number of passengers was 1.0% higher than in 2015. There is no discernible trend in the number of movements over the last ten years (refer to Figure 1). This is because there is little room for growth as the airport is already operating close to the cap of 480,000 ATMs. Instead much of the year-to-year variation can be explained by external events such as the weather or (in 2010) the Eyjafjallajökull eruption. Despite this, the number of passengers shows an increase over the period, averaging 1.2% per year (1.7% per year over the last 5 years), and the number of passengers per movement is increasing steadily (refer to Figure 2).

The calculated value of total aircraft NO_x emissions in the Landing and Take-Off (LTO) cycle (up to 1000 m height) is 2.0% higher for 2016 than for 2015. For PM_{10} ($PM_{2.5}$), the 2016 value for total LTO emissions is 3.6% (3.9%) higher than for 2015. The calculated value of ground-level aircraft NO_x emissions (which are more important than elevated emissions from the perspective of local air quality) is 4.5% higher for 2016 than for 2015. The calculated value of ground-level aircraft PM_{10} ($PM_{2.5}$) the emissions is 4.9% (5.7%) higher than for 2015. Ground-level emissions since 2008/9 are plotted in Figure 9.

The main reason for these increases is changes in APU running times and taxi and hold times. In the case of NO_x, meteorological effects are also an important contributor to the increases. Other factors influencing the increases include changes to the aircraft fleet and engine mix.

Figure 10 shows the ground-level NO_x emissions per movement and per passenger. The calculated value of NO_x emissions per movement in 2016 stands clearly above the long term trend, which had been relatively constant. Prior to 2016 NO_x emissions per passenger had been falling. However, in 2016 they reverted to levels last seen in 2012.

Figure 11 and Figure 12 show the ground-level emissions per movement and per passenger, for PM_{10} and $PM_{2.5}$, respectively. As for NOx, emissions per movement in 2016 stand clearly above the long term trend, and having been falling prior to 2016, emission per passenger in 2016 reverted to levels last seen in 2013.

Table 29 Summary of total LTO emissions

	2013	2014	2015	2016	Change from (%)			Alternative
					2013[a]	2014[b]	2015[c]	
NO_x (t/year)	4285.76	4543.80	4497.28	4586.80	7.0	0.9	2.0	4515.18
NO_x (g/pax[1])	59.25	61.93	60.00	60.61	2.3	−2.1	1.0	59.67
NO_x (kg/mvt[2])	9.08	9.61	9.49	9.66	6.3	0.5	1.8	9.51
PM_{10} (t/year)	50.97	49.69	49.56	51.34	0.7	3.3	3.6	49.88
PM_{10} (g/pax[1])	0.70	0.68	0.66	0.68	−3.7	0.2	2.6	0.66
PM_{10} (kg/mvt[2])	0.11	0.11	0.10	0.11	0.1	2.8	3.4	0.11
$PM_{2.5}$ (t/year)	43.57	42.12	41.88	43.52	−0.1	3.3	3.9	42.07
$PM_{2.5}$ (g/pax[1])	0.60	0.57	0.56	0.58	−4.5	0.2	2.9	0.56
$PM_{2.5}$ (kg/mvt[2])	0.09	0.09	0.09	0.09	−0.8	2.9	3.7	0.09
CO_2 (kt/year)	1047.82	1054.02	1060.01	1095.80	4.6	4.0	3.4	1061.27
CO_2 (kg/pax[1])	14.49	14.37	14.14	14.48	0.0	0.8	2.4	14.02
CO_2 (t/mvt[2])	2.22	2.23	2.24	2.31	3.9	3.5	3.2	2.23

[1] Excludes transit passengers
[2] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 30 Summary of ground-level emissions

	2013	2014	2015	2016	Change from (%)			Alternative
					2013[a]	2014[b]	2015[c]	
NO_x (t/year)	1524.36	1624.28	1621.14	1694.21	11.1	4.3	4.5	1622.59
NO_x (g/pax[1])	21.07	22.14	21.63	22.39	6.2	1.1	3.5	21.44
NO_x (kg/mvt[2])	3.23	3.44	3.42	3.57	10.4	3.8	4.3	3.42
PM_{10} (t/year)	35.51	35.19	35.24	36.96	4.1	5.0	4.9	35.51
PM_{10} (g/pax[1])	0.49	0.48	0.47	0.49	−0.5	1.8	3.9	0.47
PM_{10} (kg/mvt[2])	0.08	0.07	0.07	0.08	3.4	4.5	4.7	0.07
$PM_{2.5}$ (t/year)	28.11	27.62	27.56	29.14	3.7	5.5	5.7	27.69
$PM_{2.5}$ (g/pax[1])	0.39	0.38	0.37	0.39	−0.9	2.3	4.7	0.37
$PM_{2.5}$ (kg/mvt[2])	0.06	0.06	0.06	0.06	3.0	5.0	5.5	0.06

[1] Excludes transit passengers
[2] ATMs and non-ATMs
[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Figure 9 Ground-level emissions of NO_x, PM_{10} and $PM_{2.5}$

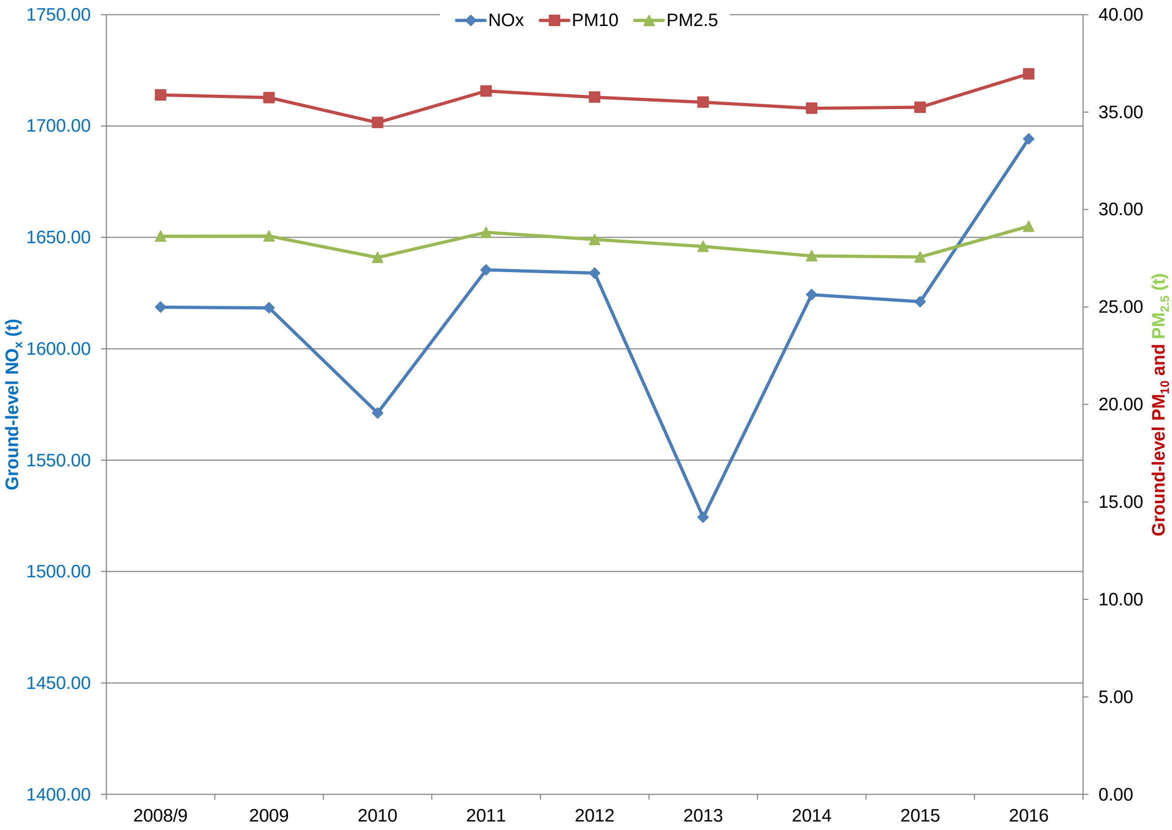


Figure 10 Ground-level NO_x emissions per movement and per passenger

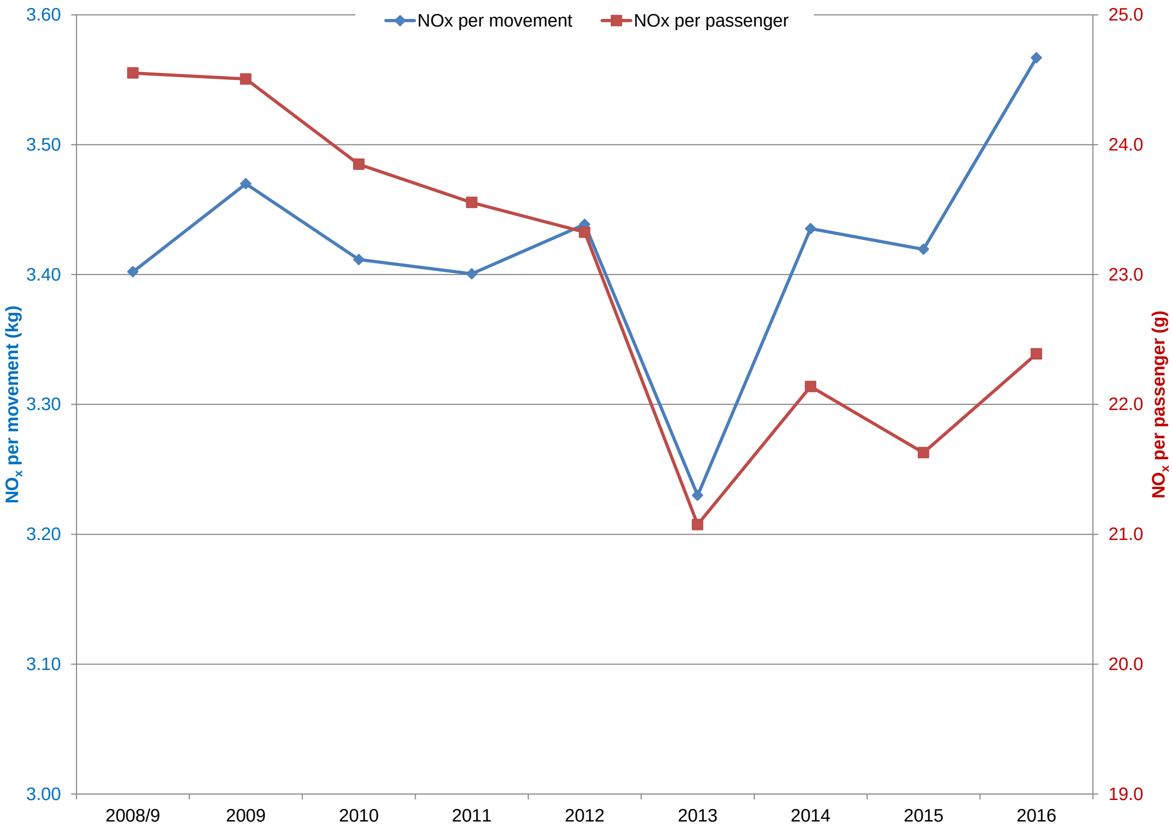


Figure 11 Ground-level PM_{10} emissions per movement and per passenger

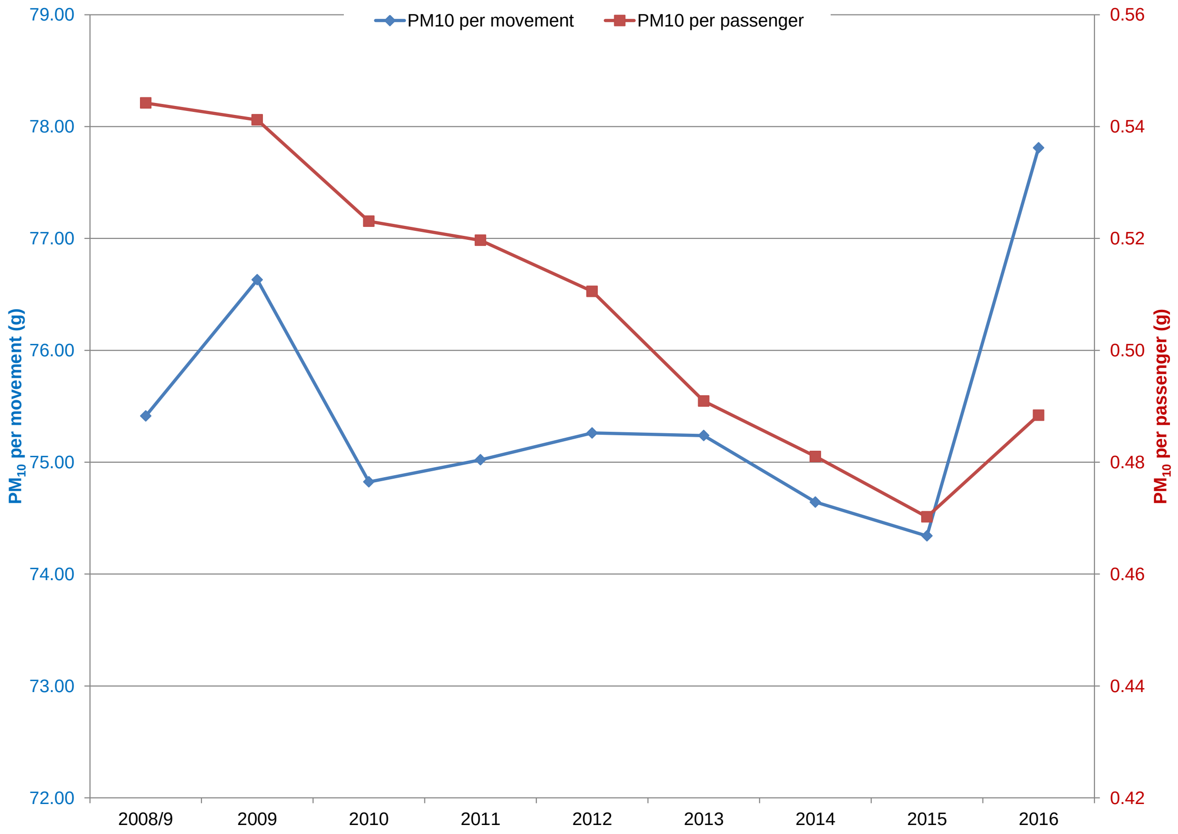
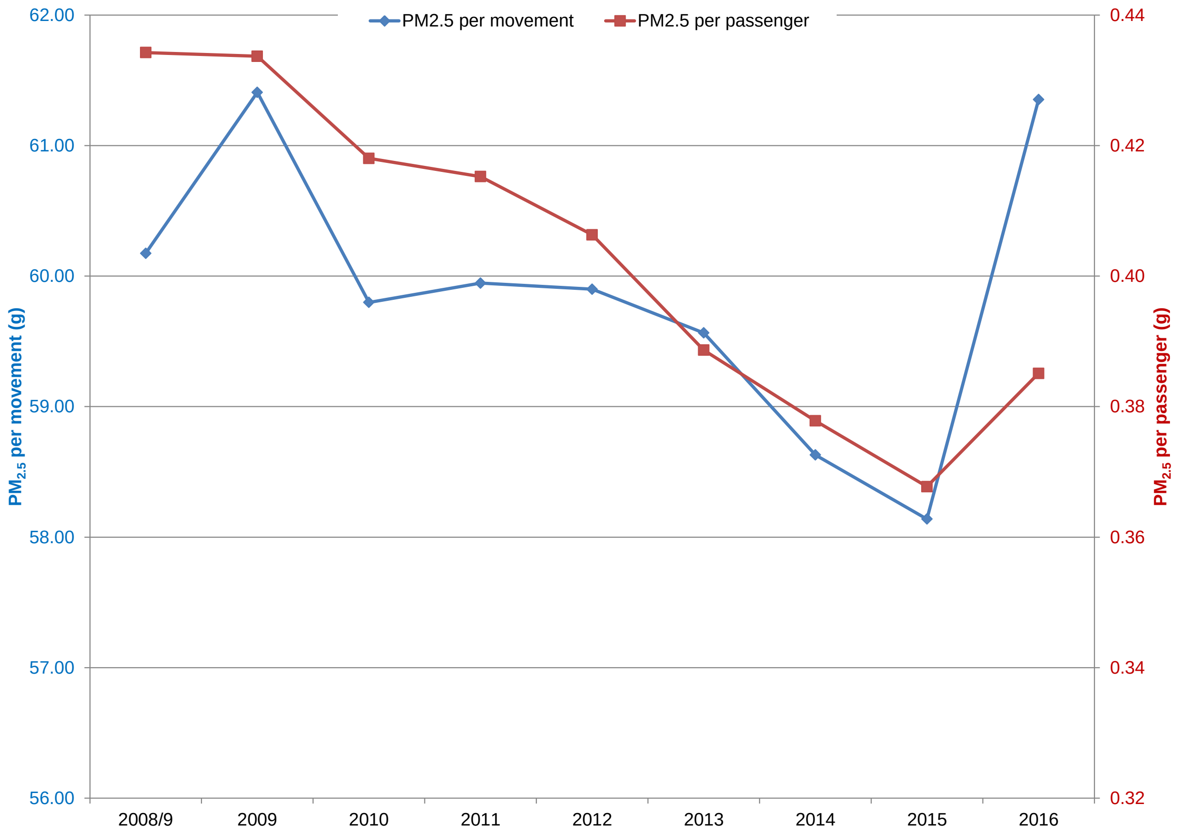


Figure 12 Ground-level $PM_{2.5}$ emissions per movement and per passenger



5.1 Reduced-engine taxi

Reduced-engine taxing at currently recorded use levels (~18% on taxi-out) offer only modest savings over conventional taxiing. Savings from reduced-engine taxiing in 2016 were almost completely offset by increased emissions from APUs. The net effect is that with reduced-engine taxi ground-level NO_x, PM_{10} and $PM_{2.5}$ are 0.1%, 0.2% and 0.3% lower than with conventional taxi, respectively.

We recommend that Heathrow should continue to record the use of reduced-engine taxiing for both departures and implement a new system to record use on arrivals. They should also consider recording the duration of reduced-engine taxiing and off-stand APU use.

Emissions from APUs and aircraft main engines (during taxiing) have different dispersion characteristics, so any air quality modelling should take account of reduced-engine taxiing.

6 References

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Appendix – alternative operating times

NO_x

APUs

Table 31 presents NO_x emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 APU times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 APU times). Table 31 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) were 0.8% higher in 2016 than in 2015. APU emissions were 4.6% higher than in 2015 and ground-level aircraft emissions were 1.1% higher than in 2015.

Table 31 Aircraft NO_x emissions using 'alternative' APU times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 APU times)

Mode	Annual NO_x emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
APU	182.05	187.00	211.63	221.43	21.6	18.4	4.6
Ground-level	1524.36	1626.04	1642.75	1660.20	8.9	2.1	1.1
Total aircraft LTO	4285.76	4545.56	4518.89	4552.79	6.2	0.2	0.8

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 32 compares the two methodologies, showing emissions calculated for the 2016 aircraft movements using the 'alternative' 2013 APU times (refer to Table 31) and using the 2014, 2015 and 2016 APU times (refer to Table 7). Note that all other emission sources are unchanged between the three calculations presented in Table 32. The APU emissions calculated using the 2016 times are 15.4% higher than those calculated using the 'alternative' 2013 times. This is a reflection of the differences in the running times as given in Table 2; the higher APU running times for narrow and wide-bodied aircraft far outweigh the lower running times for the A380.

Table 32 Aircraft NO_x emissions – 2016: comparison of emissions calculated using 2016 APU times with those calculated using 2013, 2014 and 2015 APU times

Mode	2016 NO_x emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
APU	221.43	225.96	199.78	255.45	15.4	13.1	27.9
Ground-level	1660.20	1664.73	1638.55	1694.21	2.0	1.8	3.4
Total aircraft LTO	4552.79	4557.32	4531.14	4586.80	0.7	0.6	1.2

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Taxi and hold

Table 33 presents NO_x emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 taxi and hold times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 taxi and hold times). Table 33 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) were 1.6% higher in 2016 than in 2015 and ground-level aircraft emissions were 3.6% higher than in 2015.

Table 33 Aircraft NO_x emissions using 'alternative' taxi and hold times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 taxi and hold times)

Mode	Annual NO_x emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	153.51	159.61	161.92	159.29	3.8	−0.2	−1.6
Taxi-out	237.53	242.53	244.33	240.96	1.4	−0.6	−1.4
Hold	225.63	225.52	229.41	222.90	−1.2	−1.2	−2.8
Ground-level	1524.36	1601.36	1599.68	1656.60	8.7	3.4	3.6
Total aircraft LTO	4285.76	4520.88	4475.82	4549.19	6.1	0.6	1.6

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 34 compares the two methodologies, showing emissions calculated for the 2016 aircraft movements using the 'alternative' 2013 taxi and hold times (refer to Table 33) and using the 2014, 2015 and 2016 taxi and hold times (refer to Table 7). Overall, emissions from taxi-in, taxi-out and hold calculated using the 2016 times are higher than those calculated using the 'alternative' 2013 times (by 1.9%, 4.7% and 10.4% respectively). These differences are greater than would be expected from the differences in overall average taxi and hold times (refer to Table 6), but could be explained by the considerable variation in the differences between the runway and terminal pairings seen in Table 3, Table 4 and Table 5.

Table 34 Aircraft NO_x emissions – 2016: comparison of emissions calculated using 2016 taxi and hold times with those calculated using 2013, 2014 and 2015 taxi and hold times

Mode	2016 NO_x emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	159.29	161.07	157.50	162.24	1.9	0.7	3.0
Taxi-out	240.96	240.67	248.50	252.36	4.7	4.9	1.6
Hold	222.90	228.08	227.97	246.16	10.4	7.9	8.0
Ground-level	1656.60	1663.28	1667.43	1694.21	2.3	1.9	1.6
Total aircraft LTO	4549.19	4555.87	4560.02	4586.80	0.8	0.7	0.6

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

PM_{10} and $PM_{2.5}$

APUs

Table 35 and Table 36 present PM_{10} and $PM_{2.5}$ emissions, respectively, calculated for the 2016 aircraft movements using the 'alternative' 2013 APU times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 APU times). Table 35 and Table 36 show that calculated aircraft emissions of PM_{10} ($PM_{2.5}$) for the whole LTO cycle were 1.2% (1.1%) higher in 2016 than in 2015. APU emissions were 0.3% (0.3%) lower than in 2015 and ground-level aircraft emissions were 1.5% (1.4%) higher than in 2015.

Table 35 Aircraft PM_{10} emissions using 'alternative' APU times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 APU times)

Mode	Annual PM_{10} emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
APU	3.52	3.49	3.47	3.46	−1.6	−0.7	−0.3
Ground-level	35.51	35.21	35.57	36.09	1.6	2.5	1.5
Total aircraft LTO	50.97	49.71	49.88	50.47	−1.0	1.5	1.2

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 36 Aircraft $PM_{2.5}$ emissions using 'alternative' APU times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 APU times)

Mode	Annual $PM_{2.5}$ emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
APU	3.52	3.49	3.47	3.46	−1.6	−0.7	−0.3
Ground-level	28.11	27.64	27.88	28.27	0.6	2.3	1.4
Total aircraft LTO	43.57	42.14	42.20	42.65	−2.1	1.2	1.1

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 37 and Table 38 compare the two methodologies, showing emissions calculated for the 2016 aircraft movements using the 'alternative' 2013 APU times (refer to Table 35 and Table 36) and using the 2014, 2015 and 2016 APU times (refer to Table 13 and Table 14). The APU emissions calculated using the 2016 times are 25.0% higher than those calculated using the 'alternative' 2013 times, for both size fractions. This is a reflection of the differences in the running times as given in Table 2; the higher APU running times for narrow and wide-bodied aircraft far outweigh the lower running times for the A380.

Table 37 Aircraft PM_{10} emissions – 2016: comparison of emissions calculated using 2016 APU times with those calculated using 2013, 2014 and 2015 APU times

Mode	2016 PM_{10} emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
APU	3.46	3.46	3.14	4.33	25.0	25.1	37.7
Ground-level	36.09	36.09	35.77	36.96	2.4	2.4	3.3
Total aircraft LTO	50.47	50.47	50.15	51.34	1.7	1.7	2.4

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Table 38 Aircraft $PM_{2.5}$ emissions – 2016: comparison of emissions calculated using 2016 APU times with those calculated using 2013, 2014 and 2015 APU times

Mode	2016 $PM_{2.5}$ emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
APU	3.46	3.46	3.14	4.33	25.0	25.1	37.7
Ground-level	28.27	28.27	27.95	29.14	3.1	3.1	4.2
Total aircraft LTO	42.65	42.65	42.33	43.52	2.0	2.0	2.8

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Taxi and hold

Table 39 and Table 40 present PM_{10} and $PM_{2.5}$ emissions, respectively, for the 2016 aircraft movements calculated using the 'alternative' 2013 taxi and hold times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 taxi and hold times). Table 39 and Table 40 show that calculated aircraft emissions of PM_{10} ($PM_{2.5}$) for the whole LTO cycle were 2.9% (3.1%) higher in 2016 than in 2015 and ground-level aircraft emissions were 3.9% (4.5%) higher than in 2015.

Table 39 Aircraft PM_{10} emissions using 'alternative' taxi and hold times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 taxi and hold times)

Mode	Annual PM_{10} emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	3.18	3.10	3.17	3.16	−0.9	1.8	−0.6
Taxi-out	4.90	4.64	4.71	4.70	−4.1	1.3	−0.3
Hold	4.62	4.32	4.42	4.35	−6.0	0.7	−1.7
Ground-level	35.51	34.90	35.00	36.37	2.4	4.2	3.9
Total aircraft LTO	50.97	49.40	49.31	50.75	−0.4	2.7	2.9

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 40 Aircraft $PM_{2.5}$ emissions using 'alternative' taxi and hold times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 taxi and hold times)

Mode	Annual $PM_{2.5}$ emissions (tonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	3.18	3.10	3.17	3.16	−0.9	1.8	−0.6
Taxi-out	4.90	4.64	4.71	4.70	−4.1	1.3	−0.3
Hold	4.62	4.32	4.42	4.35	−6.0	0.7	−1.7
Ground-level	28.11	27.33	27.32	28.55	1.6	4.5	4.5
Total aircraft LTO	43.57	41.83	41.63	42.93	−1.5	2.6	3.1

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 41 and Table 42 compare the two methodologies, showing emissions calculated for 2016 using the 'alternative' 2013 taxi and hold times (as shown in Table 39 and Table 40) and using the 2014, 2015 and 2016 taxi and hold times (refer to Table 13 and Table 14). Overall, emissions from taxi-in, taxi-out and hold calculated using the 2016 times are higher than those calculated using the 'alternative' 2013 times (by 0.4%, 3.6% and 9.3%, respectively, for both size fractions). These differences are greater than what would be expected from the differences in overall average taxi and hold times (refer to Table 6), but could be explained by the considerable variation in the differences between the runway and terminal pairings seen in Table 3, Table 4 and Table 5.

Table 41 Aircraft PM_{10} emissions – 2016: comparison of emissions calculated using 2016 taxi and hold times with those calculated using 2013, 2014 and 2015 taxi and hold times

Mode	2016 PM_{10} emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	3.16	3.19	3.12	3.17	0.4	−0.6	1.4
Taxi-out	4.70	4.68	4.85	4.87	3.6	3.9	0.4
Hold	4.35	4.45	4.45	4.75	9.3	6.7	6.9
Ground-level	36.37	36.50	36.59	36.96	1.6	1.3	1.0
Total aircraft LTO	50.75	50.88	50.97	51.34	1.2	0.9	0.7

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Table 42 Aircraft $PM_{2.5}$ emissions – 2016: comparison of emissions calculated using 2016 taxi and hold times with those calculated using 2013, 2014 and 2015 taxi and hold times

Mode	2016 $PM_{2.5}$ emissions (tonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	3.16	3.19	3.12	3.17	0.4	−0.6	1.4
Taxi-out	4.70	4.68	4.85	4.87	3.6	3.9	0.4
Hold	4.35	4.45	4.45	4.75	9.3	6.7	6.9
Ground-level	28.55	28.68	28.77	29.14	2.1	1.6	1.3
Total aircraft LTO	42.93	43.06	43.15	43.52	1.4	1.1	0.9

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

CO_2

APUs

Table 43 presents CO_2 emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 APU times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 APU times). Table 43 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) were 1.6% higher in 2016 than in 2015. APU emissions were 2.6% higher than in 2015 and ground-level aircraft emissions were 2.0% higher than in 2015.

Table 43 Aircraft CO_2 emissions using 'alternative' APU times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 APU times)

Mode	Annual CO_2 emissions (kilotonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
APU	63.98	65.20	71.44	73.29	14.5	12.4	2.6
Ground-level	596.46	607.32	619.99	632.35	6.0	4.1	2.0
Total aircraft LTO	1047.82	1054.81	1067.31	1084.73	3.5	2.8	1.6

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 44 compares the two methodologies, showing emissions calculated for the 2016 aircraft movements using the 'alternative' 2013 APU times (refer to Table 43) and using the 2014, 2015 and 2016 APU times (refer to Table 23). The APU emissions calculated using the 2016 times are 15.1% higher than those calculated using the 'alternative' 2013 times. This is a reflection of the differences in the running times as given in Table 2; the higher APU running times for narrow and wide-bodied aircraft far outweigh the lower running times for the A380.

Table 44 Aircraft CO_2 emissions – 2016: comparison of emissions calculated using 2016 APU times with those calculated using 2013, 2014 and 2015 APU times

Mode	2016 CO_2 emissions (kilotonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
APU	73.29	74.24	66.15	84.36	15.1	13.6	27.5
Ground-level	632.35	633.30	625.21	643.42	1.8	1.6	2.9
Total aircraft LTO	1084.73	1085.67	1077.59	1095.80	1.0	0.9	1.7

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

Taxi and hold

Table 45 presents CO_2 emissions for the 2016 aircraft movements calculated using the 'alternative' 2013 taxi and hold times, comparing them with the emissions calculated for 2013, 2014 and 2015 (also calculated using the 'alternative' 2013 taxi and hold times). Table 45 shows that calculated aircraft emissions for the whole LTO cycle (including elevated) in 2016 were 2.3% higher than in 2015 and ground-level aircraft emissions were 3.2% higher in 2016 than in 2015.

Table 45 Aircraft CO_2 emissions using 'alternative' taxi and hold times: comparison of 2016 with 2013, 2014 and 2015 (all calculated using 2013 taxi and hold times)

Mode	Annual CO_2 emissions (kilotonnes)				Change from (%)		
	2013	2014	2015	2016	2013[a]	2014[b]	2015[c]
Taxi-in	105.45	106.43	108.79	108.64	3.0	2.1	−0.1
Taxi-out	161.15	159.90	162.20	162.27	0.7	1.5	0.0
Hold	152.63	148.67	152.28	150.27	−1.5	1.1	−1.3
Ground-level	596.46	592.77	600.77	619.96	3.9	4.6	3.2
Total aircraft LTO	1047.82	1040.26	1048.08	1072.34	2.3	3.1	2.3

[a] Change % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Change % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Change % = 100 * (2016 value − 2015 value) / (2015 value)

Table 46 compares the two methodologies, showing emissions calculated for 2016 using the 'alternative' 2013 taxi and hold times (refer to Table 45) and using the 2014, 2015 and 2016 taxi and hold times (refer to Table 23). Overall, emissions from taxi-in, taxi-out and hold calculated using the 2016 times are higher than those calculated using the 'alternative' 2013 times (1.5%, 4.4% and 9.8% respectively). These differences are greater than would be expected from the differences in overall average taxi and hold times (refer to Table 6), but could be explained by the considerable variation in the differences between the runway and terminal pairings seen in Table 3, Table 4 and Table 5.

Table 46 Aircraft CO_2 emissions – 2016: comparison of emissions calculated using 2016 taxi and hold times with those calculated using 2013, 2014 and 2015 taxi and hold times

Mode	2016 CO_2 emissions (kilotonnes)				Difference (%)		
	2013 times	2014 times	2015 times	2016 times	2013[a]	2014[b]	2015[c]
Taxi-in	108.64	109.82	107.43	110.26	1.5	0.4	2.6
Taxi-out	162.27	161.83	167.03	169.39	4.4	4.7	1.4
Hold	150.27	153.71	153.63	164.99	9.8	7.3	7.4
Ground-level	619.96	624.14	626.87	643.42	3.8	3.1	2.6
Total aircraft LTO	1072.34	1076.52	1079.25	1095.80	2.2	1.8	1.5

[a] Difference % = 100 * (2016 value − 2013 value) / (2013 value)
[b] Difference % = 100 * (2016 value − 2014 value) / (2014 value)
[c] Difference % = 100 * (2016 value − 2015 value) / (2015 value)

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